

DISSERTATION

Titel der Arbeit:

Guideline for an installation of a charging infrastructure for electric vehicles in Beijing A spatial analysis based on driving and charging profiles

zur Erlangung des akademischen Grades
doctor rerum naturalium (Dr. rer. nat.)
im Fach Geographie

eingereicht an der
Mathematisch-Naturwissenschaftlichen Fakultät
der Humboldt-Universität zu Berlin

von
Dipl. Wirtsch.-Ing. (FH) Andreas Hecker

Präsidentin der Humboldt-Universität zu Berlin
Prof. Dr.-Ing. habil. Dr. Sabine Kunst

Dekan der Mathematisch-Naturwissenschaftlichen Fakultät
Prof. Dr. Elmar Kulke

- 1. Gutachter: Prof. Dr. Barbara Lenz
- 2. Gutachter: Prof. Dr.-Ing. Klaus Bogenberger
- 3. Gutachter: Prof. Dr. Elmar Kulke

Tag der mündlichen Prüfung:
15.12.2016

Acknowledgment

This dissertation would not have been possible without the great help and support of many people. First of all I want to thank my Professor Dr. Lenz who has been available for questions and advice at all times during my three years stay in China. Her engagement to visit me in Beijing emphasizes even her personal commitment and interest in this topic. Next to her my two supervisors at BWM, Dr. Wies and Dr. Brösse, supported me from the beginning and during the problems of the everyday life in China– this is not to be under appreciated.

During the completion of this paper many other colleagues and friends helped me to program software, analyze data, hold for consultation and interviews as well as proof read the text. In the interests of simplification, I want to thank: Olaf Kastner, Albrecht Pfeiffer, Christoph Hein, Florian Völk, David Wittelsberger, Erwin Knippel, John de Bohr, Jonathan Cummins, Johannes Müller and Kerry Wood.

Statement of Authorship

Ich erkläre ausdrücklich, dass es sich bei der von mir eingereichten schriftlichen Arbeit um eine von mir selbstständig und ohne fremde Hilfe verfasste Arbeit handelt.

Ich erkläre ausdrücklich, dass ich sämtliche in der oben genannten Arbeit verwendeten fremden Quellen, auch aus dem Internet (einschließlich Tabellen, Grafiken u. Ä.) als solche kenntlich gemacht habe. Insbesondere bestätige ich, dass ich ausnahmslos sowohl bei wörtlich übernommenen Aussagen bzw. unverändert übernommenen Tabellen, Grafiken u. Ä. (Zitaten) als auch bei in eigenen Worten wiedergegebenen Aussagen bzw. von mir abgewandelten Tabellen, Grafiken u. Ä. anderer Autorinnen und Autoren (Paraphrasen) die Quelle angegeben habe.

Mir ist bewusst, dass Verstöße gegen die Grundsätze der Selbstständigkeit als Täuschung betrachtet und entsprechend der Prüfungsordnung und/oder der Allgemeinen Satzung für Studien- und Prüfungsangelegenheiten der HU geahndet werden.

München, im Juni 2016

Andreas Hecker

Contents

Acknowledgment	ii
Statement of Authorship	iv
List of Figures	viii
List of Tables	ix
List of Maps	x
Nomenclature	xi
1 Introduction	1
1.1 Presentation of the Research Question	1
1.2 Goal of the Study	2
1.3 Approach and Methodology	3
2 Factors of Influence	6
2.1 Political aspects	8
2.1.1 Policy levers	9
2.1.2 Regulations	10
2.1.3 Incentives and Subsidies	12
2.1.4 Demonstration projects	14
2.1.5 Section summary	16
2.2 Technical Aspects	17
2.2.1 General Charging Information	18
2.2.2 Charging Modes	21
2.3 Economical aspects	30
2.3.1 Identification of market players in China	30
2.3.2 EV market	32
2.3.3 Business models	33
2.4 Conclusions of this chapter	36
3 Spatial Analysis of Beijing	37
3.1 Methodology of the Spatial Analysis	37

3.2	Urban Geography of Beijing	39
3.2.1	POIs related to the charging infrastructure	46
3.3	Public Parking Conditions	47
3.4	Private Parking Conditions	52
3.4.1	Gated Communities	53
3.4.2	Villas	60
3.4.3	The Historical Downtown	61
3.4.4	Conclusion of the section	61
3.5	Existing Charging Stations in Beijing	64
3.6	Conclusion of the chapter	67
4	Behavior of EV users in Beijing	69
4.1	The importance of user aspects on the charging infrastructure	69
4.2	Customer groups of electric vehicles	70
4.3	Methodology of the user behaviors analysis	72
4.4	Initial conditions	76
4.4.1	The Reference vehicle: Zinoro E1	76
4.4.2	The real-time-monitoring device	78
4.4.3	Fault tolerance	79
4.5	General travel patterns in Beijing	81
4.6	Case Study	83
4.6.1	Driving analysis	84
4.6.2	Parking behavior analysis	91
4.6.3	E-drive analysis	94
4.6.4	Charging analysis	96
4.7	Conclusion of user behavior analysis	97
5	Guideline for a Charging Infrastructure installation	102
5.1	Alignment with the spatial surroundings	104
5.1.1	Charging locations in mono centric regions	106
5.1.2	Charging facilities in poly-centric regions	108
5.1.3	POIs near Parking locations	109
5.2	Alignment with the needs of the user	112
5.2.1	Satisfying the need for energy	113
5.2.2	Satisfying the indirect demand for charging	114
5.3	Expansion of a charging network	117
6	Conclusions, critical appraisal and outlook	118
	Bibliography	122
	Appendix	134
A	Interviewees of the expert discussion	135

B	Detail maps of the six zones	136
C	QlikView source code	142
D	List of POIs in ArcMap 10.2.2	156

List of Figures

2.1	Factors of Influence of a Charging Infrastructure	7
2.2	Charging stations for taxi fleets	15
2.3	Power supply modes for NEVs	18
2.4	Cable with ICCB	19
2.5	Electric vehicle service equipment	22
2.6	International plug standards for electric vehicles	23
2.7	Type 2 Plug	24
2.8	Industrial plug	25
2.9	Charging connection case <i>A</i> , <i>B</i> and <i>C</i>	26
2.10	Charging Times of a Tesla Model S	28
2.11	State grid's public charging pillars	35
3.1	Layer structure of <i>ArcMap</i>	38
3.2	Roadside parking at Sanlitun village	49
3.3	Exemplary parking lots in Beijing I	50
3.4	Preferred locations for public charging facilities	51
3.5	Exemplary Parking lots in Beijing II	52
3.6	Types of Compounds in Beijing	55
3.7	Parking ratio inside the Compounds	57
3.8	Private parking conditions in an entry level compound	57
3.9	Private parking conditions and ownership of the parking spaces	58
3.10	Distribution of Compounds in Beijing	58
3.11	Public charging stations	65
4.1	Different segmentation of customer groups	71
4.2	The Zinoro E1	76
4.3	Real-time-monitoring device (RTM) for the Zinoro E1	79
4.4	Classification of traveled distances	85
4.5	Distribution of the charging events	97
4.6	Radar charts of typical EV drivers	101
5.1	The four priorities for build-up a charging infrastructure	103
5.2	Exemplary Compound elements	107
5.3	General parking locations of drivers	111

List of Tables

2.1	Subsidies for NEVs in China 2013-2020	13
2.2	Competitive tendering procedure for license plates	13
2.3	Difference between fast and slow charging methods with voltage of 220V	20
2.4	Charging times for selected EVs available in China	27
2.5	Electricity Rates for Beijing	31
2.6	Most sold EVs in Beijing with charging related specifications	32
3.1	Used coordination systems for the Layers, Shapefiles and Feature Classes	39
3.2	POI categorization for a charging infrastructure	47
3.3	Quantity and categories of parking lots and spaces in Beijing	48
3.4	Feasible charging solutions for parking categories	49
3.5	Distribution of car ownership in different housing types	56
3.6	Types of private parking lots	63
3.7	POIs around existing charging stations	66
4.1	Defined terms for the data logger analysis	74
4.2	Methodology and research questions for the analysis of the user patterns	75
4.3	Product data sheet of the Zinoro E1	77
4.4	User groups of analyzed Zinoro E1 driver	78
4.5	Used signals from the data logger	80
4.6	Classification of tours in Beijing	82
4.7	Mileage and driving time analysis	84
4.8	Track analysis	88
4.9	Distribution of the parking events	94
4.10	Battery status at the beginning and end of a day / trip	94
4.11	Overview of charging processes	96
5.1	Approached POIs around parking events	112
A.1	List of interviewees for the expert discussions	135

List of Maps

1	Service area around Sanlitun	34
2	Urban geography strategy of the Beijing government	40
3	Distribution of shopping, accommodations and working POIs in Beijing	41
4	Main clusters and ROIs in Beijing	42
5	Study-zones for an closer analysis of the POIs	44
6	Compounds in the Chaoyang district	54
7	Villas and Danwei communes in Beijing	60
8	Map of the Hutongs	62
9	Public fast and normal charging stations in Beijing	64
10	Overall driving routes during the recording time	86
11	Hot spot analysis of the overall driving routes	87
12	Sample of a trip analysis	90
13	Night time parking locations	92
14	Daytime parking locations	93
15	Driving routes with different SOC	95
16	Charging locations	98
17	Sample of a mono-centric area in Beijing	106
18	Sample of a poly-centric area in Beijing	108
19	Sample for the POIs around parking events	110
20	Concept of a charging infrastructure build up	115
21	Carrefour supermarkets with attended buffer	116
22	Zone 1 analysis	136
23	Zone 2 analysis	137
24	Zone 3 analysis	138
25	Zone 4 analysis	139
26	Zone 5 analysis	140
27	Zone 6 analysis	141

Nomenclature

A	Ampere, unit of electric current
AC	Alternating current
AFV	Alternative fuel vehicle
Ah	Ampere-hours
BBA	BMW Brilliance Automotive Ltd.
BEV	Battery electric vehicle
BM	Business model
BMTC	Beijing Municipal Commission of Transportation
CAN	Controller Area Network
CATARC	China Automotive Technology & Research Center
CCS	Combined charging system
CS	Charging Station
CW	Calendar week
DC	Direct current
DD	Decimal degrees (Geographic coordinates)
DID	Densely inhabited districts
E-range	Electric range of a BEV
E-range	Electric range
Economic clusters ...	EC
EU	European Union
EV	Electric vehicle
EVSE	Electric vehicle supply-equipment
FAR	Floor area ratio

FCV	Fuel cell vehicle
FYP	Five-year plan (of the People's Republic of China)
G2V	Grid to vehicle
GB	Guo Biao (Chinese for "National Standard")
GC	Gated Communities
GPS	Global positioning system
h	Hour
HEV	Hybrid electric vehicle
ICCB	In-cable-control-box
ICE	Internal combustion engine vehicle
IEC	International Electrotechnical Commission
kWh	Kilowatt-hours, unit of battery capacity
MIIT	Ministry of Industry and Information Technology
MOF	Ministry of Finance
MOST	Ministry of Science and & Technology
MRD	Micro Residential District
NDRC	National Development and Reform Commission
NEV	New energy vehicle
OEM	Original equipment manufacturer, in this case car manufacturer
PHEV	Plug-in hybrid electric vehicle
PMA	Property management agency
PMO	Property management office
POIs	Points of Interested
POPS	Privately owned public spaces
PPH	Persons per hectare
PT	Public transportation
PWM	Pulse-width modulation, Type of transmission for communication information
R&R	Park and Ride

RMB	Renminbi, currency of the P.R. of China
RTM	Real-time-monitoring
SAE	Society of Automotive Engineers
SD	Small Districts
SGEVCP	Sino-German EV Charging Project
SIM	Subscriber identification module
SOC	State of charge
SOE	State owned enterprises
V	Volt, i.a. unit of electric potential
V2G	Vehicle to grid
VIN	Vehicle identification number

1 Introduction

1.1 Presentation of the Research Question

China's ambitious willingness to promote and support new energy vehicles (NEVs) is stated in the 12th Five-Year Plan of the Communist Party (Fulton, 2011). The main reason for this promotion is to improve China's air quality. Here, 25% of China's annual amount of NO_x and CO_2 is caused by car pollution (Eakin, 2015). To support environment-friendly vehicles in Beijing and other large cities in China, the national and local governments started paying subsidies and giving incentives for the purchase of NEVs. This act should at last improve the air quality by reducing carbon emissions and should furthermore reduce noise in the cities.

Next to the pollution topic, road traffic, especially in Beijing, has been increasing over the last number of years. The fact that more and more citizens want to have individual mobility results in a huge increase of new car registrations. To regulate and control this rapid demand, a competitive tendering procedure for license plates is organized by means of a lottery for Beijing citizens (Yang et al., 2014). Whereas the application process for a license plate is elaborate and time consuming. Some applicants wait years to get a plate although a draw is held every two months and attendance is free. Moreover a selected person has to pay a regular price for a license plate of around 3,000 Yuan per month. Beyond these regulations, the Chinese government will keep increasing the number of new license plates until 2017 when the maximum limit of around six million registrations shall not be exceeded (General office of Beijing Municipal People's Government, 10/8/2013). However, the allocation of plates for NEVs will rise through 2017 to support electric mobility. In conclusion, the allocation of plates for vehicles with internal combustion engines (ICE) will not cover all applications. At the moment the chance of getting a NEV plate is much higher and is the fastest way to obtain individual mobility. As of January 2014, about 15,000 NEVs are currently being driven on Beijing's roads (Yang et al., 2014). New energy vehicles (NEVs) consist of Electric vehicles (EVs), battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in electric vehicles (PHEVs) and fuel cell vehicles (FCV). Some of them get their energy from a combustion engine, using carbon neutral alternative fuels, while others run on pure electric energy.

Together with the number of NEVs, the demand for charging will rise. So far, the

existing charging network in Beijing is not designed for a higher amount of EVs and more electric vehicles will be registered in the next years. Therefore, it is still an open question how a public charging infrastructure is used by the EV drivers. This paper focuses on BEVs and specifically on the topic of charging, which is essential for operating BEVs. It will discuss the problems of how to set up a charging network by analyzing it from different points of view.

An adequate and user-friendly network of charging stations (CS) has to be installed in order to implement electric mobility and reach the authority's objectives. In the last years, the Chinese government has not focused on this development for the reason that until recently, only a few electric vehicles were licensed in Beijing. A charging network for EV taxis and commercial service vehicles is already in operation. However, the incompatibility of using different technical standards and non-standardized payment methods deters private EV owners from using these charging stations. A breakthrough and implementation is only guaranteed if a charging infrastructure is open to all EVs, demand-orientated and cross-linked to the existing mobility network. Furthermore, a charging infrastructure has to be tailor-made for each city.

1.2 Goal of the Study

The electrical individual transportation is permanently linked to a charging infrastructure. This important urban planning shift is intensified by the size of Beijing. This paper addresses this situation and generates a methodology and guideline for a build up strategy for an EV charging infrastructure in Beijing. The conclusion can be used as a manual for operators of charging stations. The title of the dissertation is:

*Guideline for the installation of a charging infrastructure
for electric vehicles in Beijing
A spatial analysis based on driving and charging profiles*

The field of electric mobility touches many disciplines in different areas. The implementation of a charging infrastructure demands cross-disciplinary connections. Therefore, the first part of the dissertation deals with the *factors of influence* of a charging network for electric vehicles. This chapter gives an overview of the "world of charging infrastructure" by listing, ordering and categorizing all aspects that influence the installation and operation of a charging network. Important factors will be highlighted by analyzing literature and interviewing experts. Thereby the focus is on China and the consideration is on local conditions in Beijing.

Another goal is to *analyze the urban geography* of Beijing with respect to necessary, feasible and valuable locations for charging pillars. For this, qualified spatial data

of points of interest, living conditions as well as parking conditions are analyzed and evaluated. In the next step, EV-users' driving and charging behaviors are added to the spatial analysis to work out a *build up strategy* for charging pillars.

The dissertation's increase of knowledge is the combination of urban geography, technical data from electric vehicles and the behavior of electric vehicle drivers to build up a charging infrastructure for electric vehicles in Beijing.

This paper makes no claims of being complete, especially in the economic aspects, which include business models for charging stations. However, this analysis can be seen as groundwork for such further research. Instead, the political frameworks, the technical standards and existing driving profiles are presented to provide an overall view of this topic.

1.3 Approach and Methodology

As written above, the intricacy of this topic is caused by the cross-disciplinary connections between many scientific fields. There are different approaches from disparate perspectives. There would be a risk involved in focusing on just one aspect and making assumptions within the fields out of its range or totally excluding facts that have an impact on the aspect's exploration. This basic problem is not solved by this dissertation but it will combine new points of view to understand the influencing factors on charging infrastructures for EVs.

The most utilized approach for the implementation of an EV charging network is done by analyzing the user's driving behavior. The MINI-E study, for example, is based on the driving behaviors of EV users around the world (UC Davis, 2011). From this data, the daily range and charging frequency is worked out. Thereby, spatial aspects of the users and the charging stations were not included. In his dissertation, Fabian Kley describes the build up of a charging network based on the driving patterns of ICE vehicles and business models for operation of the network (Kley, 2011). In his investigation, he also analyzed travel diaries (data source: "Mobilität in Deutschland") and included plug-in electric vehicles (PHEVs). Certainly, he included conductive charging, as it is done in this paper, but he doesn't mention spatial aspects. A different approach to finding locations for charging stations is followed by Liu (Liu, 2012). Beginning with the locations of local refueling stations, communities, and public parking spaces in the region, a charging network for Beijing is constructed. The user behaviors or business models are not part of the research. However, the model for a development of a regional charging infrastructure for electric vehicles in the German metropolitan region of Stuttgart was researched by the European Institute for Energy Research (Wirges and Linder, 2012). Out of a time-spatial view, the charging network for around 35,000

EVs, which should be charged with a cable, was developed. Therefore, potential *early adopters* were constructed. The number of households falling into these categories was determined for each municipality of the region. Wirges et. al make assumptions about charging behavior to create a formula that allows the calculation of demand for a number of charging stations created by a given number of EVs.

The city of London had a target of 25,000 charging points by 2015 (Mayor of London, 2009). Due to fewer public parking lots, the location for charging stations should be workplace car parks. By 2015, every resident of the city should be less than one mile away from the next charging point. This approach has partly answered *where* the drivers park, charge and which routes on which roads were traveled. However, this is not based on real driving profiles. The outcome of these studies is that most charging cases can be covered by home charging. Whereas public charging is common at supermarkets, malls or road-side, but only for emergency or spontaneous charging events. This study includes the spatial aspects to generate a new viewpoint.

The methodology of this paper is different from existing strategies on building-up a charging infrastructure because all quantitative data is analyzed in spatial terms and combined with the urban geography. The data comes from electric vehicle customers (cf. page 76). The drivers have to deal with ordinary charging processes and, hence, new insights of real EV driving patterns were generated. Moreover, the connection to the EV's battery data and GPS positions allows for the combination of technical and spatial knowledge of charging behaviors. The first chapter on page 7 gives an overview of the complexity by listing, ordering and describing all influencing factors for the build up and operation of a charging infrastructure. Out of an extensive literature review, a determination of all aspects will be conducted and existing charging networks will be presented. In combination with an expert discussion, all factors are categorized into five groups: *political aspects*, *economic aspects*, *technical aspects*, *user behavior aspects* and *spatial aspects*. An evaluation made from interviews with respect to the construction of a charging network in China completes the analysis and filters the critical variables. This qualitative analysis was chosen because of a lack of long-term experience and quantitative data in the field of operated charging networks. Moreover, fast-changing laws in the field of electric mobility can distort the market and focus.

A build up strategy for a charging network from a purely spatial perspective in Beijing will be implemented in chapter 3 on page 37. At the beginning, the focus of the research is on the urban geography of Beijing. First of all, the most important urban districts, areas and regions of interest (ROIs) are charted on a map to provide an overview of the municipality of Beijing. On this spatial framework, the different parking conditions in the city are studied. Beginning with parking lots on private grounds: so-called compounds are characteristic for present-day living conditions in Chinese cities and dominate the cityscape. Depending on the year of construction as well as the ground prices and location, these closed residential complexes vary in the type

and amount of parking lots. Because some of them even host kindergartens or small shops, semi-public charging can be offered alongside private charging. The historical city center, as well as detached houses in the suburbs of Beijing, are part of this chapter as well. The amount, density, and location of the different living conditions is examined to get information about potential charging spots and the installation of private and semi-public charging facilities. In the next step, the public parking conditions are analyzed and evaluated. For this study, the location, density and type of parking lots are of interest. Especially, reserved parking lots with the possibility of long-term parking are highlighted. Furthermore, public buildings like train stations or malls, as well as all qualified points of interests (POIs), for example museums, parks, or hotels, are part of the investigation. A categorization into various use cases should give an overview on the locations and act as a foundation for further research. At last, the existing charging network is studied. Because they use different technical standards, these closed charging systems limit access to specific electric vehicles but represent a part of the whole infrastructure.

In addition to the previous investigations above, data from electric vehicles provides a main input for the analysis and represents user behavior. Chapter 4 shows the result of a study with data coming from real-time-monitoring devices (RTM) which are installed in a mid-size electric vehicles. This RTM system records various vehicle data like time, battery status, speed and charging current. Because data from 60 vehicles was recorded over a period of two weeks, approximate representative data are yielded. The first part of this investigation answers vehicle-relevant questions while the second part combines this data with the movement profiles from the EVs. In the end, the driving and charging profiles are spatially edited. These new insights make a detailed investigation possible and provide an illustration of where and how electric vehicles drive, park, and charge by charting movement profiles on a map.

Chapter 5.1 summarizes the previous findings. Firstly, conclusions and results are presented. Through a neighborhood analysis, POIs around parking and charging locations are investigated and provide answers on how the actions of the study interact with the urban geography and connect the two fields of user and space. Finally, a guideline combines the influencing factors and the results of the study in chapter 5. Charging profiles for each charging location and user group are developed and enable scientific statements regarding how to implement a network of charging points. The guideline gives simple charging strategies and build up plans for a charging network in Beijing.

2 Factors of Influence on an Implementation of a Charging Infrastructure

As mentioned in the introduction, the charging infrastructure for electric vehicles is influenced by many factors from different scientific fields (Lenz, 2012). It is necessary to do interdisciplinary research. The following sections present and discuss the influencing factors. Firstly, as a matter of principle, the perspective is crucial for a closer look on this topic. Most papers and publications focus on one or two factors to describe a build up of charging infrastructure for electric vehicles (Wang et al., 2013) (Kuo, 2011) (Wu et al., 2013). This dissertation claims to give an overall view in the first part and highlight the most important aspects from all influencing factors. A complete view is the goal, although not all aspects can be described in detail. It's rather a question of whether all influencing factors are combined and related to each other. Of course, most of them are influenced by each other and an evaluation regarding the most critical ones become a matter of opinion with the result that experts in different countries come to various conclusions. An example of this is the handling of public space, respectively the parking space, in Germany and China. The parking management is handled in different ways which leads to another interpretation of parking space within urban areas.

As mentioned above, the literature spreads the influencing factors into five groups: political aspects, economic aspects, technical aspects, spatial aspects and the user behavior (see figure 2.1 on page 7). All of these feature further sub-categories which will be mentioned hereafter. These influencing factors cause the expansion of a charging network. Furthermore, a division of the infrastructure for EVs can be split into two types: *Hard charging infrastructures* describe the pillars, the grid and spatial environment (e.g. parking lots or transportation patterns), whereas *soft charging infrastructures* consist of regulations, standards, schemes, business models, degree of community engagement and the driving and charging behaviors of users (Beeton, 2011). The complex topic of building up and optimizing a charging infrastructure (and, thereby, a part of e-mobility) cannot be answered by only analyzing the users' behaviors and technical vehicle concepts. Ideas and proposals for authorities and local authorities are also important. All of these factors are correlated and must be well balanced. In most markets, the consumer slowly defines the demand for and set-up of charging points. Whereas in China, the set-up can

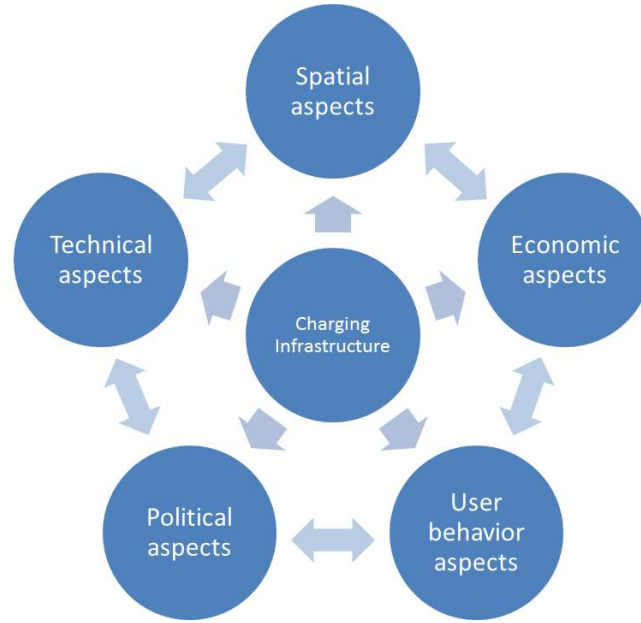


Figure 2.1: Factors of Influence of a Charging Infrastructure

be steered by authorities, driving the fast roll out of a charging network in accordance to these parameters. Hatton et. al. have highlighted three important issues for an EV penetration and, thereby, for a charging network: *The specifications and capabilities of the vehicles (speed, torque, handling), the action radius and availability of recharging facilities and the placement of EVs in the automotive market* (Hatton et al., 2009). But again, all of them can be found in this paper as well. However, this chapter only focuses on the political, economic and technical aspects. The spatial aspects and user behavior are transferred into separate chapters because they reflect the dissertation's main parts.

2.1 Political aspects

The first and main influencing factor is the political aspect because the Chinese government pushes electric mobility in many areas with laws and regulations in order to promote the penetration of EVs and their environment. Of course, part of this environment is the charging infrastructure. But this section also deals with the political framework around the charging pillars itself, like financial subsidizes, the registration process for vehicles and initial demonstration projects. In addition to such affirmative action, governments and local authorities are able to promote e-mobility in terms of traffic. This paragraph broaches this subject by presenting and introducing the most important factors in China.

Wiederer and Philip categorize the policies for charging infrastructure into monetary and non-monetary incentives, regulatory, real estate, advocacy and public relations and procurement (Wiederer and Philip, 2010). In their paper, the authors identify different tool-kits for city governments to assist in creating goals and road maps for a successful implementation of a charging network. Although their discussion is based on the American market and a different environment, a modified categorization can be used for the Chinese market to describe the situation in Beijing. However, the authors recommend unique EV strategies and programs for cities as their key outcomes. Because of the limited financial scope of most municipalities for the direct support for EV or charging stations, indirect public sponsorship is an option to promote e-mobility as well.

The next chapters and sections use three important terms which are common in almost all markets although they are not officially defined. For a better understanding of this paper, three definitions are put forth:

Private Charging: A charging station¹ for private usage, installed on private ground and operated by one person who is using their own EV for the charging process. A predefined group has access to the facility whereas the ownership of a parking lot belongs to the car or property owner. Payment and billing are concluded between one person and the grid company.

Semi-public Charging: This term describes a charging process at a privately owned parking lot which is primarily open for everyone but can have temporary or financial access restrictions. Thereby, the charging stations on these privately owned public spaces (POPS) can be open 24/7 or can be closed by the corresponding facility. (Kwan, 2013) (City of New York, 2014)

¹also termed as *wallbox* by some OEMs

Public Charging: The parking space with the charging station is open to public and on public ground (e.g. road-side parking or car park). The European Parliament defines it as: *"A recharging [...] point accessible to the public means a recharging or refueling point to supply an alternative fuel which provides Union-wide nondiscriminatory access to the users. Non-discriminatory access may include different terms of authentication, use and payment."* (European Parliament, 2014-04-15)

2.1.1 Policy levers

The market penetration of electric vehicles is difficult because of their high acquisition costs and limited e-range² compared to vehicles with an internal combustion engine (ICE). But, from the governments point of view, EVs help to reduce air-pollution in cities and put down a marker for the implementation of an innovative industry sector. At least, these goals are determined in the 12th Five Year Plan of the Chinese central government (Fulton, 2011). Consequently, the cities and authorities are interested in the needs of (potential) NEV buyers and, if necessary, in supporting them. Beside the regulations and incentives, which are presented in the following subsections, various levers can be used to remove barriers in the industries and for the end-user.

First of all, cities have the possibility to shift parts of their public transportation (PT) from vehicles with combustion engines into hybrid-electric vehicles or full electrical vehicles. Especially buses, service vehicles like street sweepers or rubbish collectors are potential traffic participants for e-mobility. These kinds of vehicles are perpetually driving within a defined spatial area and all of their routes are fixed. In addition, their routes are predictable and repetitive. These circumstances result in the easy planning of charging strategies. Otherwise, the consumption of these vehicles is higher than in electric passenger cars. These commercially used NEVs were the reason for a custom-built infrastructure, which is only usable for a selected group of NEVs. Most of these charging points are realized by building battery swapping stations or high voltage charging stations with direct current and are not accessible for private users (cf. the section "Existing Charging Stations in Beijing", page 64).

Municipally, governments are big advocates for e-mobility and use public relations to support it. Thereby, the advertisement for promoting EVs and the appropriated charging stations is free of cost for the authorities. OEMs and operators of the stations also benefit from this issue (Wiederer and Philip, 2010). A positive public image can be easily implemented by the conversion of government car-fleets. Besides the procurement of NEVs, a high distribution of charging pillars, which can be used as (semi-public)

²The term *e-range* (electric range) is used in this paper for the range for BEVs

work charging stations, is established on existing government real-estate or on public grounds in the city. Furthermore, this approach gives an incentive to the industry for investing in public infrastructure because a significant quantity of EVs are driven in everyday life. These procurements are the first steps to unrolling a charging network without considering the private sector. Simultaneously, the focus on the authorities at a higher level further serves as an icebreaker (Liu and Kokko, 2013).

Another policy lever is the general administration of public space like sidewalks, public garages, and road-site parking lots (Hassenpflug, 2010). The *ownership* of these areas has to be clear to prepare them for charging pillars. Only local authorities have the power to promote, reserve and change the public space. Thus, city governments become key players in the field of public chargers because of their role as a steering committee. A reliable parking management system with a unification of public space for charging pillars is also necessary (cf. section "Public Parking Conditions" on page 47). A comprehensive identification of parking lots with charging options is indispensable. A problem occurs while using a satellite navigation system in a car which routes to a feasible charging location but this cannot be found by the driver because the charging pillar itself is located somewhere in the underground garage, hidden by pillars or is, simply, hard to find.

2.1.2 Regulations

The local and national governments issue laws or guidelines with the goal of forming a safe, user-friendly and efficient charging network. The municipal government of Beijing, for example, has issued the goal for the installation of one thousand public charging stations by the end of 2014 and issued a law that 18% of parking spaces in new or renovated developments have to be equipped for electric-car charging (Edelstein, 2014). Although just a few of these stations were constructed, these zoning and building codes can help to overcome an investment barrier. Furthermore, the local government forced OEMs to install charging stations with fast DC-stations (direct current) and normal AC-chargers (alternating current) in front of chosen car dealers. Unfortunately, in two ways, this regulation misses the point.

Firstly, European car makers do not support the Chinese DC-standard. Therefore, imported EVs are not able to charge on these pillars (cf. section "Technical aspects" on page 17). The reason is a missing communication signal between the EV and the charging station. This leads to another powerful tool of the government: the determination and approval of *standards*. If the EVs, the charging equipment, technical specifications, and signals can't be connected or communicate with each other, a charging infrastructure

can't properly work³. In the end, these political decisions result in preferences for state owned enterprises (SOE) .

Secondly, the choice of location was not well selected due to the fact that EV drivers will not drive to a car dealer to charge their EVs without any personal added value (cf. page 109).

The guidelines of Hong Kong, for example, can be seen as a transparent implementation and introduction of e-mobility. The city has implemented diverse regulations and guidelines for building an EV charging infrastructure (Environment Bureau). One of them includes setting-up standards for charging facilities in car parks. Other arrangements have been set for new building developments and technical guidelines on the setting up of EV chargers. These papers represent a user-friendly communication and define clear rules for the installation of private and public charging facilities. Whereas the regulations in mainland China are not that clear as of 2015 (Geinitz, 2014-01-10). Particularly, technical test acceptances and the involvement of all participants like constructors, operators, and users of the charging pillars into the installation process are not clearly defined. Indeed, there are several ways to protocol installation and testing processes (cf. the "Sino-German EV Charging project" on page 15). However, for example, there is a specific law which prohibits DC-charging underground. The reason for this prohibition is charging underground may be a fire hazard or block fire-fighting efforts. Barriers like this make an implementation and a roll-out more difficult for all participants.

E-mobility and NEVs are going to play an important role in implementing a smart transportation system with an intermodal traffic network. The EV's dependency on charging facilities must be reflected when integrating them into the current traffic infrastructure. With additional e-services, city governments and local authorities have instruments to steer, control, and promote e-mobility. For example, the existing CCTV infrastructure (which is currently used for speed monitoring) can distinguish between NEVs and ICEs. This technology allows the restriction or promotion of certain types of vehicles to enter areas or traffic lanes. The tools of e-Lanes or e-Zones could generate further demand for NEVs in cities. Since the Olympic Games in 2008, the city of Beijing has established driving bans within the 5th Ring road (Wang et al., 2007). This act regulates the traffic by reducing congestion as well as reducing air-pollution. Once a week, vehicles with even or odd license plates are not allowed to enter the 5th ring road between 7 AM and 8 PM. In 2015, EVs were removed from this act and constitute an exception to further promote e-mobility in the city of Beijing. In the end, the idea behind green-energy-transport with alternative engines is more than a focus on NEVs. Therefore, the using of park-and-ride areas (P&R) with EVs and charging

³By the end of 2015, the DC-standard was still not passed by the authorities

points encourages intermodal passenger transport in the city. Additionally, Beijing is constructing new subway lines and connecting more and more rural areas with the public transportation network. E-mobility has the potential to complete this network.

2.1.3 Incentives and Subsidies

Monetary subsidies and incentives represent the most effective and popular kind of support for e-mobility. Direct subsidies have effects on the price of the hardware, like EVs or charging stations, whereas indirect subsidies decline follow-up costs. Both exist in China, although neither the central government nor the local governments directly support charging stations themselves. Furthermore, local regulations can help adjust the goals to urban environments by directly addressing the customers (Sebastian Heilmann, 2004) (Edelstein). The cost benefit for the end user is a strong signal.

Each city has its unique environment, within which different incentives will have different appeal for policy-makers, consumers, utilities and charging infrastructure providers. (Wiederer and Philip, 2010)

However, the national and local authorities in Beijing have established three direct subsidies for end users. Other cities and provinces have different development plans that vary in method and value. Potential EV customers have the opportunity to obtain the following promotions:

Subsidy from the National Government All locally produced NEVs in China receive monetary support from the central government. The Ministry of Industry and Information Technology (MIIT) is maintaining these regulations and distributing the money. The amount is related to the e-range of the EV and is divided into three groups (see table 2.1). The buyer of an EV receives a subsidy from the government after the purchase. Each year until 2015, there was a 5% decrease in the subsidy. An official draft provides a further reduction of 10% every second year beginning from 2016, together with the increase of the minimum e-range to 100 km.

Before 2013, the monetary subsidies were based on the battery capacity. During that time, the government distributed 3,000 Yuan per kilowatt-hour to all kinds of NEVs which were produced within China.

Subsidy from Local Governments The municipal administration or city governments are working with an EV-catalog which they themselves maintain. Independent from the national subsidies, cities can set their own priorities. Shanghai, for example, lists all NEVs, including PHEVs, while the city of Beijing just promotes pure EVs with local subsidies. The city of Beijing borrowed the financial support

E-range of EV	National subsidy					
	2013	2014	2015	2016	2018	2020
$\geq 80 \text{ km} \leq 150 \text{ km}$	35	33.25	31.5			
$\geq 100 \text{ km} \leq 150 \text{ km}$				28.35	25.5	23
$> 150 \text{ km} \leq 250 \text{ km}$	50	47.5	45	40.5	36.45	33
$> 250 \text{ km}$	60	57	54	48.6	43.8	39

Table 2.1: Subsidies from the Central government for BEVs in China 2013-2020; rounded numbers; all numbers in 1,000 Yuan (Ministry of Industry and Information Technology of The People's Republic of China, 2015)

from the central government. The total amount which a buyer of an EV receives is the same as the national governments subsidy. These regulations can be seen as a kind of protection if they are applied only to locally produced vehicles. However, customers can receive more than 60,000 Yuan in total for the purchase of an NEV in 2015.

Registration Process Beijing's government has established a competitive tendering procedure for license plates because of the rapid increase of vehicles in recent years (China Daily). To get a license plate for an ICE or NEV, all applicants have to apply at the municipal government of Beijing which hosts a lottery draw every second month. This regulation was implemented to deal with the huge amount of passenger vehicles. BEVs form an exception in this process. As table 2.2 shows, the chance to obtain a plate for an EV is much higher and incentivizes customers. Other cities, like the city of Shanghai, hold an auction for all license plates.

	ICE plates	NEV plates
Private applications	2,012,497	2,420
Commercial applications	57,946	2,557
Private payout	20,195	1,666
Commercial payout	1,300	1,666
Private chance of success	1%	69%
Commercial chance of success	2%	65%

Table 2.2: Competitive tendering procedure for license plates in Beijing for April 2014 (Beijing Municipal Commission of Transport, BMCT, 2015)

All these subsidies are granted when the NEV/EV is locally produced and is equipped with a special data logger (cf. section "The Real-time-monitoring device" on page 78). Subsidies for charging pillars or stations are not offered by the government. Unlike in Los Angeles where subsidies for home chargers of up to \$ 2,000 for the first 5,000 residential customers were assigned in December 2012 (Gallego, 2012).

2.1.4 Demonstration projects

The initialization and promotion of EVs started with the government. China's ambitious efforts in this green industry sector came from two aspects. The first is the state funding of local car producers and the second is the reduction of pollution in cities. To see the technical limitations and to acquire experience, the national and municipal governments have established *demonstration projects*. For a specific period of time a selected group of people is allowed to use NEVs. Almost all projects are supervised by questionnaires, monitoring or analysis by the government, universities or research companies. After the operative implementation, the procedures and practices are transferred and/or published. In the e-mobility field, the administrators in China established a number of demonstration test projects in provinces, districts or cities. Below, the most important projects are listed to give an overview. Thereby, the responsibility for these projects and the development and enforcement of alternative fuel vehicle (AFV) policies are shared by four ministries under the State Council: The Ministry of Finance (MOF), the Ministry of Science and & Technology (MOST), the Ministry of Industry and Information Technology (MIIT) and the National Development and Reform Commission (NDRC) (Zhen et al., 2012). These institutions steer and monitor the demonstration projects, recommend further steps and pass legislation. In the last few years, the laws were more focused on the development of EVs than on the implementation of charging infrastructure. The following paragraph summarizes the most important programs.

The *863 program*, China's most advanced technology research, development and demonstration program, was launched in March 1986 and has covered many technology fields for the last few decades. Later, the MOST included the *EV Key Project* in the 863-umbrella-program during the 10th Five-year plan (2001-2005). The General Office of the State Council issued the *Plan on Shaping and Revitalizing the Auto Industry* in 2009, which set out a production target of 500 thousand EVs (including PEV, HEV, and PHEV) and a 5% AFV share of all vehicle sales between 2009 and 2012 (Zhen et al., 2012). In the same year, the *National Energy-Conservation and Alternative Fuel Vehicle Demonstration Program* was launched by the MOF and MOST. This program finally included plans to build a charging grid that supports fast charging of EVs and the budget for public charging facilities construction (Ministry of Finance of the People's Republic of China, 2009). The *National Clean Vehicle Action* HEVs, PEHs and fuel cell vehicles (FCVs) were chosen as the major type of AFVs to deploy. All these projects and programs force the development of mostly EVs and, in the last step, the production and mass fleet tests, which peaked in the *Ten Cities, Ten Thousand Vehicles* program in 2012. One thousand EVs each in at least ten metropolitan or provincial capitals should be used as public service fleets, such as buses and taxis to get information, data and experience of every-day usage (Zhang, 2011).

Other projects are focusing on limited areas such as single cities or districts. Worth mentioning are the *EV Zone* in Shanghai and the taxi fleet in Shenzhen. The project in



Figure 2.2: Fast DC charging stations for taxi fleets between two highways in the north of Beijing; source: own research

Shanghai monitors and analyzes the data loggers from all private EVs in the north-west of the city. This organization is emerging as a rental company for EVs as well as a research center for the incidental data (EV Zone, 2012). The taxi fleet in Shenzhen was established as a demonstration project with EVs by the manufacturer BYD and the newly founded Pengcheng Electric Taxi Company in 2010. In contrast to the EV Zone in Shanghai, the fleet was studied regarding their suitability for daily use. The city of Beijing has advertised four districts where E-mobility is tested. In Yanqing, Fangshan, Baodi, and Miyun, locally produced vehicles are used as taxis as well and collect information and experience (see figure 2.2).

The Sino-German EV Charging Project (SGEVCP) is an international cooperation between the Chinese and German governments as well as OEMs, grid companies, technical support organizations like the China Automotive Technology & Research Center (CATARC) and universities from both countries. The goals are the installation of a trial public and private charging network, the preparation of guidelines for the installation and the implementation of processes for the cooperation between market players. A comprehensive analysis on customer requirements, infrastructure supply, installation process, grid implications, regulation gaps, technical standards and sustainable business models has been examined to give an overview on the situation in China (Deutschen Gesellschaft für Internationale Zusammenarbeit). Since some of the results and outcomes are already published, this paper will make references to them in the appropriate chapters.

2.1.5 Section summary

China's government has pushed and still pushes the topic of electric mobility by monetary incentives for EVs. Demonstration projects in cities, regions and provinces collect empirical data and analyze user behaviors. Though, in the last years the focus was more on EVs than on the charging infrastructure. Time consuming standardization processes and a change in strategy from battery swapping stations, from fast charging with only Chinese standards to the implementation of international standards, blocked the fast roll out of a nationwide charging infrastructure. Furthermore, an overall plan for an e-mobility network is still not published. At least the license plate scenario is exceptional in that more people are able to move by individual e-transport.

2.2 Technical Aspects

The following paragraph gives an overview of the well-established common terms, technologies and standards of charging hardware. Moreover, this section gives an overview on how to connect an EV to a power supply station, what kind of technical solutions are feasible and why these are necessary to operate a safe charging process. Technical specifications play a key role in charging networks and these standards are the foundation for compatibility between all EVs and charging facilities. Therefore, the technical equipment is an important influencing factor for the implementation and operation of a charging network - insofar that these regulations are default by the Chinese government (cf. previous chapter). Next, the basic terms and principles of electrical engineering are explained to give non-specialist readers a basic understanding of the technical aspects in the field of EV charging.

First of all, charging devices are designed by private and state-owned institutions, organizations and companies for different business models and operating strategies. As e-mobility is widespread and has been developed in several countries with different power grids, many different hardware devices have been designed and software solutions have been programmed. Additionally, all of the parameters, such as current or voltage, can be further adjusted for a tailored charging process and for diverse EVs. The amount of these variables make an implementation of a network with one technical solution difficult. Over the years, different solutions for the charging process have been developed. Various methods were established and cover almost all use cases, business plans and spatial conditions. In China, plugs or communication signals are not yet fully standardized. This fact results in a complex charging system on the hardware and software side. OEMs and customers are faced with many solutions and in the end, this leads to *parallel charging infrastructure*. Lawson has summarized this situation as follows:

On the one hand, national and international standards organizations attempt to find definitive solutions to these issues, but there are so many competing national standards. On the other hand commercial enterprises attempt to leapfrog the competition by coming up with new and unique innovative solutions to differentiate their offerings. (Lawson, 2005)

In general, the charging methods for electric vehicles can be divided into tethered charging, also called conductive charging, as well as wireless or so called inductive charging. The method of battery-swapping is another way to supply an EV with electric energy (cf. page 29).

This paper deals with the most common and cheapest way to charge EV batteries: tethered charging. This is also supported by political institutions in China (see section "Demonstration projects" on page 14). A further distinction within conductive charging

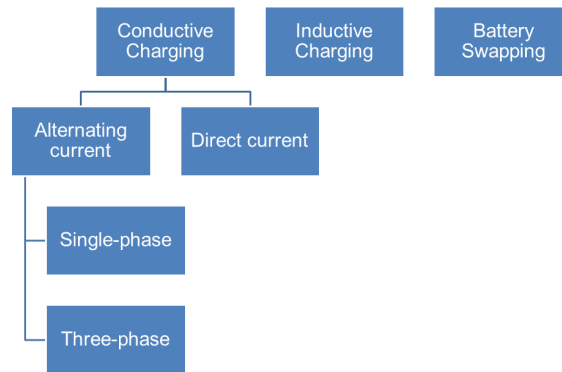


Figure 2.3: An overview of the different power supply modes for NEVs

can be made between charging with alternating current (AC) and with direct current (DC). Although AC charging is often considered slow charging and DC charging is considered fast charging, both technical solutions can be operated with higher currents. Consequently, AC charging can be as fast as DC charging in certain cases. But generally, DC charging is faster because batteries are always charged with direct current⁴.

2.2.1 General Charging Information

First of all, the terms of *charging station*, *charging pillar*, *charger*, and *charging location* have to be clear for the upcoming sections. A *charging pillar* is an electrical device which supplies AC or DC electrical energy to an EV by using one or two cables attached to the device. Some OEMs also call a private charging pillar a wallbox. In most cases, a pillar can provide electricity to one or two parking spaces. Whereas, a charging station is composed of several charging pillars and affords an opportunity to charge many vehicles at the same time – much like fuel stations. Most of these facilities are operated by a single organization and are frequently found in semi-public and public areas. The *on-board charger* is built into the EV and performs the actual conversion from the alternate current power source into direct current in order to charge the battery (Zeltner, 2010). Furthermore, the charger protects the EV battery from excessive voltage, current and heat. The on-board charger is specially dimensioned for each vehicle (see the charging cases on page 26) and is specific to the AC charging process. A *charging location* can be a simple cable coming from a house hold socket. In this case, the

⁴For a charging process with DC no on-board inverter is needed, in contrast to charging with alternating current. However, DC-charging also requires an inverter. It is just an off-board inverter. For AC-charging an on-board charger is needed. Thus there is a method called "inverter charging" using the power electronics of the e-motor. Latter is very rare due to high leakage currents.

transmission of electrical power highly depends on the diameter of the cable and the power electronics. Therefore, it is secondary if the cable is permanently attached to the power supply, the vehicle or vice versa.

The term *EVSE* , or electric-vehicle-supply-equipment, is the physical and operating infrastructure which allows electrical energy to be transferred to the charging socket of an EV. EVSE can take many diverse forms. Examples include a charging station with or without a permanently attached cable as well as a portable charging device whose power supply is a regular household electrical socket. The portable device shares the same safety and communication technology of the charging station by use of an ICCB (in-cable-control-box). The ICCB is necessary if the EV is connected to a household socket. In the end, the device serves as protection to prevent the car from surge (see figure 2.4).



Figure 2.4: Zinoro E1 cable with ICCB (BMW Brilliance Automotive Ltd, 2014)

A classification into at least three different power levels has been made by the California Air Resources Board in the United States. The standards in Europe are similar but based on different existing power grid standards of the national electricity generating utilities (Lawson, 2005). However, the levels reflect national regulations and became the standards. In addition to these three power levels, *rapid charging* has been established as a common term for the maximum power which can be physically transferred. The following descriptions explain the standards.

Level 1 Based on the American ground household outlet with a voltage of 120V and 16A. The maximum power for level 1 is 1.92kW and allows broad access to charge an EV (Nuzzi, 2010). It's also the most simple charging process with household power, single-phase alternating current and an ICCB (Botsford and Szczepanek, 2009).

Level 2 This is the primary and preferred method of EV charging at both private and public facilities because it represents the best cost-benefit ratio. It requires

special equipment and connection to an electric power supply dedicated to AC Charging. The voltage of this connection is either 240 volts or 208 volts, the current is 32 A. Level 2 electrical power stations have up to 20 kW of power from either single- or three-phase alternating current. (Lawson, 2005) Level 2 charging is also typically associated with overnight charging (Nuzzi, 2010). The lowest charging level defined by the European Parliament is *"a charging process with a power of equal or less than 22 kW can be described as a slow charging. Excluded are devices with a power of less or equal to 3,7 kW, which are installed in private households or whose primary purpose is not recharging electric vehicles, and which are not accessible to the public."* (European Parliament, 2014-04-15)

Level 3 This fast charging method is the EV equivalent of a commercial gasoline dispensing station and charges an EV a bit longer than it takes to refuel a conventional vehicle (clearly it takes more than 20 minutes (rapid charging) so it is not a bit longer than pumping gas. Because of individual supply requirements and available source voltages, exact voltage and load specifications for Level 3 charging have not been defined as in Level 1 and Level 2. These power requirements are specified by the equipment manufacturer (Nuzzi, 2010). The quick charging method in the EU is *"a charging process with an electric power more than 22 kW."* (European Parliament, 2014-04-15) However, the term should not be bound to direct current due to the fact that alternating current with three-phase electric power can be used for fast charging as well.

Rapid Charging The fastest method is a charging process with a direct current of 180 A and up to 400 kW. Charging times are reduced to 20 minutes (Elm EV Ltd., 2014). Japanese CHAdeMO chargers represent a rapid charging method but are not common in China.

Table 2.3 illustrates the different power levels. It should be considered that the American method is based on the voltage (volts) and the European on the electrical power (watt). Most public charging stations in Beijing are using Level 2 while most private charging pillars in Beijing are using Level 1.

Level 1 1-phase			Level 2 3-phase			Level 3 direct current
8 A	16 A	32 A	16 A	32 A	63 A	
220 V	220 V	220 V	380 V	400 V	400 V	
1.7 kW	3.5 kW	7.2 kW	10.5 kW	21 kW	41 kW	22 kW - 200 kW

Table 2.3: Difference between fast and slow charging methods with voltage of 220V

Charging pillar design is crucial for its utilization. Basically, a charging pillar consists of four parts: the control unit, switches, a power inverter, a cable and, if applicable, an AC/DC inverter. However, a charging pillar is not specifically needed. The combination

of a power outlet, a modem and a cable are enough and can be seen as a charging facility. Additionally, a user interface, a payment system and an Internet connection are built into the devices. These gadgets are requirements for additional services, e.g. software updates for the EV. This can be called *smart charging*. However, this term is used widely in the field of E-Mobility. Many definitions, use cases and requirements are linked to this phrase. First of all, smart charging is an intercommunication between the EV, the battery management system, the charging station, the grid and the internet. This intelligent system transfers electrical power and digital data between all devices. The data interchange guarantees a stable grid as well as an allocation for charging times or the cheapest electricity price to improve a sustainable, efficient, safe and user friendly distribution of electricity for EVs. During a normal charging event the power supply is charging the battery. This process is called *grid to vehicle* (G2V) and already becomes a simple smart charging process when the back-end of the power supply calculates the maximum current and voltage. The next step is the automatic calculation of the optimal charging time. The start or end time of the process can be predefined by the user. The most advanced technology is represented by the *vehicle to grid* (V2G) technology. The EV would be able to feed excess capacity back to the grid if required and necessary. This could be a possibility for a smart and decentralized energy storage system.

The obstacle in the whole system is the *grid transformer* because the power of each charger depends on the transmitted electric current and voltage. Thereby, the *transformer* can reduce the maximum power from the grid and convey less energy. The size and quantity of the installed pins in the plug as well as the diameter of the cable are further variables of the electrical power.

2.2.2 Charging Modes

The charging modes are similar to the power levels but define the kind of connection between the socket outlet and the EV. The four modes are split into four distinct types of installation and cover various applications as well as charging requirements. The socket outlet is often placed in a charging station itself. If the socket outlet of the EVSE is a house hold socket, an ICCB will be connected between socket outlet and the EV. Household sockets provide alternating current as single-phase current and are used for smaller household customers and installations. Most charging pillars provide this kind of power for the end user. However, alternating current can be also transferred as three-phase current for a higher power output. The following norms have been adopted by the International Electrotechnical Commission (IEC). (International Electrotechnical Commission, 2010)

Mode 1 Low power AC-charging method from a household socket-outlet is using an on-board charger not exceeding 3.7 kW (16A) and 250V for single phase or 11

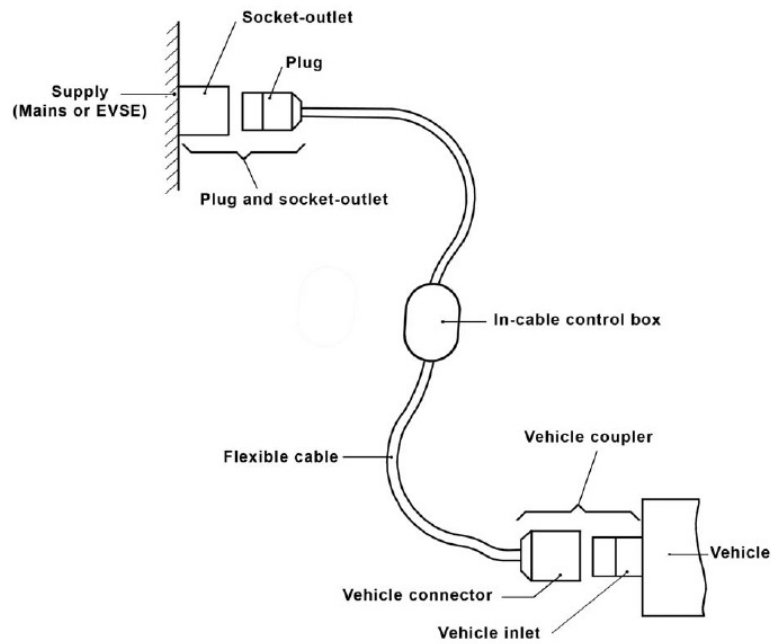


Figure 2.5: Electric vehicle service equipment (EVSE) defined by the International Electrotechnical Commission; this figure shows the charging mode 2 (Volkswagen Group China, 2012)

kW (16 A) for three-phase current. This mode has in-vehicle interlocking but no electrical control and protection. The latter generates two potential risks. The first is an increased risk of electrical fire because the cables and connectors have no protective equipment. The second risk comes from the extension sharing a socket on the main home electrical switchboard. This constellation risks drawing too much power and tripping the whole circuit. Due to these points, a safe operation is not guaranteed and not allowed in various countries, including China. (Johnson, 2015)

Mode 2 Low power AC-charging from a household-type socket-outlet with an integrated ICCB which incorporates a shock protection device, earthing cable and uses an on-board charger. Mode 2 is designed for up to 7.4 kW (32 A) with single-phase and 22 kW (32 A) for three-phase current and suffers the same voltage limitations in order to avoid tripping. In-vehicle interlocking is installed for electromechanical protection.

Mode 3 Level 1 and 2 charging use an EV socket-outlet with integrated control and protection function as well as an on-board charger with power up to 14.5 kW (63 A) for single phase and 43.5 kW (63 A) for three-phase current. Normally, Mode 3 is combined with the connector Type 3 (EVConnectors Ltd., 2014). Mode 3 incorporates a dedicated circuit in the home, thus bypassing the circuit overload problems Mode 1 and 2 encounter. Household appliances can be operated as

normal with no repercussions during car charging (Johnson, 2015).

The Japanese charging standard CHAdeMO uses an off-board charger for fast charging. The power supply cable is directly connected to the grid, thus the household circuit is protected. It can be found almost worldwide (Lawson, 2005). Many OEMs have equipped their EVs with CHAdeMO sockets to afford a fast charging solution before the European standard was established in 2010. It is only designed for DC-current with up to 62.5 kW (200 A) (CHAdeMO Association, 2014). The idea behind this standard is based on the fact that no dedicated chargers in EVs are necessary. The current should conduct without any rectifier in the charging pillar or the EV. By circumventing this obstacle, the power-output has no effective limit. This Level 3 charging supplier is also designed for smart charging, including a PWM-signal and a V2G feature.

Charging Types

The vehicle connectors are attaching the EVSE with the electric vehicle. These plugs make a differentiation evident for the end customer and characterize the charging method. The connectors are categorized by region and type of current (see figure 2.6). Next to the AC plugs and DC plugs, the new combined charging system (CCS) uses both kinds.

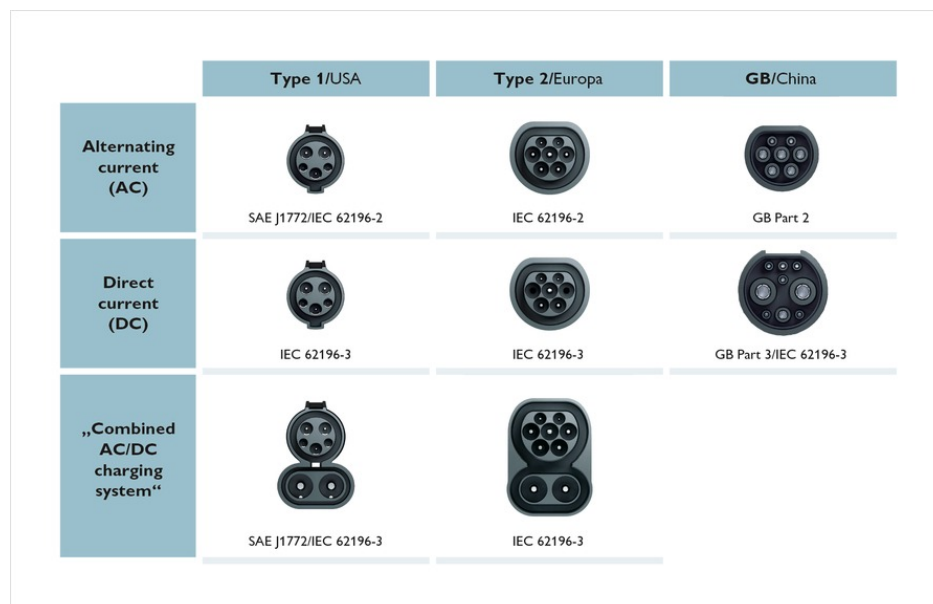


Figure 2.6: International standards and plug-in charging systems for electric mobility (PHOENIX CONTACT, 2014a)

Type 1 Mainly designed by the Japanese Yazaki cooperation, this plug is used in the USA as well as Japan and verified with the standard *J1772* by the Society of

Automotive Engineers (SAE) with up to 1.92 kW (16 A) for single-phase. This specifications cover Level 1 and 2. The DC version provides up to 36 kW (80 A) for Level 1 and 90 kW (200 A) for Level 2.

Type 2 The plug was invented by Mennekes which is the reason for it's more common name "Mennekes connector". It became the standard *IEC 62196-2* plug for EVs in the European Union and was designed from the beginning with the pulse-width modulation (PWM) . (International Electrotechnical Commission, 2010)

Type 3 Also known as GB/T standard (*guo biao* for Chinese "national standard" / T stands for *tuijian* "recommended"). This standard is designed for the Chinese market and is similar to the European "Type 2" plug, but features (male) pins instead of the (female) plugs in the Chinese version. The AC-version is approved and used by all EVs which are driving in China. The Chinese DC-version of Type 3 is designed with a mechanical locking system for preventing premature removal during the charging process. An electric locking bolt and snap-in locking ensure that the battery is charged safely (PHOENIX CONTACT, 2014b). However, this standard is not classified as safe from European OEMs because of un-insulated pins which can be touched by the user while they are working with voltage-carrying parts.

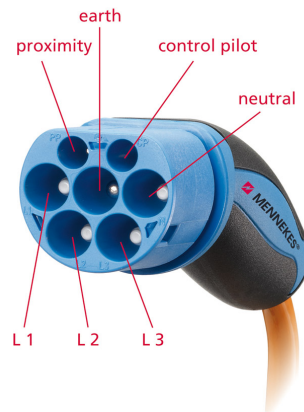


Figure 2.7: Type 2 plug with labeled socket pins (Mennekes, 2011)

Figure 2.7 shows the functions of the seven socket pins of an European Type 2 plug. The Chinese GB/T standard is almost the same, just with opposite pins. The functions of the pins are as follows: If the plug is used for a three-phase charging process, the terminals *L1*, *L2* and *L3* are reserved for the three alternating current phases. *N* is the neutral terminal which is connected to the ground and carries current on normal operation. For a single-phase usage of the plug *L1* becomes the positive pole, whereas *N* becomes the negative pole. The proximity pin *PP* is the signal to the EV and checks through a voltage surge if the vehicle is engaged correctly to the power supply. *CP* means control pilot and monitors the maximum output current by a pulse-width modulation (PWM). Together with the *PE*-pin (protective earth), it closes a circuit.

This electrical guard saves the battery from unregulated currents and covers the same tasks as the ICCB. This communication system between the EV and the power supply is a European-specific feature. The Zinoro E1 (cf. subsection "The Reference vehicle: Zinoro E1" on page 76), for example, needs a PWM-signal to start the charging process. Other Chinese vehicles do not request this signal. This exclusion criterion is a huge gap and results in charging options where EVs need a PWM-signal or not.

The international standard IEC 60309 which regulates the plugs, socket-outlets and couplers for industrial purposes (see figure 2.8) is often used in households. This is a standard application for electrical devices. However, the Chinese GB standard 2099.1 isn't provided for EV usage, although the plugs and sockets are designed for electricity with up to 690 V and 125 A (Rey and Lenferna Ltd.).



Figure 2.8: 2 mated 3P+N+PE industrial plugs and wall-mounted sockets (Barfod, 2006)

Charging Cases

The charging cases define the wiring between the EV and the charging facility. They are specified in the IEC standard 62196-1 (International Electrotechnical Commission, 2010). Figure 2.9 gives an overview of the cases.

Case A The connection between an EV and a AC supply network (e.g. a charging station) utilizing a supply cable and plug which is permanently attached to the EV. This case represents charging *Mode 1* and *Mode 2*, see page 21.

Case B The connection of the EV to the AC supply network utilizing a detachable cable assembly with a vehicle connector and AC supply equipment (on-board charger). This case can be often found in the EU and utilizes the *Type 2* connector.

Case C The connection of an EV to AC supply network utilizing a supply cable and

vehicle connector permanently attached to the supply equipment. Only *Case C* is allowed for *Mode 4*-charging (fast charging). Because this charging case is mostly installed in the USA, the *Type 1* connector is used. Based on the fact that the cable is fixed to the supply network, it is susceptible to vandalism. For example the cable can be cut off.

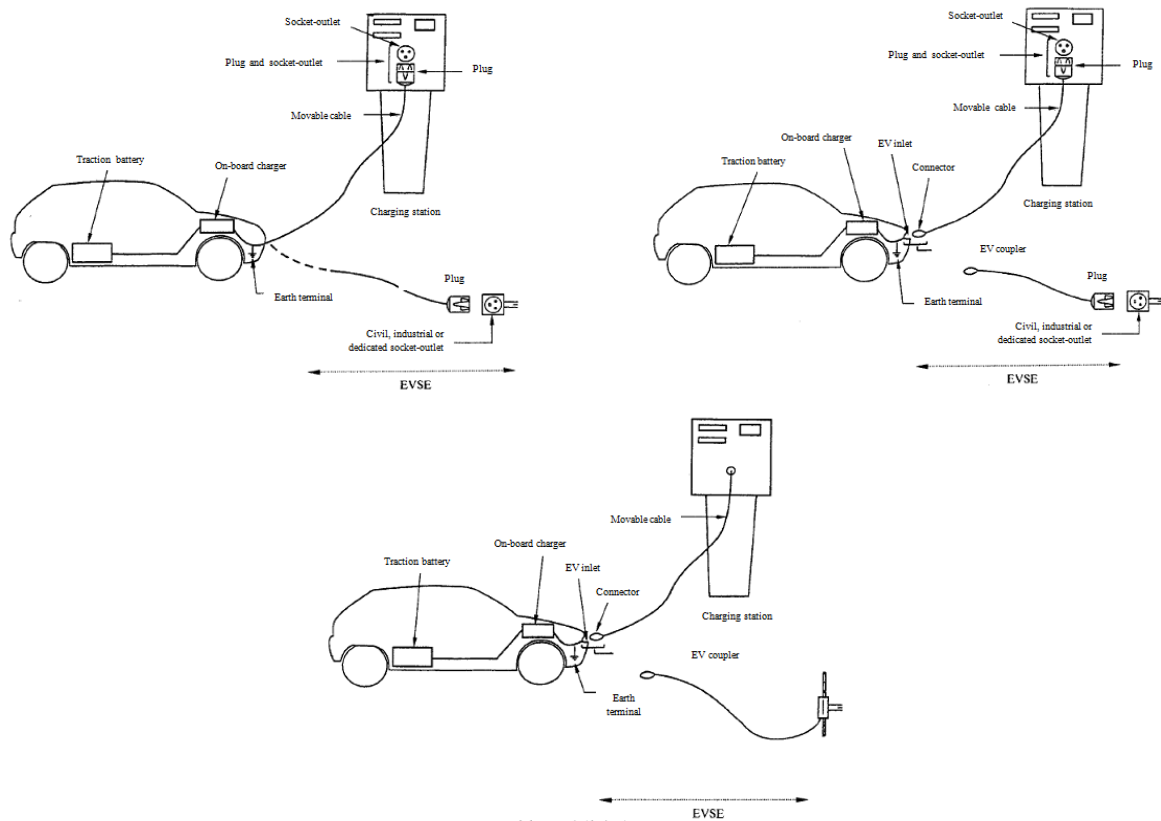


Figure 2.9: Charging connection case A, B and C

Charging Times

EV charging time is often an exclusion criterion for people who could buy such a vehicle. Although charging during the night time is designated by OEMs and service providers, most people are familiar with the short refueling process from ICE-vehicles at gasoline stations. For the service provider of charging stations and the operator for commercial EVs, charge times which become too long are unprofitable and wasteful. Figure 2.10 visualizes the charging time for a Tesla Model S. This physical effect occurs at AC and DC charging stations. Table 2.4 gives an overview of charging times of some popular EVs in China. Due to the fact that most charging processes use alternating current, it is the battery size of the EVs which becomes crucial. For example, the *BYD E6* has a battery capacity of 61.4 kWh (BYD Auto, 2014) and the *Tesla Model S* has a battery capacity of 60 kWh (Tesla Motors, 2014).

	Mode 2	Mode 2	Mode 3	Mode 3
	6A / 220V 1.32kW 1-phase	16A / 220V 3.52 kW 1-phase	16A / 220V 10.6kW 3-phase	3 × 32A / 220V 22kW
Zinoro E1	18.2 h	6.9 h	n.a.	n.a.
BMW i3	13.6 h	5.1 h	n.a.	n.a.
Denza	34.1 h	17.3 h	n.a.	2.1 h
BYD E6	41.7 h	15.6 h	5.2 h	n.a.
Tesla Model S	64.4 h	24.1 h	8.0 h	4.0 h
BAIC E150	17.4 h	6.5 h	n.a.	1.1 h
E-Smart	11.4 h	4.3 h	1.4 h	n.a.
Hyundai BlueOn	10.6 h	4.0 h	n.a.	0.7 h
Average	26.4 h	10.4 h		

Table 2.4: Charging times for selected EVs available in China

Battery charging time depends on three key factors. The first factor is the *electrical voltage and current*. The higher the current the faster the charging process. In China, the voltage used in cities is around 220 V and the current for most AC charging pillars is between 16 A and 32 A. Below 8 A, the charging process is not efficient anymore because the internal resistance of the battery will become too high. The voltage is subject to fluctuations especially in rural areas and is a reason for different charging times.

Another important factor for the charging time is the *battery size*. The most common term for the capacity is kilowatt-hours (kWh). It is a measure of the actual energy content of the battery. It measures how much power (watts) the battery can supply multiplied by the number of hours it can function before it runs out. Whereas ampere-hours (Ah) is a measure of charge and multiplies current by time. When only an Ah specification is given it shows how long a current can be taken from the battery until it is empty. However, the bigger the battery, the longer the charging process.

The last critical parameter is the (outside) temperature. The battery charge is diminished by low temperatures because electrons exhibit decelerate reaction rates and the internal resistance increases. To remedy this problem, battery packs can be heated in winter and cooled down at high temperatures in summer. The energy to regulate the climate is used either from the charging current which limits the charging efficiency or the battery energy which limits the range of the vehicle. The charging mode (describes the kind of cable and process, see above) and the charging type (kind of plug) have more influence on the charging time than the charging case (usage of cable).

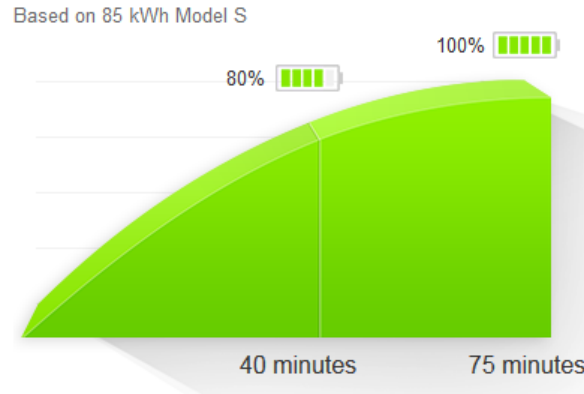


Figure 2.10: As written on the Tesla website: *Charging from 10% to 80% is quick and typically provides ample range to travel between most Superchargers. Charging from 80% to 100% doubles the charge time because the car must reduce current to top off cells. Actual charge times may vary* (Tesla Motors, 2015). This technical fact can be applied to most of the EVs in the market if they are using DC charging.

Electrical grid

The stability of the electrical grid is essential for all kinds of electrical consumers. Particularly, the topic of EV charging is a subject of discussion. (Zeltner, 2010) (Zimmerman and Bass, 2013) If all EVs on one street, compound or block are charging at the same time, e.g. in the evening, a blackout of the grid is forecast by e-mobility opponents. The apprehension of an ageing and not very advanced grid in older compounds could not accommodate the high peaks during charging rush hours. The China Automotive Energy Research Center at Tsinghua University (CAERC) simulated various charging scenarios and studied the impact on the electrical grid in Beijing. They found out that charging during different seasons, such as summer or winter, and charging at different times of the day have no serious impact on the charging process.

It is evident that electricity consumption by electric vehicles is very small, and it has no significant impact on the balance of power supply and demand in either scenario. (Zhu et al., 2013)

The study involved between 50,000 to 200,000 EVs with a charging efficiency of 0.9, a charging power of 4kW and a SOC-lift of 60%. This investigation explored a free, a time-delayed and an orderly charging scenario. From their point of view, it is unlikely that even a substantial amount of EVs could be responsible for an electrical shut-down, even if all of them charge at the same time.

Battery swapping

Although this method of energy supply is not part of the paper, a short paragraph will give an overview of how it works. Battery swapping is a method to recharge EVs as quickly as the refueling process for ICE vehicles. It was mainly invented and distributed by the Israeli company "Better place". The Chinese government took over the idea for a huge roll-out in China. However, the disadvantages of this system prevented success. Generally, the idea behind a battery swapping station is the replacement of the whole battery pack. This includes all cells, connectors and cables in the battery box. After the EV was parked in an apparatus, a robot lifts the vehicle, and grapples detach the battery box and put a new one into it. This process enables a quick charging process for the user. On the other hand, a huge area and infrastructure is required for this apparatus because all new batteries have to be stored. A much higher energy consumption for the charging process in one spot exacerbates the search for a proper location. In the end, it was this problem and two more reasons that basically put an end to the system. Firstly, customers do not know if they get a physically new battery or an old one which was charged. Secondly, OEMs had to design all EVs with one battery size. Furthermore, the locking mechanism would predispose the EVs for crashes or bumps on streets.

Summary

The technical issues highly influence the charging infrastructure. Plugs, connections and protocols generate a huge diversity of variants and cases of application. A nationwide standardization of this hardware and software is a governmental task. In the end, an interaction of all devices and cases has to lead to a user-friendly charging application. This also includes the payment and billing system of the charging stations. As long as the Chinese standards are still under discussion, different systems have been rolled out in parallel. The competition of commercial enterprises for their products on the one hand and the Chinese government with standardization processes on the other hand involve the danger of a slower market penetration and customer frustration. Today, private websites list and check the charging stations in Beijing regarding their interoperability for NEVs.

2.3 Economical aspects

The economic perspective of the charging infrastructure is an important influencing factor for the drivers of EVs, operators and stake holders as well. Generally, this field of study covers the business models for charging facilities, the market players, the EV market as well as the prices for electricity and the charging stations itself. The aspects of profitability and total cost of ownership are subjects of many research studies but all aspects have not, to this day, been analyzed together and in relation to each other, particularly in combination with spatial aspects. This overview will list and introduce the most important economic aspects for the charging infrastructure of electric vehicles. An overview of the market and already existing solutions is not within the purview of this research.

For some EV users the decision to purchase an EV are lower fixed or variable costs. That is to say, the operation costs are lower because the price per driven kilometer is lower than for ICE vehicles. On the other hand, the purchase of a charging station is a huge investment. Here, the costs of AC charging stations are proportionately lower than for DC stations. However, charging station operators and providers calculate with a high workload on charging facilities in order to generate a high turnover.

This section deals with a rough overview of the economic aspects. This section is not intended to generate a detailed business plan or calculate total costs of ownership, but rather aims to list and explain the most important market players, factors and issues in this field.

2.3.1 Identification of market players in China

Many different organizations, companies and authorities are participating in the charging infrastructure market in various ways. Some are active and have direct influence on the infrastructure, such as the customers or governments; others are passive and have indirect influence on the market (e.g. by providing different gasoline or electricity prices). Below, the most important stakeholders are listed with their position and role in the EV charging market.

EV Users The drivers of EVs are the customers of the electricity providers. The electricity prices can be crucial for users to decide whether to charge at home, at work or at public places because the tariffs are dependent on the location of the charging pillars (Li and Ouyang, 2011). The price for a kilowatt hour at commercial buildings is much higher than at private households in Beijing. This fact can have an influence on the driver's charging behavior (Ma and He, 2008). Price-conscious users might prefer locations with lower prices, even though the

location is not convenient for their travel. At this point in time, the Chinese government does not have any plans to incentivize the purchase of charging facilities or introduce new price models for the charging station's electricity.

Tariff	Electricity rate
Tariff for heavy industry	0.65 - 0.7 Yuan/kWh
Tariff public parking spaces and for the commercial/trade industry	0.85 - 0.91 Yuan/kWh
Tariff for households	0.47 Yuan/kWh

Table 2.5: Electricity Rates for Beijing (Beijing Municipal Commission of Transport, BMCT, 2015). Private electricity is cheaper than industrial energy. The price for charging an EV depends on the type of property at the charging station. Consequently, charging at work is more expensive than charging at home.

Special prices for fast charging options are already established in the U.S. (eVgo, 2014). For users who are using a third party's charging network, the electricity price for normal charging (charging with AC) is the same at all locations. This means private charging at home costs the same as normal charging in public or at a shopping mall. The electricity price for fast charging (DC charging or 3-phase charging) is relatively higher.

Authorities National and local governments regulate the country's strategy on e-mobility, award subsidies and incentives, as well as steer the urban instruments for an implementation and roll-out of charging stations and EVs.

Grid Operator The installation of charging stations is highly dependent on the grid. The operator is responsible for the stability and final check of the facility.

OEM Car manufactures influence the market by the production of NEVs and the decision on their battery-size. They also use their market power to implement standards, technologies, business models and private charging stations.

Property Owner The property management office (PMO), the property management agency (PMA) and the property owner approve the construction of charging stations. Their role in the market is determined as a supervisor for the facilities. However, they can become an operator and owner as well.

Parking Lot Operator The parking management provides the charging space, either on public or private ground. The parking operator can also, but does not have to, be the charging operator at the same time. In either case, an adaptation of parking and charging fees is necessary.

Equipment and Service Providers The charging station operator/3rd parties are the

actual connection between the user and the electricity grid.

2.3.2 EV market

Charging infrastructure is also highly dependent on the quantity, range and charging time of different EV models, Table 2.6 lists the most popular EVs in Beijing and their e-drive data. This overview illustrates the huge variety of technical specifications and the important fact that not all of them can use the same charging solution. This categorizes the EV market into various groups. For the end customer these groups and the charging solutions are hard to comprehend.

OEM and Model type	Battery capacity	E-range	Charging type
BAIC E200	25.6 kWh	150 km	GB AC (no PWM) + GB DC
BBA Zinoro E1	24 kWh	150 km	GB AC (PWM)
BMW i3	24 kWh	160 km	GB AC (PWM)
BYD Denza	47.5 kWh	300 km	GB/T
BYD E6	60.0 kWh	300 km	GB AC (no PWM) + GB DC
Chang'an E30	24.6 kWh	160 km	GB AC (no PWM) + DC
Daimler Smart ED	17.6 kWh	145 km	Type 2 AC (3-phase)
JAC iev4	19.2 kWh	160 km	GB AC (no PWM) + DC
Tesla Model S*	85 kWh	500 km	all (with adapters)
Venuria E30	24 kWh	150 km	GB AC (no PWM)
Zhongtai E20	19.5 kWh	120 km	GB AC (no PWM) + DC
Average	33.3 kWh	203 km	

* Tesla Model S also available with smaller 60 kWh battery and an e-range of 375 km

Table 2.6: Most sold EVs in Beijing with charging related specifications

The charging time is highly dependent on the battery size of the vehicle (cf. subsection "Charging Times" on page 26). Some OEMs are focusing on bigger battery capacity whereas others have chosen smaller batteries to reduce the total cost of the vehicle as well as the charging time. Both kinds of battery sizes have advantages and disadvantages. Bigger batteries need longer to charge with alternating current and enable a longer e-range. But if the charging procedure exceeds the parking time during night, the user is reliant on other charging locations, e.g. public charging pillars, but preferably fast charging. Or, alternatively, the user recharges longer. Smaller batteries, on the other hand, are faster to charge and can even be charged with a normal household cable. Here, a reasonable charging time of two hours can raise the e-range. However, EVs with smaller batteries have to utilize chargers more often if they want to travel the same distance as ICE vehicles. In this context, it is important to mention that DC chargers

have higher investment costs than chargers utilizing alternating current. It does not matter if it is for private or public charging.

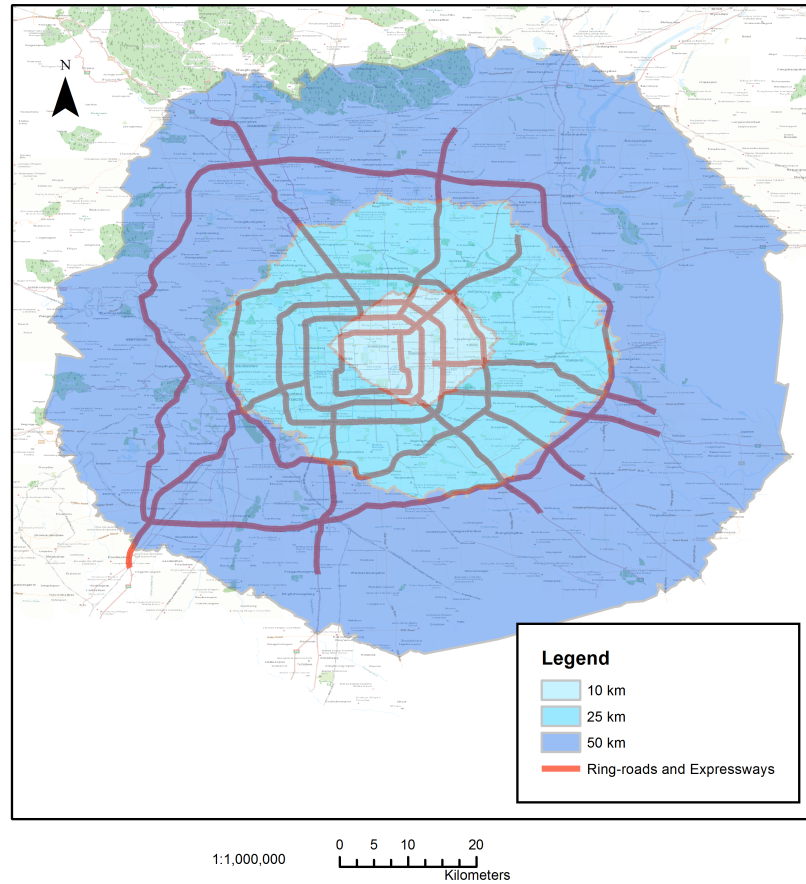
Though this paper focuses on BEVs, charging infrastructure should also be available for PHEVs. These kind of NEVs exhibit a smaller battery and a combustion engine as a second power train. Consequently, PHEVs can be driven with an empty battery as well. This engine concept removes *range anxiety* because the user has no need to charge. An investigation into this topic is not available for Beijing but it is obvious that PHEVs will have a different usage of the (public) charging infrastructure than BEVs. Ultimately, various types of EVs are distinctly using a charging network. Frequency and duration of each EV user are connected to the range and model type including the charging type. This constellation can lead to profitable workload for charging facilities. Good examples are the Smart ED and the Denza because of their different battery sizes and their resulting requirements for a charging network.

Not every user really needs a fast public charging station. Map 1 on page 34 shows the service area of three ranges outbound from the Sanlitun area in the north-east of Beijing in the Chaoyang district. The map visualizes the e-range of 10 km, 25 km and 50 km based on the road network as well as the road mileage and includes eventual detours. The outline of the service area indicates the middle of the journey if the driver wants to return to the departure point without charging. Trips inside the 5th Ring road are almost fully covered and the e-range guarantees no charging for even two return trips. All service areas can be interpreted in different ways. Firstly, the areas can represent the battery sizes of the PHEVs. Secondly, they can represent batteries with a low state of charge.

Regardless, the covering of almost the entire inner city of Beijing unveils the possibilities of most of the NEVs. Of course, this map is showing the e-range just for one outbound trip, and further trips need eventual additional charging events, but with one return trip users can use an EV as a commuter vehicle inside Beijing. Charging stations would extend the service areas and thus the e-range of the NEVs. But if the user has installed a home charging facility for night charging, the covering of the inner city of Beijing is no issue.

2.3.3 Business models

Business models (BM) for charging services are essential for the successful implementation of a charging network because the Chinese government opened the market and does not insist on having a monopoly. However, the national grid companies, State Grid and Beijing Grid, are the leaders in public charging stations. This is based on the fact that these state owned enterprises (SOE) have easier access to public space and can regulate the market e.g. by adjusting prices for electricity at charging stations. On



Map 1: Service area around Sanlitun with a road mileage of 10 km, 25 km and 50 km.

the other hand, the private charging market is dominated by private companies. Most pillars for home charging solutions are delivered together with the EV and are property of the EV owner. From an economic view, this correlation leads again to a *parallel infrastructure* because the customer has two different billing systems. To have a charging network with the same access at everyone's disposal, companies founded joint-ventures or partnerships. This incorporation of OEMs, charging station manufacturers, parking lot operators and electricity suppliers could start services to provide home and (semi-) public charging under one roof.

Starting with private users and home charging, the point of profitability is influencing the purchase of an EV. Economic comparison calculations with ICE vehicles and, especially, with gasoline prices brings users to purchase an NEV. However, depending on the battery size of the vehicle, different charging facilities can be selected for a home installation. EVs with a small battery, like the Smart ED with a capacity of 12 kWh, do not need a high power charging solution because the charging time is acceptable even with a standard charger. Based on a cost-benefit calculation, EV-batteries with a capacity above 50 kWh operate best with direct current (DC) chargers because these facilities can provide the highest electrical power. But these chargers have the highest

acquisition and running costs. DC charging stations are up to ten times more expensive than AC stations and, because of the higher electricity flow rate, more money has to be paid for electricity as well. These rough calculations are thus more necessary for public charging stations (Schroeder and Traber, 2012). For these cases the operating hours have to be higher than a private DC station to generate a turnover. Accordingly, the amount and density of these high-power stations have to be well selected.



Figure 2.11: State grid's public charging pillars: clearly evident are the two different user interfaces and control concepts; source: own research

First of all, a distinction has to be made between the provider of pure public stations, pure private stations and the companies which provides charging at home and in public (Snyder et al., 2012). All of them can provide electricity for one car. At least every EV is connected to one pillar, but a pillar sharing concept and interoperability by one company is still rare in 2015 (ElBanhawy et al.). Generally, billing at charging stations is feasible with different options. From the point of view of an operator who is offering private and public charging facilities, some options are presented:

By Time The user pays e.g. per minute. Thereby, it doesn't matter how much energy is transferred between the charging facility and the EV. This option is similar to the parking lots business model where the user is paying for the time he occupies the parking space. The payment according to time is realizable at home and at public stations. The software would recognize the connection of the plug and starts to count. A credit system like "Anytime Minutes" for mobile phones can be copied for the charger customers.

By Electricity The amount of kilowatt hours (kWh) is invoiced. This becomes a matter when charging facilities are equipped with different cables which can transfer different amounts of electricity. This model is similar to gasoline stations, where customers pay per liter/gallon and get a fixed unit of energy for the vehicle. Paying by kWh makes a comparison between the tariffs easier for the end user as the grid companies offer daytime and nighttime tariffs as well as tariffs for different locations. Furthermore, it allows the customer an easy payment with his household electricity.

By Usage The payment observes how many charging stops the user has done in a specific period of time. The duration of each single event or the quantity of kilowatt hours are irrelevant for the price. Some operators are offering this payment model with a limited amount of access to public fast charging stations per week. The customer can order this package in addition to the home charger.

Flat Rate This payment model offers the customer an overall service to private chargers and all kind of public chargers. The customer buys a subscription. Additionally, a freemium model can be offered where users have access to (rented) home chargers but have to pay for public chargers of the same provider.

These options are already implemented in some EV markets. Some operators distinguish between home and public, as well as between fast and slow chargers. (Langezaal and Bouman, 2011) As green energy is highly recommended for a sustainable usage of EVs, customers can take out an option for it as well.

2.4 Conclusions of this chapter

The three influencing factors in this chapter illustrate the wide range of technical possibilities and implementations into business plans. In doing so, the biggest political restriction for charging infrastructure operators is on the still-open fast charging standard and the fact that the public authorities do not promote the implementation of charging stations, either private or public. It is to be expected that this political orientation will not change in the next years. However, using payment and booking services allows charging station operators and customers to cover a wide range of individual use cases. In particular, the integration of smart phones with cashless payment transactions enables an easy combination of home chargers with public and semi-public charging stations for one user. This circumstance is essential for a further integrally thought-out solution. With the addition that standards are unified, including the energy supply.

3 Spatial Analysis of Beijing

This part constitutes another influencing factor but, because of its more important status in this paper, it is presented in a separate chapter. Beijing's unique geographical structure and living conditions demand a closer look in the context of a charging network built up. Examining China's capital, the country-specific features related to the parking conditions are analyzed in a more detailed way to show the difficulties which occur when install charging stations.

3.1 Methodology of the Spatial Analysis

This spatial analysis deals with the urban geography of Beijing. With respect to the installation of charging stations and charging pillars: the city's structure, qualifying points of interest (POIs), parking conditions as well as the land use are categorized, evaluated and interpreted. After an introduction to the software tool, which was used for the study, this chapter will give the reader a spatial overview of Beijing's districts, city centers and regions of interest (ROIs). Major sub-districts and important urban-areas have been examined as well. The urban structure of Beijing will be used as a reference and basis for the analysis of driving patterns later in chapter 4 (see page 69). POIs which are related to the charging infrastructure are presented and discussed afterward as well. Therefore, their density and frequency is examined for potential charging locations. However, this study also tries to investigate potential locations in the form of POIs or potential ROIs for a charging infrastructure, detached from the EV user behavior in chapter 4.

As most of the charging process is done during the night, the locations of different living accommodations and their corresponding parking conditions will be studied as well. Gated communities, villas and the historical downtown of Beijing are the main distinctions in this category. However, there also exist different types of gated communities in Beijing. Particular attention will be paid to their parking conditions as this data is urgently required. Additional information like location, quantity of parking spaces in the parking lots, owner of the ground and type (under-ground, road-side, free of charge) are essential for a comprehensive result in the field of private charging but were not available.

The analysis of the public parking conditions is done in the following section of the dissertation. A rough spatial investigation of the 1.6 million public parking spaces should at least find indicators like the distribution and density of potential parking lots in the municipal area of Beijing. At last, the study of the existing charging infrastructure for EVs in Beijing is part of this spatial analysis.

The usage of the Geographical information system

The analysis of the space in Beijing was done with the geographic information system (GIS) *ArcMap 10.2.2* from ESRI. The basis for the study is a detailed vector map of the Beijing Municipality which includes 14 districts and two counties¹. This area constitutes the study area of this dissertation and represents the area of the most driving profiles. To avoid any misunderstandings, the technical terms and phrases of *ArcMap* were used. Especially names of tools and processes in the program are adopted to avoid confusion.

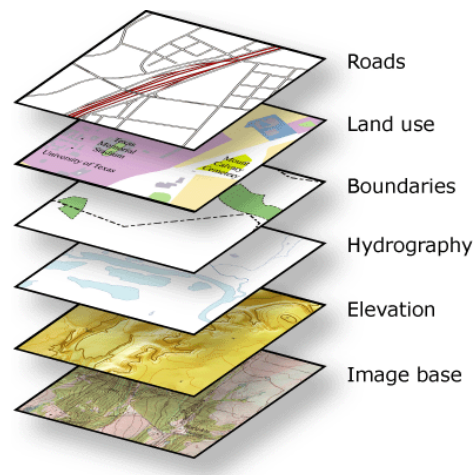


Figure 3.1: Layer structure of *ArcMap* [Esri]

Figure 3.1 shows the theoretical map structure of the software. The image base is like a photo on which all layers are added. To these belong the POIs (points), the road network (lines), areas like districts or communities (polygons) as well as the driving profiles of the EVs and their further analysis. However, not all maps of this dissertation are made by the author, e.g. map 2. All results are based on the accuracy and validity of the vector maps. All geographical coordinates in this study are in *decimal degrees* (DD). This also includes the GPS data from the data logger (see page 78). Layer, Shapefiles and Feature Classes make use of the following reference system:

¹The map data was updated in 2014

Geographic Coordinate System:	GCS WGS 1984
Datum:	D WGS 1984
Prime Meridian:	Greenwich
Angular Unit:	Degree
Projected Coordinate System:	WGS 1984 Web Mercator Auxiliary Sphere
Projection:	Mercator Auxiliary Sphere

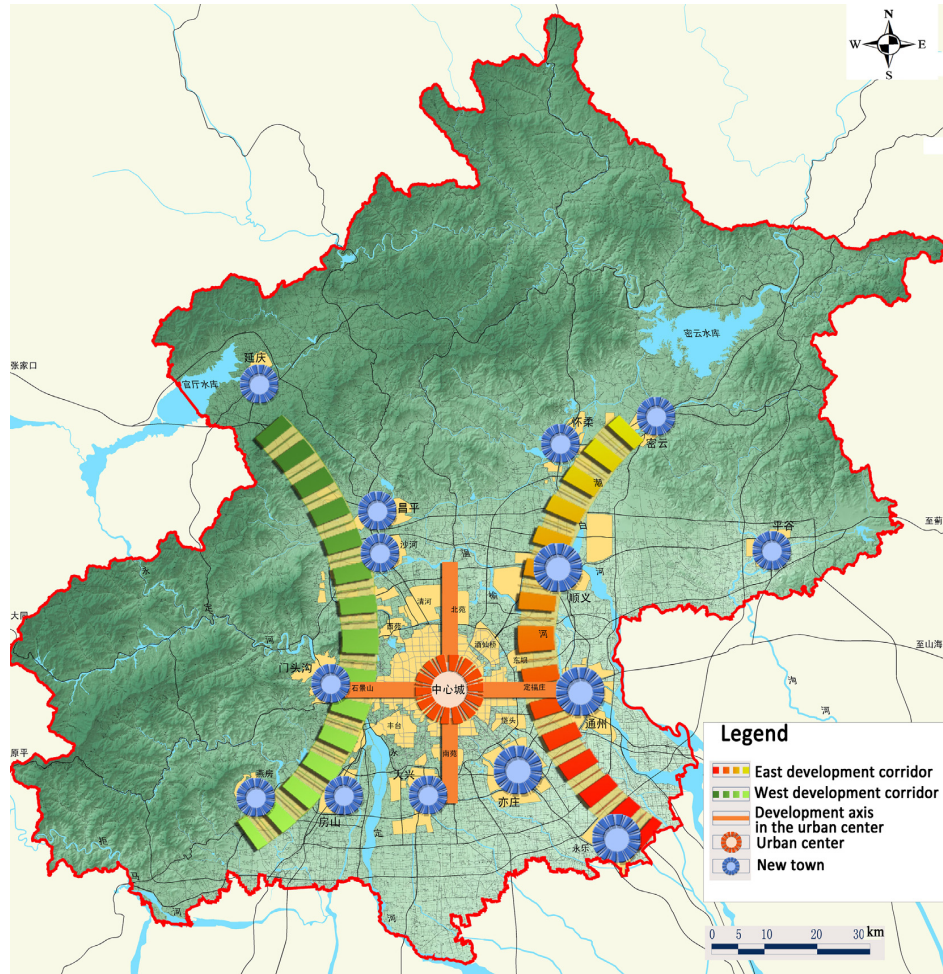
Table 3.1: Used coordination systems for the Layers, Shapefiles and Feature Classes

Because of the different scales and information, the structure couldn't follow the same symbols and colors for the same objects on all maps. The preparation of the maps was based on readability and a harmonization of the colors. Therefore objects like parking positions are visualized by different colors on the maps.

3.2 Urban Geography of Beijing

This section deals with the spatial analysis of the research area, which matches the province of Beijing. Map 2 illustrates the province including the 14 districts and 2 counties within the municipal area of Beijing. This metropolitan area has more than 20 million inhabitants and is 16,410 km² in dimension with an urban area of 1,368 km² and a rural area of 15,042 km² (Long et al., 2013). By the end of 2010, Beijing had a total urban road length of 6,355 km which includes 263 km of expressways, 874 km of primary roads, 652 km of secondary roads and 4,566 km of local roads. The total road area reached was 93.95 million square meters and the road density was 4.8 square meters per person (Ming et al., 2012).

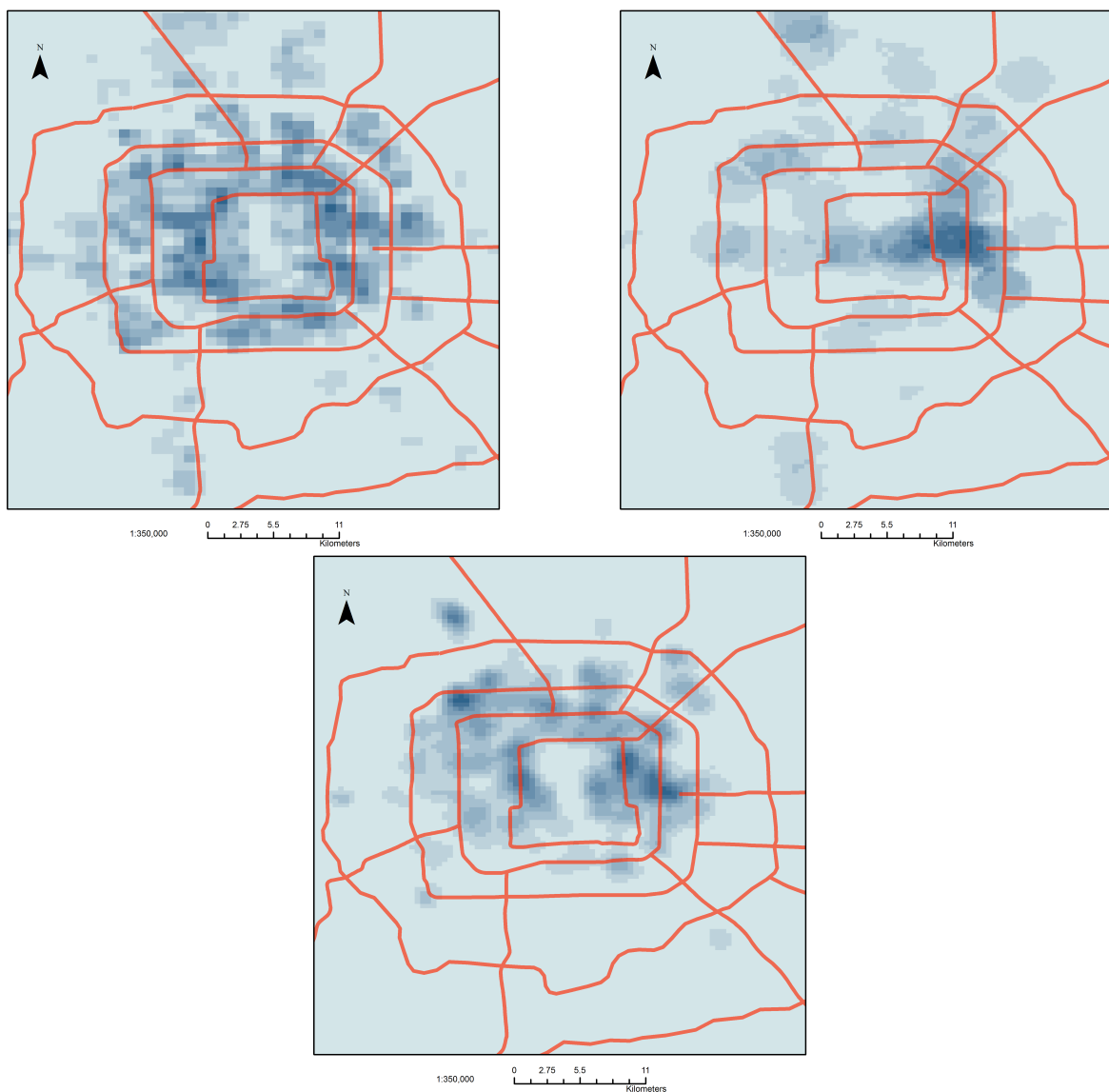
The topography of the area inside the 5th Ring road is low and features no drivable hills or mountains. Here the elevation is generally between 40-60 meters above sea level. In the west of the city, the Beijing Xishan mountains covers the Fangshan and Mentougou districts. The Yan Mountains with the Great Wall extend north of the sixth Ring Road. Both mountain areas are riddled with scenic and tourism POIs. In total, the mountain area accounts for 60% of the municipal area of Beijing. The topography has to be regarded because it can affect the e-range of the EVs. However, later in this paper, the climbing of hills by EVs will be ignored as long it is inside the sixth Ring road. In the south-east, 140 km away from Beijing, is Tianjin Municipality, the fourth largest agglomeration in China with a population of more than 14 million. The city is not placed on the maps used for this study but represents a counterpart of Beijing in respect to population and urban geography. Several highways and railway tracks connect both cities and are the reason for a high quantity of commuters.



Map 2: The urban geography strategy of the Beijing government: *Two axis, two belts, multi-sub-centers* (Beijing Municipal Commission of Urban Planning, 2005)
This area reflects the area where the GPS data of the examined vehicles can be projected on a vector-map in ArcMap.

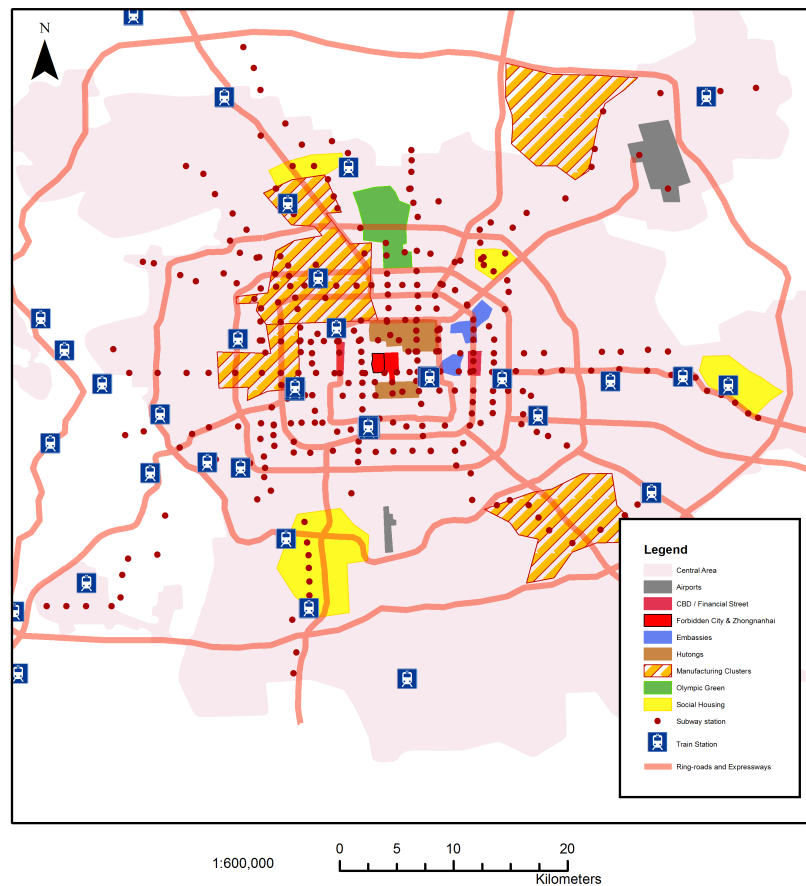
Map 2 also visualizes the development strategy of Beijing. The north-south axis represents the historical axis of the city. Since the 1978 master plan, the east-west axis represents another new urban axis of Beijing. The two belts are the concept of a municipal organization, comprised of an eastern belt focused on economic function and a western belt focused on environmental protection (Beijing Municipal Commission of Urban Planning, 2005). The mountain area in the west will be exempt from heavy industry and should become a green retreat area for the city's residents. In the east, economic and trade zones are found (confer map 4 on page 42). The rough commuting flows within the municipality of Beijing can also be explained in this map as well. Many people are traveling on working days between the satellite cities (here named as "new towns") and the inner city of Beijing. Beijing's ROIs and sub-urban areas play an important role in the landscape of the city because some of them have a specific function or represent a cluster of similar POIs (Kulke, 2006) (Heineberg, 2006) (Ried,

2013). To understand the driving and parking behaviors later in the paper, a general spatial background provides information about the urban geography of Beijing. A more detailed analysis is giving in chapter "Alignment with the Spatial Surroundings" on page 104. Generally, the accommodations as well as work places are distributed all over the city. However, some areas represent a working area with a higher density of offices. On the other hand, regions with more apartments can be an indicator for less office places in a ROI. The three maps (summarized in map 3) show the densities of accommodation, shopping possibilities and office buildings in Beijing. These three categories were chosen mainly because Ma, Mitchell and Heppenstall, as well as the SGEVCP, found out that these are the most approached POIs for drivers of passenger cars (Ma et al., 2014).



Map 3: Clockwise, the distribution of accommodations, shopping possibilities and office buildings in Beijing (Esri, 2014)

Readily identifiable are the main areas of each category. Most of them are inside the fourth Ring road, which covers an area of around 400 km². The resident areas are almost homogeneously distributed, but extend towards the north east. The shopping possibilities, by contrast, are located on the west-east axis and north of it. The same conspicuity can be found for office buildings. Both kinds of POIs are rare in the southern part of the city. As shopping and office POIs are predetermined for semi-public charging, this issue can become a matter when pure public charging stations are built. A closer look at the area inside the sixth Ring road is illustrated on map 4. The location of the most important and biggest ROIs in Beijing, including the official "Central area", are highlighted. Whereby, the Central area's fringe is the city boundary of Beijing. Additionally, all train and subway stations are marked. The map serves to reveal the distribution of these POIs because they have a high priority for charging infrastructure and stand out from the rest of the city. Moreover, these POIs and ROIs represent destinations for commuters and tourists. An intermodal charging and parking concept can be established by connecting the railway and subway stations to the charging network. As these POIs are already placed all over the city, an installation of charging facilities would make sense.



Map 4: Main clusters and ROIs in Beijing

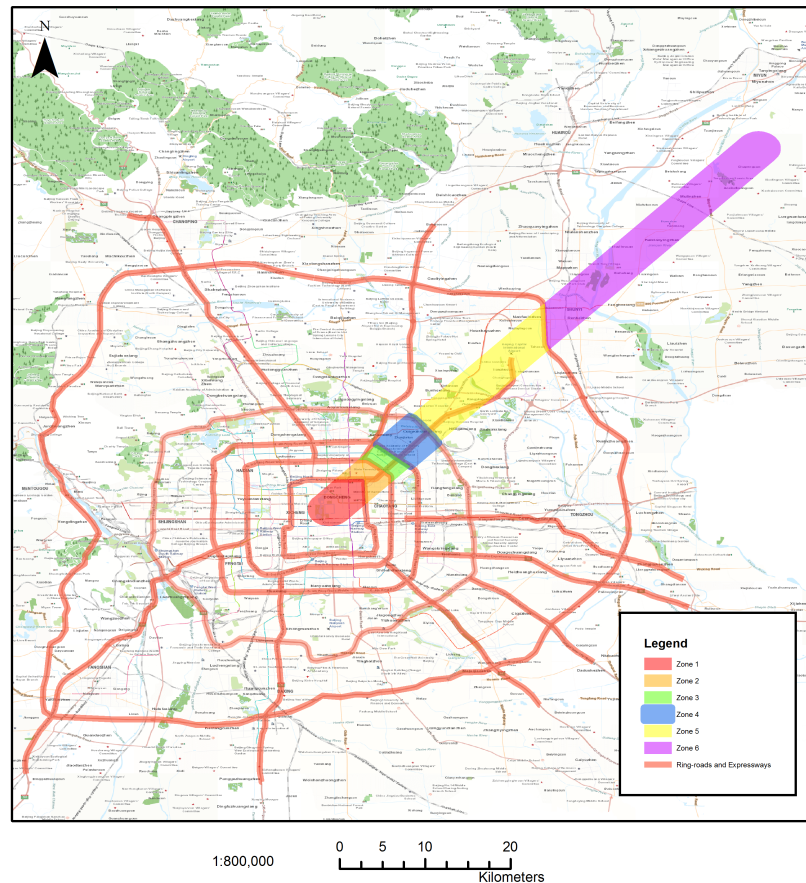
For a better orientation, the six Ring roads and expressways will be a marker instead

of the districts and counties from now on. A division made by these roads simplifies the further investigation of the city as well as the driving analysis because the six concentric Ring roads in Beijing provide a basic framework for the city's overall spatial pattern and cut the city into four metropolitan regions which are surrogate for the classic *concentric zone theory*. This theory identifies the transition zone, the working class zone, the residential zone and the commuter zone, (Heineberg, 2006). These are found in the inner center within the third Ring road, the outer center between the third and fifth Ring road, the inner periphery between the fifth and sixth Ring road and the outer periphery outside the sixth ring-road (Tian et al., 2010). However, as a boundary inside Beijing's municipal area the fourth ring road is predetermined for a further cut. This can be explained by the fact that the undeveloped areas outside the fourth Ring road are higher than inside and the quantity of residential communities are higher within the fourth Ring road (cf. map 3 on page 41).

The structure of Beijing contains some important parts of the city (clusters). Most of these clusters are located inside a district and assume a specific role in the city. Two main kinds of clusters were worked out by Dang et. al.: manufacturing clusters and social housing areas (Dang et al., 2014). The orange striped areas in map 4 accommodate the manufacturing sector, e.g. IT or heavy industry, and the service contractors. In Beijing, three of these areas are located in the northeast, the northwest and southeast. Therefore, the areas feature a higher density of these POIs. Industry or service providers can be found in other areas as well. The social housing areas (yellow regions) have a higher density of council housing in the form of compounds. They are outside the fourth Ring road in the north, east and south.

To describe a more detailed spatial view of the distribution and frequency of the POI's, the four classic concentric zones by Tian are too big in size. Therefore, smaller *study-zones* are drawn between each ring-road. As map 5 on page 44 in the appendix shows, these zones reflect a cross-section, cover all areas in the municipal area of Beijing and split Beijing into six parts instead of the four zones in the literature. This finer breakdown is clearer with the scale of 1:60,000 giving an introduction to the urban structure, the sub-districts and neighborhoods. The 57 km long study area starts from the center of Beijing, the Forbidden City, and ends at the suburbs in the northeast. It has a width of 4 km and covers a surface of 240 km². The spatial analysis focuses on three superior POI-categories which represent the most common destinations for passenger car drivers (cf. table 4.6 on page 82): residential communities, office buildings and shopping possibilities. Additionally, train, especially subway, stations are chosen to show the density and distribution of public transportation. Social-demographic data, as well as other POIs like hotels, hospitals and education buildings, are not visualized for reasons of simplicity and map clarity. Parking lots are addressed in another chapter (see page 47).

Hereafter, the most important and popular economic clusters (EC), densely inhabited



Map 5: The six study-zones for an closer analysis of the POIs between the Ring roads in Beijing

districts (DID) and core zones are listed and introduced. The accommodation, working and shopping POIs are highlighted on maps to get an idea of the neighborhoods.

The urban geography of the inner city within the second Ring road accommodates the most popular buildings such as the Forbidden City, Tiananmen Square, the Zhongnanhai Government District, the Wangfujing shopping road as well as parks and the historical downtown with the Hutongs (cf. page 61). The Beijing main railway station is located in the eastern part of this area. Residential compounds, general stores and office buildings are found near the second Ring road, especially in the west and east. Apart from this, the center of Beijing is characterized by relatively low population density because of the huge area of low story buildings. Concerning the charging infrastructure, some stations and pillars are already installed in this region. Because of the high attraction for tourists, the unique shopping facilities and high density of government institutions, companies decided to start the roll out of their charging network inside the second Ring road (see section "Existing Charging Stations in Beijing" on page 64).

Map 23 on page 137 shows the area between the second and third ring-road in the northeast and allows a closer look at a typical neighborhood. Compared to zone 1,

zone 2 has a higher density of multi-floor buildings and residential compounds, general stores, parking lots and office buildings. Subway line 2 follows the second Ring road and forms the main transportation in this area. The main sub clusters are Beijing's Central Business District (CBD) at the Guomao in the east of the city, the finance center on Financial Street at Jinrong Jie, the embassies area and it's connected military-guarded diplomatic residential compounds (DRC) at Sanlitun (Basic Beijing, 2015) citepYang.2015.

The distance between the third and fourth ring-road is just 2 to 3 km and is denoted as the first part of the outer city. Five expressways start from the third ring-road and travel in all cardinal directions and subway line 10, the most frequented line in the Beijing subway network, is built under the third Ring road (Beijing subway, 2015). These are indicators of the high population density and the mixed land-usage in this area. The Airport-Expressway to the International Airport outside the fifth Ring road and the Airport-Express, a railway line, start from the third ring-road in the northeast. Because accommodation, shopping possibilities and office buildings are located next to the third Ring road, the features have the same density as the developments in zone 2. Especially in the north and northeast of Beijing, the popular districts and sub districts mark the landscape. However, the Haidian district in the northwest of Beijing, approximately ten kilometers away from Tiananmen Square, accommodates a huge area for education as well as information and technology. Attached is the Zhongguancun Science Park (ZSP) which accommodates universities, the Chinese Academy of Sciences (CAS), the headquarters of Internet companies, PC manufacturers and many multinational companies. At last, the Chaoyang Park, beside the Olympic-green and the green area around the Summer Palace, is one of the biggest undeveloped areas in the east of the city.

The outlying suburb-districts of Beijing are located in zone 4 (cf. map on page 139). In the northwest part of Beijing, China's most popular universities, Tsinghua and Peking University, have their campuses. Four major train stations provide the transportation hubs for long distance trains arriving and departing Beijing. The Olympic Park, located in the north between the fourth and fifth Ring-road, includes the National Stadium, the National Aquatics Center and the National Convention Center. North of this area is the Olympic Forest Park, one of the biggest green spaces in Beijing. Wangjing, one of the social housing clusters, represents one of the major centers for new technological companies. It also accommodates one of the biggest compounds and Beijing's Koreatown. Beijing's smaller Nanyang Airport is located in the south of the city. Although half is used by the military, it is also a hub for domestic flights. Farther south, a new airport will be built and should be finished around 2020. The 798 District, a famous art district in the northeast of Beijing and a main tourist attraction outside of the historical spots, represents the most important modern art collections in the city. At last the Summer Palace, the second center of attraction after the museums in the inner city, is located in the northwest. It is also a retreat area for citizens.

The area outside of the fifth Ring-road is officially labeled as the periphery of Beijing. In the last few years, many subway lines connected this huge area to the inner city. Today 15 train stations and over 70 subway stations ensure connectivity. The area is characterized by scattered residential complexes and heavy industries. The most important POIs is the Beijing Capital International Airport in the northeast, a workplace and destination for many people. Around the area, a huge bordering industry has settled down. The Beijing Economic-Technological Development Area (BDA) is an official high tech industry park in the southeast of the city. The area includes businesses from medicine, IT and electronics. (China Knowledge Online, 2015). Daxing, a district in the south, accommodates some universities but, nowadays, is better known as the location of Beijing's new airport (see above). In the future, the world's biggest airport will be built in this district. Most of the single detached-houses, in China known as villas, are located in the periphery. These communities are similar to the one with high rises buildings, but are characterized by more open space (cf. page 60).

The sixth zone (cf. map on page 141), outside of the sixth Ring-road, is still part of the metropolitan area of Beijing, but is basically a rural area. Smaller towns and villages are connected by ordinary roads. During weekends and official holidays leisure possibilities, like the forests, National Parks as well as the Great Wall, are used by Beijing city residents. As a result, traffic jams and overcrowded parking lots at the hot-spots are the rule.

In 2010, most of the districts were less than 3 km from both sides of the expressways. Ji et. al. have found that there is a relationship between land cover, population and building density and the expressways. Furthermore, these highways handle most of the travel demand because five of them are directly connected to the third Ring road (Ji et al., 2014). The subway stations in Beijing have a higher density inside the fourth Ring road and cover this area. Four lines are following the expressways to the suburbs and even connect areas outside the sixth Ring road to the subway network. The train stations are mostly distributed in the west and on the west east axis of the city. Because most people either travel on a highway or use the train system, a charging infrastructure at these POIs and the above mentioned ROIs is advisable for a first time roll out. Even if the workload of these chargers is low, visibility could be guaranteed.

3.2.1 POIs related to the charging infrastructure

The vector-maps for the municipality of Beijing comprise more than 380,000 POIs in 20 categories (see the whole list of categories in the appendix on page 156). Though, this presorted categorization from the map supplier is just partly useful for an analysis in the field of charging infrastructure because only a few are of particular interest to charging. First, not all POIs are necessary for this study because, for this car related topic, a POI needs a parking lot in the proximity. On the other hand, public parking lots are never

a destination by themselves, but always connected to other POIs (e.g. a park or an airport). Therefore, POIs with no relation to parking or a long idle time, like ATMs or highway exits, are excluded. To analyze and structure the data concerning the density and location of prospective charging pillars, a grouping by land-usage (necessary if the price for electricity is in the focus), by property owner (if only one installation contract is desirable) or by parking conditions (if a distinction has to be made regarding public, semi-public or private chargers) can be helpful. A combination is appropriate because some POIs are already predetermined for an installation. Due to missing data in this field, the focus will be on the general POI category. Table 3.2 categorizes potential POIs referring to the charging events. The classification is created from expert discussions (see list of interviewees on page 135).

POIs for public charging	POIs for semi-public charging	POIs for private charging
Recreational	Convention centers	Compounds
Culture	Hotels	Residence communities
Tourism	Shopping centers	Office buildings
Nature	Malls	
Health care services	Supermarkets	
Parking	Restaurants	
Gas stations	Education	
Subway stations	Sport courts	
	(Embassies)	
	(Research institutions)	

Table 3.2: Feasible POI categorization for a charging infrastructure

The three groups were borrowed from the definitions on page 8 and will be also used later in this study for the parking analysis (cf. table 5.1 on page 112). This categorization is applicable in every city because most of this POIs are everyday life destinations and feature parking lots or parking possibilities in their direct neighborhood. A spatial analysis regarding all of them can be valuable and helpful. Especially POIs which belong to one brand name are of particular interest. The density and distribution of the locations can provide information regarding eventual business plans. For example, a supermarket or hotel brand can offer all of their charging facilities to a group of users (cf. page 114).

3.3 Public Parking Conditions

The economic upturn in the last few decades and the fact that the urban residents in total population has grown from circa 20% in 1980 to over 50% in the year 2012 have substantially changed the cityscape. The current population density of over 23,000

residents per square kilometer in the central area brings the demand for mobility for everyone on a road space per capita which is half the size compared to New York's. (Ng et al., 2010) Most of the mobility is achieved by private cars (Rui and Quan, 2013). As a result, Beijing's private and public parking supply has had to rapidly increase in the last years. In 2014, the city provided 6,143 million parking spaces and 6,156 parking lots in 17 districts (BMCT, 2014). In comparison with the total amount of cars in Beijing, which add up to 5,58 million, such a ratio testifies to the huge demand for parking spaces in China's capital. Beijing Municipal Commission of Transportation (BMCT) divides the parking conditions into six categories. The provider of the digital vector maps, Esri, categorizes the parking lots into three groups. Table 3.3 gives an overview of them.

Official categories by BMCT	Assigned parking categories by Esri	Quantity of lots	Quantity of spaces
Temporary roadside parking	Curb parking	626	45,277
Parking under overpasses	Public parking	31	2,759
Off-street public parking	Public parking	1,111	21,667
Residential parking	Reserved parking	2,629	962,357
Public facility dedicate parking	Reserved parking	1,225	339,108
Parking on government ground	Reserved parking	431	63,331
Other (P+R)	Public parking	103	13,638
Total		6,156	1,643,141

Table 3.3: Overview of the parking categories and the amount of lots and spaces in the Beijing municipal area in 2014

The three biggest groups (i.e. off-street parking, residential parking and public facility dedicated parking) represent 80% of the lots and spaces in Beijing. However, these three groups cannot satisfy the demand of all the privately parked vehicles anymore. The installation of charging pillars and stations increases the demand additionally because parking spaces with chargers have to (or should) be reserved for NEVs. Parking lots occupied by ICE vehicles would make charging infrastructure unproductive. That is to say, parking lots with charging facilities, either public or private, take current space away. This general problem complicates the search for optimal charging locations (Xue, 2013).

Each kind of parking lot will cover a use case for drivers, e.g. for work, tourism, amusement or home (Xiaolong et al., 2013). Thereby, the different parking lots should be equipped with different charging facilities, depending on the parking duration or on the location of the parking lot. Table 3.4 connects the official parking categories with feasible charging types (cf. page 8) and serves as a first point of reference for further

analysis.²

Official categories by BMCT	Assigned parking categories by Esri	Feasible charging solution
Temporary roadside parking	Curb parking	Public charging
Parking under overpasses	Public parking	Public charging
Off-street public parking	Public parking	Public charging
Residential parking	Reserved parking	Private charging
Public facility dedicate parking	Reserved parking	Semi-public charging
Parking on government ground	Reserved parking	Private charging
Other (P+R)	Public parking	Public charging

Table 3.4: Feasible charging solutions for parking categories in the Beijing municipal area

The parking market is growing. Most of the latest parking lots can be found outside of the city core and most of them are off-street lots, not on-street parking lots (Rui and Quan, 2013). However, if charging facilities are connected to one parking lot, more parking spaces will still be needed inside the city core like in the Hutongs (see page 61) or inside the third Ring road. The historical part of the city is just 12% as large as that of the newly built-up area, but accounts for 25% of the total travel volume of the entire city (Zeng et al., 2009).



Figure 3.2: Roadside parking near Sanlitun village on a Saturday

The category parking under overpasses means parking lots under the Ring roads in Beijing. Although these kind of parking spaces are mostly used by public service vehicles, the locations are optimal for charging. Some of these parking lots are already equipped with DC charging stations for public vehicles. A shelter against the weather, a central and convenient approach as well as easy access to the electric grid highlight these areas in respect to charging. A consistent distribution of these Ring road parking

²This table was created from the interviews with experts.

lots would enable the installation of public charging stations all over the city. However, the POI mix in the neighborhood is still important in combining the charging process with every day activities. This is because the walking distance between the charging station and the final destination is not to be underestimated.



Figure 3.3: Parking space under the 3rd Ring road (left photo); public parking lot in the Chaoyang district (right photo)

The Beijing Municipal Commission of Transport built parking lots with 5,000 spaces at new subway stations in rural-urban areas (outside the Fourth Ring road). 3,000 spaces for bikes were also built around all subway stations (Beck, 2010). An installation of charging stations at these parking lots would change these *Park & Ride* parking lots into *Park & Ride & Charge* parking lots. This enables an intermodal transport concept for EV drivers in Beijing. However, new subway stations are most often built in the suburbs of the city. Stations in the inner city do not accommodate parking lots, they rather host bike rental stations. In April 2015, just one charging station at the end of line 15 (northeast, outside the sixth Ring road) enables the charging of EVs and taking the metro system for further travel. As mentioned before, the final destination or main POI in the neighborhood of the parking lot, could be the subway stations.

Semi-public parking

Semi-public parking is equal to semi-public charging (cf. the three charging types on page 9) and covers the places which belong to private grounds or state owned public space but feature restrictions for access. Supermarkets, malls, hotels, airports and theaters fulfill this requirement. Some of these locations limit the access by time or by an access fee, though they guarantee a secured area with guards and CCTV cameras. As most of the buildings in Beijing are equipped with an aboveground or underground parking space, the semi-public parking option may become the most common. Consequently, these parking spaces are predestined for charging stations.

Table 3.4 lists preferred locations for semi-public charging locations in Beijing. This

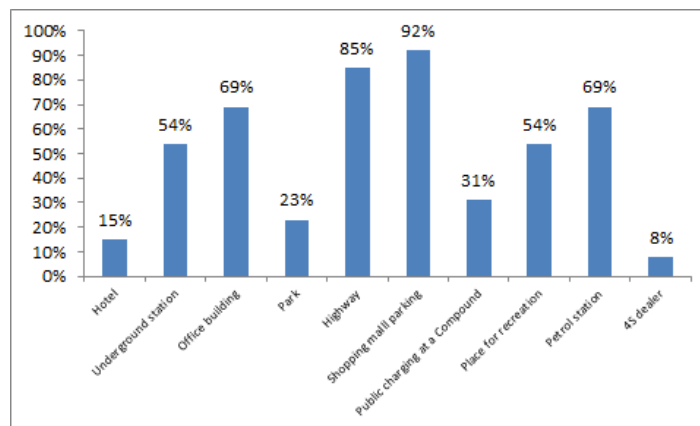


Figure 3.4: Preferred locations for public charging facilities (SGEVCP, 2015)

inquiry was done by the SGEVCP and reflects the opinion of EV and non EV drivers. Most prominent in this regard are the wishes to charge at shopping malls, office buildings and petrol stations. All of them represent daily destinations for most of the drivers who are driving an ICE vehicle. The highway charging option can be seen equal to the charging stations under the Ring roads or at petrol stations. Those kind of charging spots are providing *on-the-go charging* for EV drivers. Evidently, just 8% of the interviewees prefer to charge at a show room of car dealers (4S dealers³). The background of this question comes from an authority's regulation to equip car dealers with charging stations. There is one main reason for the unwillingness to charge at these locations: Some dealers are far away from the inner-city and, because of this, the POI mix and density in the neighborhood is not attractive for most of the drivers (cf. map 9 on page 64). The inquiry also says that not all EV drivers need to charge at these locations (as long as their home charging process is covering a daily trip). These EV drivers are using only *home charging* or so-called *destination charging* locations for their energy supply.

One of the main problems for semi-public charging locations is profitability. The strict policy of parking prices exacerbates the profitability (Wang and Liu, 2014). From 2002 to 2010, the parking price in Beijing was 0.5 RMB/h outdoor and 2 RMB/h indoor (?). Even under a marginal parking cost scheme, with a price potential increase of parking incentives, each person will park for a shorter period of time. This allows more people to use parking spaces, and subsequently increases traffic (Rui and Quan, 2013). On the other hand, the low fees for the usage of the parking lot and the optional usage of the charging station do not generate enough turnover. So much that it can't even cover the construction cost of the parking facilities. Street maintenance and sharing with other modes of transportation makes it difficult for local authorities to make a

³4S is a standard for special qualified car dealers by OEMs



Figure 3.5: Challenging installation of charging facilities: Storage parking (left photo); parking on the middle line of an end street (right photo)

profit and the willingness of parking facility developers is mainly based on the trade-off between cost and benefit (Engel-Yan et al., 2010) (Zeng et al., 2009). This results in unauthorized parking spaces, such as utilizing undesignated streets and sidewalk space for parking. The occupation of traffic lanes, dead end streets and bicycle lanes for parking became unavoidable. A stricter enforcement of policy would be an effective instrument in limiting car use if every vehicle needs its own parking lot (Weinberger, 2012).

3.4 Private Parking Conditions

Living conditions play an important role for the charging network because people with private access to charging stations are more likely to purchase an EV. First of all, the general feasibility of an installation has to be ensured. Not all housing conditions can provide parking lots, a sufficient electrical power supply or even (semi-public) space – basic requirements for charging stations and pillars. Ensuing from the history of Beijing, over the years different types of houses, quarters and even new districts give a variety of installations and use cases for a private charging network. This chapter takes a closer look at different kinds of accommodation in Beijing because the type of the private charging system depends on the user's spatial environment. Along with the electrical grid in the household and the local distribution box, the kind of private parking situation is crucial. Different parking types are connected to different housing types and hence reflect different installation cases. The following section discusses the architectural characteristics of accommodation in Beijing and list possible fields of applications for private charging pillars.

The living conditions in China have changed rapidly in the last decades. Just 100 years ago the city of Beijing was made of small, two-floor stone houses with narrow

alleys. Then, in the 1950s, the Communist Party and state owned factories built multistory houses for their workers which were borrowed from the Soviet model. After the Open-door Politics in the 1980s, private industries settled down in the big cities and caused a building boom (Staiger et al., 2009). Based on the fact that more and more people moved into the cities, more and bigger apartments were built. However, individual motorized mobility had not grown in those years as fast as the real-estate sector. This resulted in many private housing communities not having enough parking lots for the current car population. These conditions create new challenges for the charging infrastructure build up. All studies around the world start from the premise that most EV drivers charge their vehicle during the nighttime at home (Benysek and Jarnut, 2012) (Brand et al., 2012) (Dallinger et al., 2011) (Dong et al.). This fact is independent from their parking conditions. Moreover, most EV drivers can cover their daily trips by recharging the batteries with a home charger (Xu et al., 2013) (School of the Built and Natural Environment Northumbria University). However, as most of these studies are based on data from America or Europe where users have their own parking space, the specific circumstances in China were, essentially, ignored up to now.

3.4.1 Gated Communities

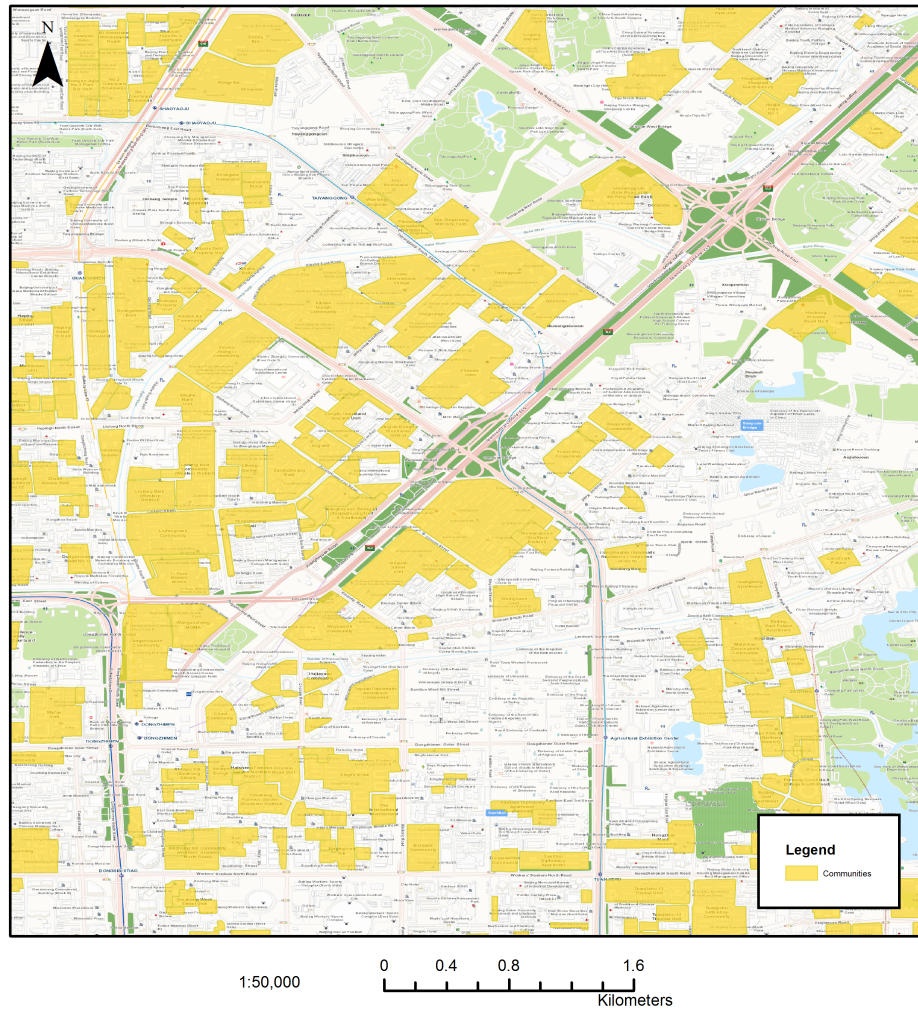
Most living accommodation in Beijing is *gated communities (GC)*. These housing complexes are also called *compounds* (common term in China), *Micro Residential District (MRD)* (Muench, 2004), *small districts (SD)* (Qiang, July 10-13, 2008) or *closed residential areas* and have become a standard for modern living in contemporary China (Qiong and Wei, 2012). American gated communities were defined by the sociologists Blakely and Gail as

areas where only residents are allowed to enter. In these regions, usually the public areas such as streets and gardens are only open to residents. These areas are surrounded with walls, fences and gates. Residents and visitors must be authenticated before entering these regions. (Blakely and Snyder, 1997)

Another definition is made by Grant and Mittelstaedt:

A gated community is a housing development on private roads closed to general traffic by a gate across the primary access. The developments may be surrounded by fences, walls, or other natural barriers that further limit public access. (Grant and Mittelsteadt, 2004)

The density of compounds in Beijing is high. Map 6 visualizes the density and size of some compounds in the Chaoyang district, while figure 3.6 shows typical compounds



Map 6: Density and size of Compounds in Beijing's Chaoyang district (Esri, 2014)

in China. Over the years, a wide range of housing types have been established in Chinese cities. The following sub-section deals with their parking conditions in respect to charging infrastructure.

Until the end of the 1990s, housing in Chinese cities had been mainly provided by employers who built *work units* for the employees and local governments (municipal housing bureaus). These "Dānwèi" commune systems were mainly built in 1958 and the pre-1979 eras (Logan et al., 2009). Those kind of buildings have few stories, no elevator and a high density of buildings within the compound (Boland and Zhu, 2012). During the years of construction, not many cars were registered in Beijing and parking lots were rarely built around the Danwei compounds. The 1988 "Rules for Parking and Design of Parking Lots" set a national standard of zero parking space per regular housing unit and 0.5 spaces per luxury or special unit. (Zeng et al., 2009) Entry-level compounds can be found all over the city because they were built next to state-owned factories or government institutions during the early socialist era. (Ma and Wu, 2005)

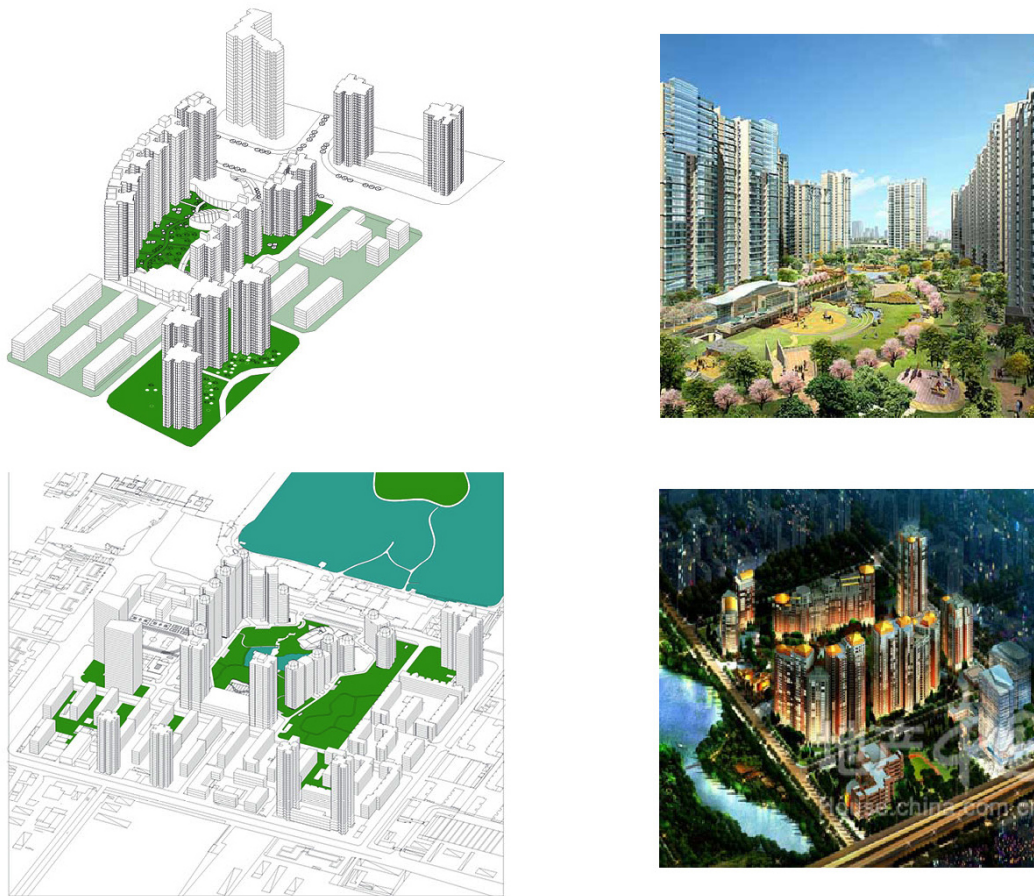


Figure 3.6: Typical structures of Compounds in China (Wang, 2012)

Nowadays, most of them are not controlled by the city government anymore, but have profit orientated PMOs. However, the Danwei compounds are still guarded and surrounded by walls. The parking conditions are insufficient and not able to ensure current standards and demands, even for the dwellers. Furthermore, the electrical grid is outdated. Consequently, an installation of charging pillars and stations is difficult due to missing space and installation problems.

High-rise buildings with up to 30 floors, parks and small convenience stores built from the 1990s on are the most common type of compounds in Beijing now. (Minghing and Xiubin, 2013) Up to ten buildings with the same architecture are allocated in such a compound and reflect the economic growth of the country in a significant way. Underground garages provide considerably more space for the residents and visitors. Because of the existence of elevators, the grid conditions are enlarged compared to the Danwei compounds. (Mak et al., 2007) The most advanced type of building are the high-level or serviced apartments. This accommodation provides hotel like living conditions. Blakely and Snyder also divided the compounds into three types: *lifestyle*,

prestige and *security zone*. Another classification was made into social terms but this division is not helpful in respect to the charging infrastructure (Hassenpflug, 2010) (Liu, 2014).

Housing type	Households with a private car	Location
Traditional residential area	13 %	Within the 5th Ring road
Traditional danwei Compound	24 %	Within the 5th Ring road
Reformed danwei Community	32 %	Within the 5th Ring road
Commodity Housing Community	61 %	Suburbs
Social Welfare Housing Community	46 %	Suburbs

Table 3.5: Distribution of car ownership in different housing types (Wang et al., 2011)

Table 3.5 gives an overview of car ownership in the various types of accommodation in Beijing. It is evidence that the higher the percentage and the newer the housing type, the more parking lots are available around this accommodation. Wang et al. have not listed bigger compounds inside the 5th Ring road but their investigation makes clear that residents of communities in the suburbs have more cars than residents in the inner city. This has an impact on two issues: This distribution can be an indication for commuting flows into the inner city and the percentage of charging facilities in the suburbs could be higher because more cars are located in these areas.

From the view of charging pillar operators, compounds are locations for private chargers and semi-public chargers (see page 8). The latter because some compounds are open for the public and make access for non-residents possible. The following aspects are a guideline to select compounds by criteria. They can be seen as further influencing factors as well.

1. The *parking coefficient* of a building provides information about the ratio of apartments to parking spaces. If it's lower than the factor 1, there are more apartments than existing parking spaces. In that case, not all dwellers are able to park their vehicle on compound ground but instead on public ground. Compounds with a ration under 1 are not qualified for an installation of a charging pillar. This is based on the fact that every EV should have its own reserved parking space which guarantees 24/7 access to the charger.

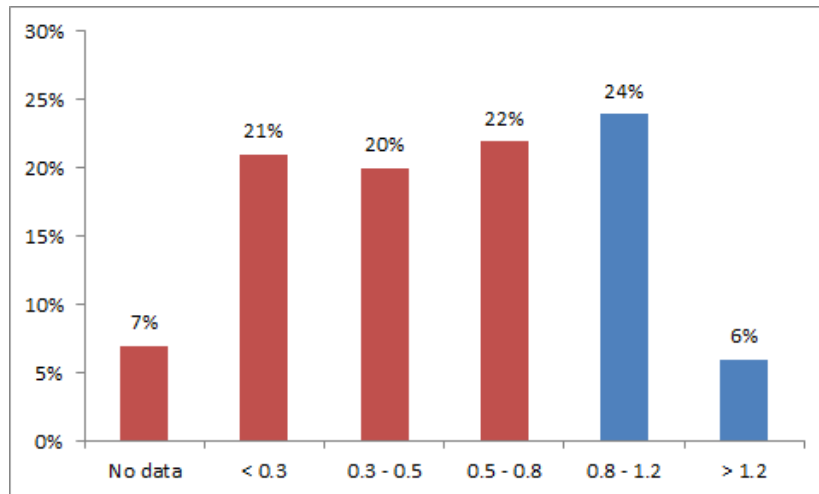


Figure 3.7: Parking ratio within the Compounds (SGEVCP, 2015)

Figure 3.7 shows that 70% of all compounds in Beijing do not have a sufficient parking coefficient for a charger installation. This is mainly based on the fact that most of the compounds are located in the inner part of the city. These compounds are older and do not feature high parking coefficients.

2. The physical set up of the *parking conditions* gives information about charger installation. Underground, indoor and covered parking spaces are optimal for an installation of charging pillars. A shelter against the weather is convenient for the user and keeps the facility clean, whereas a wall makes the installation process easier because an underground construction is not needed. In Beijing, not all compounds are equipped with an underground garage (see figure 3.9). Around one third of real estate does not fulfill this condition. This is important to know because the government prohibits a DC charging station underground in Beijing.



Figure 3.8: Private parking conditions in an entry level compound

The ownership of parking lots is very important for the installation and operation of a charging pillar. If the dweller of the apartment has bought the parking space,

the installation becomes easier because the owner does not need the permission of the PMO and can personally decide on the installation. The dweller also can choose between two rental models. One car is connected to one parking space in the directional rental model, whereas indirectional rental means a share of the parking lot and only guarantees a space inside the garage. Both models require approval from the PMO and other residents for the installation of a charging pillar.

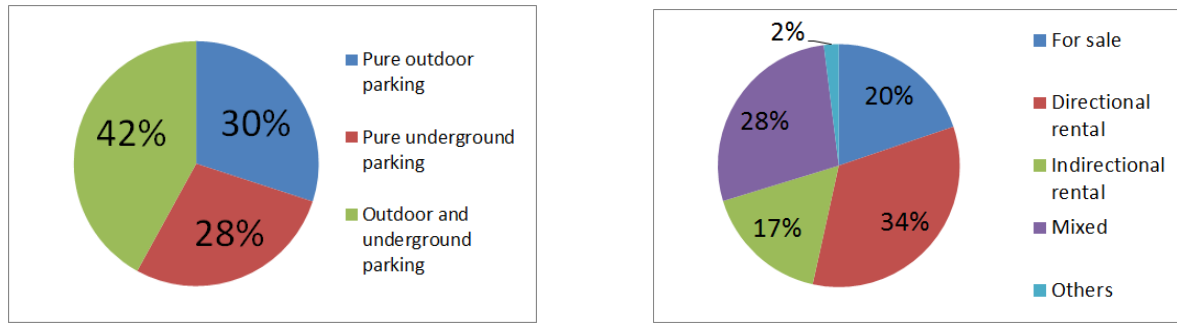


Figure 3.9: Private parking conditions and ownership of the parking spaces (SGEVCP, 2015)

3. The *location of the compound* becomes an interesting factor for entry level compounds (see figure 3.10). Due to the lack of parking lots inside this kind of compound, parking lots in the surrounding area could be used for dwellers to park and charge their EVs. Most of these compounds are located in the city center of Beijing where public or semi-public charging facilities can be used if the parking coefficient is too low.

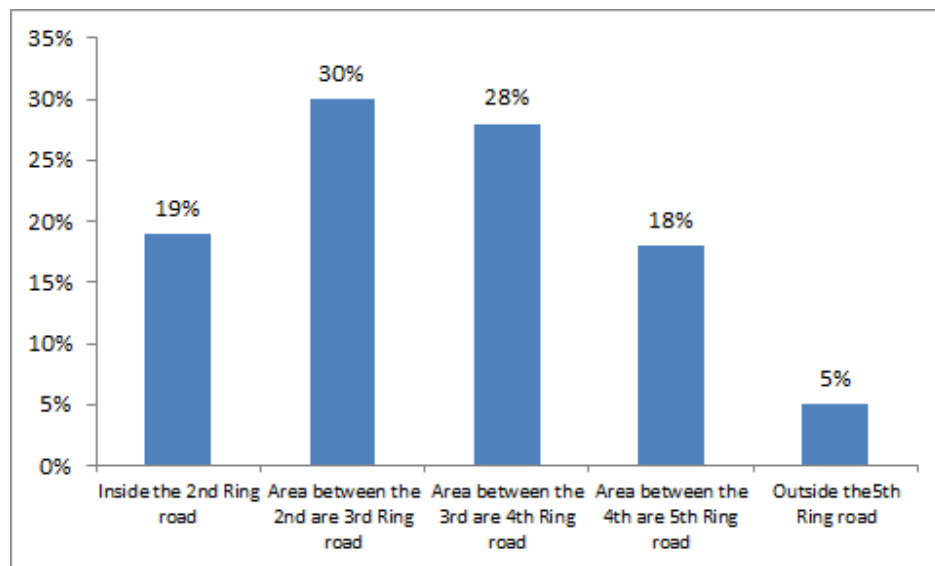


Figure 3.10: Distribution of Compounds in Beijing (Esri, 2014)

4. The *density and type of POIs around the building* provide information about

feasible fallback procedure if a charging facility can't be installed. An analysis of the neighborhood is necessary in this case. POIs related to the charging infrastructure can be selected to offer further charging spots to the dwellers (cf. subsection "POIs related to the charging infrastructure" on page 46 and subsection "The mono-centric region" on page 106).

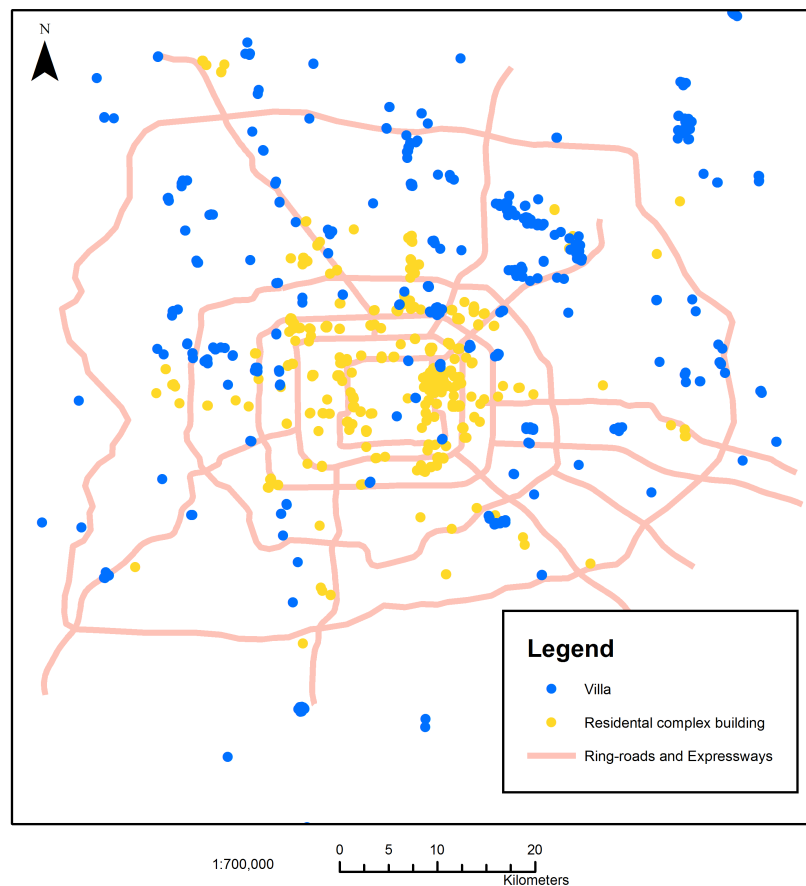
5. If the building has no underground parking, the *floor Area Ratio (FAR)* gives further information about the available space around the building. The FAR is calculated by dividing the total area of all buildings - including all stories - or structures on a lot (net area) by the total area of the lot it is built on (gross area). A lack of open space means that public or semi-public parking lots in the neighborhood have to be used. (The Ontario Plan, 2013)
6. The *electrical capacity of the district's or building's distribution box* guarantees the power supply for the charging stations. The *presence of an elevator* provides further information of whether a high voltage current is already available in the building. This makes the installation of a high voltage charging station easier.
7. The *availability of security features and barriers* provide information if the charging stations in the area can be used for semi-public charging. Furthermore, guards or a parking management service can organize the charging process as well as the payment process.
8. The *amenities and facilities inside the compound*, like the amount of the neighborhood shops or kindergartens, can be an indicator for additional traffic to these closed communities and thus generate potential charging events.
9. Furthermore, the index of *persons per hectare (PPH)* can be the decisive factor in installing charging stations.

The check points above are rough criteria for a charging station operator. They will be picked up later in this paper again in combination with the driving patterns of EV users (see page 102). Characteristics of compounds are shared street infrastructure, private, semi-private and communal spaces, functional need specific structure and a property management company (Greive and Hon, 2005) (Qiong and Wei, 2012). Concerning the charging infrastructure, these physically isolated areas represent other circumstances and challenges than in, for example, Europe. In China, an important role is occupied by the property management organization (PMO) and property management association (PMA). As the management of the compounds deals with the street infrastructure and facility management, most construction decisions are based on the willingness of the PMO. However, some decisions are also be made by a neighborhood committee. (Ma and Wu, 2005) The Sino-German EV Charging Project (cf. page 15) has found that most of them have prejudices against e-mobility. Consequently, they do not support the installations of charging pillars within their compounds. The reasons range from

safety issues to financial concerns and general doubts. Pipelines, air conditions or other equipment, as well as long distances between the charging pillar and an emergency exit, are considered as hazardous. Furthermore, the covering of the responsibilities for the installation and maintenance are not set, yet. Finally, most of PMOs do not see an advantage of offering charging facilities to inhabitants.

3.4.2 Villas

The Chinese description and term for a villa defines a detached or semi-detached house. These accommodations correspond to single-family houses in Germany or Europe. One of their characteristics is private parking lots in triple or single garages next to the building. This environment enables the easiest use case for the installation of a charging pillar. Lo and Wang call compounds with these kind of buildings a *foreign gated community* or a *lifestyle community*, where the villas are arranged in cul-de-sacs and interspersed with abundant green space (Lo and Wang, 2013). Over 200 of these detached houses can be organized in such a compound.



Map 7: Villas and Danwei communes in Beijing (Esri, 2014)

The amount and distribution of villas and residential complex buildings is shown in

map 7. The lower density of villas inside the fourth Ring road is conspicuous, whereas high-rise residential buildings can be found in this area. Again, charging locations outside of the inner city can generate the demand for public charging stations downtown if commuters are living too far away and the battery charge is not sufficient for the way back home. However, as most of the villas are located inside the sixth Ring-road and charging pillars can be easily installed, the need for a closer analysis for private chargers is not evident.

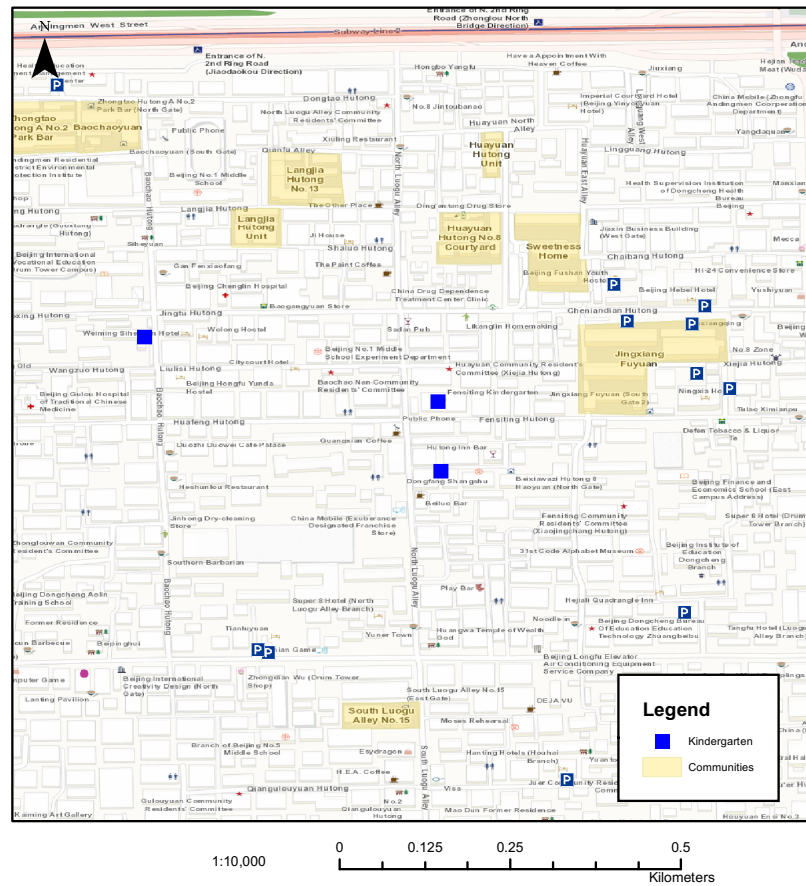
3.4.3 The Historical Downtown

The Chinese characters "hú tong" mean alley and the plural "hú tongs" denote the inner city of Beijing. The districts north and south of the Forbidden City can be seen as the historical downtown. Hutongs refer to small stone houses which are connected to each other. Four Hutongs form a "Sì hé yuàn". These districts are contorted and are crossed with tiny streets as well as cul-de-sacs (cf. map 8). Although the downtown has open access, narrowed lanes due to the construction exacerbate traffic flow. Private parking lots like garages, underground parking or ground parking do not exist. Alternatively, Hutong inhabitants use alleys to park their vehicles. Real public parking lots do not exist and the rare public space is used by small vendors, as meeting points for dwellers and as a lay down area. Therefore, a distinction between private and public parking is blurred.

These structural conditions make the installation of charging stations a challenge. For private charging infrastructure, a private charging station is connected to an assigned parking space with a personalized wall box or charging pillar. On the other hand public charging becomes more complicated because of the lack of open space. In this case, private and public charging are mingled. Although the Hutong area is not gated and is connected to public streets, daytime charging will be less frequent than in other districts due to missing shopping facilities and offices where the users can work during the charging process. The electrical wiring in these areas is based on the original construction and has developed over the years. This means a high voltage energy supply can't be guaranteed for the charging infrastructure. The construction of charging pillars within this area can only be done at selected points where there is enough space. So, real "infrastructure" is difficult to implement.

3.4.4 Conclusion of the section

Most of the compounds, (especially Dānwèi) in the inner city, can't provide enough parking spaces for all residents. This is the biggest problem in Beijing. Furthermore, the gap between supply and demand is rising more and more because of the increasing



Map 8: The Hutongs with small alleys, and the high building density. Kindergartens are the only POIs beside accommodations and restaurants in this area

number of cars. The current private parking regulations provide a ratio between dwellers and parking lots from 1:0.3 in the compounds. To defuse the situation the government planned to change the ratio to 1:1 beginning from 2014. This confronts operators with a new problem because, in most locations, the development can't be changed anymore. Xue has summarized the situations as follows:

Despite this rapid motorization, appropriate parking provisions have long been overlooked. The city's first ever minimum parking requirement established in 1994 is still in effect today. The minimum mandates at least three residential parking spaces be provided per ten dwelling units even though Beijing's current car ownership is about seven cars per ten households. On top of poor regulation, adding more parking spaces usually means a higher rent cost due to the increasing land prices. (Xue, 2013)

As a consequence, dwellers, especially from older compounds, are using public spaces to park during the nighttime. This again exacerbates the situation in the public parking lots. However, the installation of private charging facilities on accommodation grounds should have the highest priority. Typical private parking conditions are shown in the

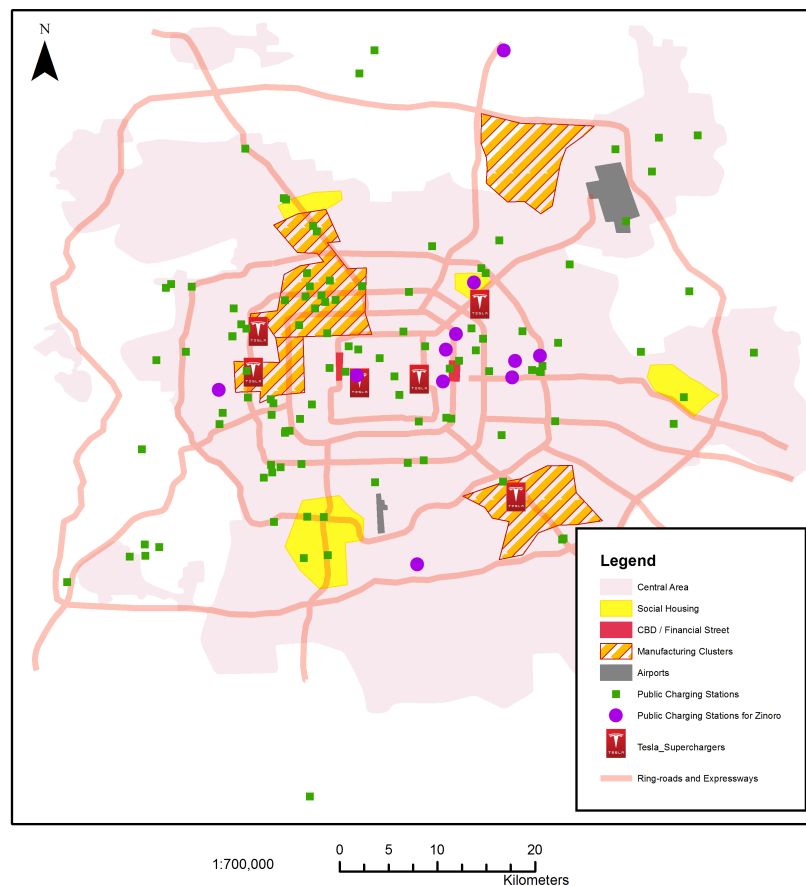
figure 3.8 (see page 57). As these parking lots are not qualified for charging stations, only villas have the best preconditions for a charging pillar installation, followed by the compounds and the Hutongs. This stems from the undeveloped space around the houses (cf. the FAR on page 59). Table 3.6 summarizes the parking situation in Beijing.

Type of parking lot	Hutongs	Compounds	Villas
Parking space in residential building's underground garage	n\ a	partly	available
Parking space in residential building's ground garage	n\ a	available	available
Single garage detached from the residence	n\ a	n\ a	available
Community garage detached from the residence	n\ a	partly	available
Single detached garage in residential property	n\ a	n\ a	available
Garage, directly adjacent to the house	n\ a	n\ a	available
Driveway to the house/courtyard, not covered	available	available	available
Driveway to the house/courtyard, covert	n\ a	partly	partly
Carport	n\ a	partly	available
Duplex garage	n\ a	n\ a	available

Table 3.6: General types of private parking lots

3.5 Existing Charging Stations in Beijing

Beijing's charging infrastructure already has a high quantity of stations and pillars. However, due to different technical specifications, not all of them belong to the same network. This yielded a *parallel infrastructure* which had been established over time and now hampers the establishment of a customer friendly environment. As stated already, the EVs in Beijing are distinguished into two groups: Chinese EVs which support the Chinese fast-charging standards (GB/T) and those who do not support it because of still open technical discussions (cf. page 23 where the technical solutions are described). This split is found in the charging network as well. The main problems are different plugs and software protocols, with the effect that one charging standard is blocking the EVs which support the other standard and vice versa.



Map 9: Public fast and normal charging stations in Beijing

Map 9 illustrates all public charging stations in the province of Beijing. There are no charging stations located in the north of the province or outside the central area (see map 2 on page 40). The 53 charging stations consist of 133 fast (DC) charging pillars

and 177 normal (AC) charging pillars and belong to different operators or owners⁴. With the exemption of station at the Airport where 25 fast and 25 normal pillars are installed, the ratio between fast to normal charging pillars is 2:3. For this study, the public charging stations which can be used by the Zinoro E1 (introduced later) are highlighted in the map in purple. These pillars are all installed on the ground of BMW dealers or the Zinoro brand center. This situation is related to the fact that the Zinoro E1 needs AC stations with a Chinese Type 2 plug and a PWM signal. Most of the charging stations on the map belong OEMs and are placed on the ground of 4S dealers. The installation of charging stations next to Ring roads and expressways is outstanding. Some of these stations are even placed on highway parking lots or next to highway junctions. However, some of these are on side-roads separated from the highway and are not easy to reach due to the fact that the next highway exit is far away. In general, charging stations are placed either next to highways or adhere to specific POIs. Especially the chargers in the south of Hǎidiàn district (northwest of Beijing), where most of the universities are located, are not placed near the Ring roads. Most of them belong to the universities or were part of demonstration projects (cf. page 14).



Figure 3.11: Public charging pillars in front of a 4S car dealer in Beijing (left) and Tesla's Supercharger (right)

Not only these two plug-alliances are competing against each other, but also market players like Tesla Motors have implemented their own standards. Tesla's Supercharger is exclusive for users of Tesla's EVs. These fast charging pillars are designed as public charging stations and should enable their users unrestricted movement. Because of the high range of the Tesla Model S, a charging network made by just ten stations covers the east coast of China from Beijing to Hong Kong. (Tesla Motors, 2015) However, Tesla's charging network in Beijing does not only consist of Superchargers. Some of the six locations inside the sixth Ring road are equipped with normal AC chargers and

⁴Because of the lack of public information or contradictory reports, this map is based on the EV charging management service platform for the city of Beijing, an official summary of all charging facilities in Beijing. The geo-data and information are transferred into *ArcMap* by hand and received all concentration of the writer.

should ensure mobility within the city (see map 9 on page 64). This results from a lack of space on the properties. Consequently, the charging facilities have to be moved to underground parking spaces where the regulations from the local government take effect. These prohibit the installation of DC chargers underground (confer page 10). These public charging stations are an essential part of the company's charging strategy for customers. The huge battery capacity of 60/85 kWh does not allow a full charge by alternating current with 120 V and 15 A during the night⁵. Drivers of the Model S need a charging station with a direct current to fulfill higher SOC-lifts in a shorter time. So, a complete exploitation of the e-range is limited by the low charging power and the short parking duration of the vehicle.

Table 3.7 lists the POIs within a range of 800m around the six Tesla stations and the six stations that are fit for the Zinoro E1. Firstly, the Tesla stations cover more than twice the amount of POIs than the Zinoro stations. Outstanding is the quantity of shopping, accommodation services and business related POIs between the two charging networks. Although the five Tesla stations are inside the 5th Ring road and four Zinoro stations are inside the fifth Ring road, the Tesla stations cover more than three times the POIs. These setup sites are investigated in more detail on page 104.

POI Category	6 Tesla CS	6 Zinoro CS
Food and Beverage	852	447
Shopping	1,355	420
Daily Service	604	333
Sports Leisure Service	136	142
Health care services	123	83
Accommodation services	162	38
Tourist Attraction	38	2
Commercial/Housing	513	276
Government and Social Groups	263	136
Science and Cultural	237	116
Transportation	643	240
Financial Insurance Institutions	339	109
Corporate/Business	944	275
Public Facility	242	100
Total	6,451	2,717

Table 3.7: POIs around existing charging stations: Categorization of POIs within a radius of 800m around 6 Tesla and 6 Zinoro charging stations (Esri, 2014), confer map 9 on page 64

⁵The Tesla Model S can charge energy for a range of 6 km per hour with 12 V and 15 A. It can be raised to 46 km per hour with a current of 50 A and 240 V or up to 92 km with a wall-box which provides 20 kW.

Street lamps constitute another solution for EV charging. In a pilot program, some of the high voltage sodium lamps, which account for over 80 percent of the city's streetlamps, are equipped with a charging socket to connect EVs. If all sodium lamps in the city's six major districts are substituted by LED and 15% of them install the direct current charging posts, Beijing would thus gain more than 30 thousand charging points (Zhang Peng, 2014). This kind of charging does not make use of any EVSE, offers 24/7 usage and covers all areas. A requirement for the driver is the obtainment of a charging cable. However, apart from the charging network for cars, other stations operate only with service vehicles like road sweepers or dustcarts. Yet another network is set up solely for electric public buses. Most of these stations are battery swapping stations and are managed by the local grid company. These stations are located under overpasses in the suburbs or under the Ring roads (see photo on page 15). But these are not the subject of this study.

3.6 Conclusion of the chapter

The goal of this chapter was the analysis of the spatial circumstances in Beijing regarding the installation of charging facilities. Beijing's urban geography and especially the street net is orientated around the city center, although various regions of interest are lined up along the Ring roads in the northern part. These areas mostly serve one purpose: banking and finance in the west (Financial street), education in the northwest (Haidian), the embassies in the northeast (Sanlitun) and the CBD in the east (Guomao). These concentrations of the same category of POIs coin the subdistricts whereas the districts itself have more of an administrative character. For a charging network, these homogenous POIs generate starting points and destinations for commuters. However, the parking conditions in these areas are more important because the charging pillars are connected to this POI category only. Generally, the distribution and quantity of parking lots is the key factor for public infrastructure. This is valid for private and public ones. Drivers who approach POIs without parking lots, like ATMs or Danwei compounds, avoid the surrounding parking lots (cf. chapter "Guideline for a Charging Infrastructure installation" on page 102). However, some areas, like the Hutongs or areas outside the fourth Ring road, do not have this possibility. In these areas, the POIs without a charging facility can be excluded from the destinations of EV drivers. But, not all parking lots meet the requirements for the installation of charging facilities. Grounded ones without a shelter against the weather as well as under grounded lots with less lighting conditions are not qualified. Additionally, in Beijing, underground parking lots are not qualified for DC charging because of safety concerns. These screenings for subcategories are miscellaneous for cities and regions. For example, in flood-prone areas the installation of charging stations can be generally forbidden.

Ultimately, the existing charging infrastructure of a city is an important criteria for

further expansion. From only the spatial point of view, areas with a higher density of (public) charging stations do not need more facilities as long as they are not in areas where drivers make outstanding use of it. It's outstanding that, in Beijing, there are no public chargers installed in the Hutongs or in the compounds. However, the existing network covers almost the entire city.

4 Behavior of EV users in Beijing

The user's behavior is the second main influencing factor on the density and quantity of a public charging network. In this section, the need for a public charging network within the city is examined from the driver's perspective¹. The user patterns are essential for a build up strategy, along with the spatial aspects and the technical circumstances. The daily routine of the road users determines their routes to work, to shopping facilities as well as to the leisure activities. These routine behaviors are especially recurring in commuters (Gather et al., 2008). Most people do not change their behaviors as long as they do not change their framework conditions, for example, a job change or relocation. This is mainly based on explicit working times and the same destinations during the week. Weekend traffic, on the other hand, is detached from these patterns. Destinations change into non-routine locations and POIs like parks, tourist spots or leisure facilities. Another pattern is forming amongst inhabitants of Chinese cities: People are moving to other districts or neighborhood areas when their children reach a compulsory school age to achieve a shorter commute to school. Therefore, a second apartment is rented (Hecker, 2014-10-29).

4.1 The importance of user aspects on the charging infrastructure

The user patterns of ICE vehicles drivers and EV drivers are not comparable in the first moment. The shorter range and the longer charging time of the batteries inevitably results in a different usage of the vehicle. Potential customers know these restrictions and most of them also know their daily routes (Ahrend, 2011). These conditions result in a situation where users only buy an EV when they can cover their daily trips easily and without any disadvantages (Kley, 2011). However, to establish e-mobility, some researchers assume that EV drivers have to cover the same distance and range as drivers of ICE vehicles (Wu et al., 2013) (Zhang et al., 2011). So unreachable areas should be equipped with fast charging stations to guarantee arrival. This solution can't be

¹An analysis of an inter-city charging infrastructure is not treated in this paper due to the missing quantitative user data and digital maps

implemented one-to-one because of the missing fast charging standard for the Zinoro and doesn't need to be implemented because users of EVs have the ability to reach almost all of their destinations with home and night charging (UC Davis, 2011).

However, the field of user behaviors is wide-ranging and encompasses at least the driving, parking and charging behaviors of different user groups who are driving different kinds of EVs during a specific time frame (Bogenberger, 2014). This section deals with the general travel behaviors in Beijing by approaching this subject with a literature review, presenting the most common methodologies as well as findings in this research field, and merging them with a case study.

4.2 Customer groups of electric vehicles

The question of who will buy the first NEVs is connected to the question of where the first charging pillars will be installed. The *early adopters*, as these people were called, are the first customers of NEVs during market penetration. These early adopters represent different user groups and therefore different demands, behaviors and ideas from those of the customers of e-mobility (Radtke et al., 2012). Industry and science have categorized (potential) groups of customers to customize EV models, business models and a charging network for the different needs and patterns. Figure 4.1 illustrates an overview of the feasible segmentation of NEV customers.

The user groups are not distinguished from each other in different countries, although the Chinese market stands out. The rapidly growing economy changes the life of city inhabitants enormously. Most people have changed from bicycle or public transportation to an owned car in the last few years. This transformation has had a big influence on the daily behavior and usage of a vehicle and brings out more user groups than before. This chapter is going to give an introduction to the user.

Wirges et al. have split the first customers by *social-demographic* criteria. (1) The urban trend-setter (18-35 years old, highly educated, high-income, interested in new technology), (2) the multiple-car family (already owning at least two cars, own garage, highly educated), where the EV is used as a second car and satisfies the demand because of the family composition and (3) the dynamic senior citizen (age between 60-75, owning high capital). The usage of census data is another method in figuring out what potential customers look like and where they live. Campbell has defined six variables (age, home ownership, detached/semi-detached house, drives a car to work, car/van ownership and socio-economic status) that allow the identification of buyers of alternative fuel vehicles (Campbell et al., 2012). He has figured out that people in middle age, who are homeowners, own a vehicle that they use to drive to work, and have a high status as a result, are the early adopters.

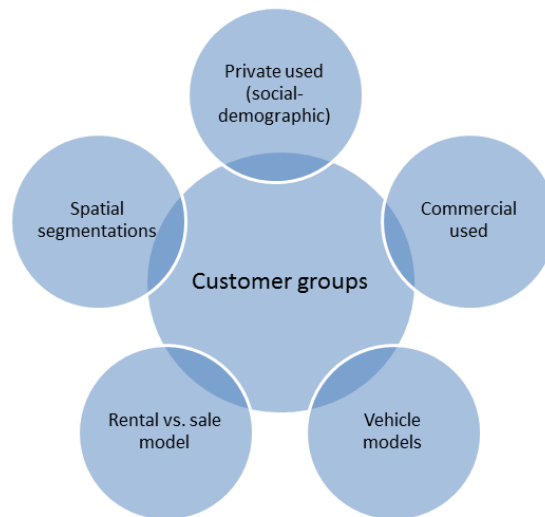


Figure 4.1: Different point of views enable the segmentation of potential NEV buyers

While the social-demographic criteria mostly describes private customers, different kinds of companies can be customers of NEVs as well. Because in these cases more than one vehicle is delivered, *company car fleets* become one early adopter, too. The innovative fleet managers of companies or technology parks (wants a innovative and environmentally friendly image for his company) (Wirges and Linder, 2012). This classification is valid for China as well. Moreover, the role of the state represents a separate user group. Electrified taxi fleets are an instrument to push this industry. At the same time these fleets are consumers for the OEMs.

Another distinction is yielded between *rented and sold* NEVs. BMW Brilliance Automotive (BBA) is only offering the rental model to its customers. Shenzhen BYD Daimler New Technology Co., Ltd. (BDNT) and Dongfeng Nissan Passenger Vehicle Company, for example, are distributing their Denza and the Venucia E30, respectively, directly to the market. Depending on the needs of the customers, both channels of distribution address different potential users. Even those without affinities to e-mobility could enter the market, whereas predefined customer groups branch to ICE vehicles.

The early adopters mentioned by Wirges and Campbell also refer to BEVs. Along with these groups, conservative ICE drivers could change to a NEV to optimize the yearly costs of ownership. Consequently, in creating a background for a charging infrastructure build up, all potential customers of NEVs should be part of the early adopters. This includes drivers of BEVs with smaller batteries (20 kWh), larger batteries (60 kWh), and even drivers of PHEVs (around 8-15 kWh). Their driving patterns are widespread and must be included in the analysis, too. A characteristic of subsidized markets is the fact that the spirit of a law doesn't match the usage or result. Because of the free license plate and the financial support of the government, PHEVs won't be used in the way that they were intended. Customers could receive the incentives for NEVs but not

use the e-drive mode in the vehicle. Because these kinds of vehicles can be driven with only the combustion engine, this results in a lack of demand on charging infrastructure.

A classification of early adopters is also possible by *location*. Potential EV customers in China live in the city, its suburbs or an agglomeration area. Countryside regions with smaller, remote villages are not the focus of OEMs or the local authorities. The reasons are a lack of grid infrastructure, the missing service dealers and the short e-range of the vehicles. Exceptions are demonstration projects established by the government. Company fleets, state owned enterprises (SOE) or taxi fleets were converted into NEVs when they were used in a spatial limited area. However, commuters living in the suburbs are an advertised user group for BEVs, although they do not match any of the criteria above (Kane, 2014) (Honda Worldwide, 2012).

In the end, two main groups of customers represent the users of public charging pillars. Firstly, the customers of NEVs who are buying a NEV or those who conclude a long-term rental contract for a NEV. Both groups know the technical specifications of the vehicle and their daily routine. Their charging locations are determined before the purchase. This group also includes customers who use a NEV as a second car. Secondly, customers of rental companies, who are driving a NEV just for a few hours or days, as well as driver of company cars that are shared within the enterprise. The need for a public charging infrastructure is significantly higher because these two groups have never dealt with e-mobility before. Some of them will use a NEV out of interest, others by chance.

4.3 Methodology of the user behaviors analysis

The analysis of user behavior of users of electric vehicles is based on GPS data and data logger data (see section 4.4.2 on page 78) coming from the electric Zinoro E1. This not only allows the study of the trip meter, the vehicle's speed and the point of time where the route starts or ends (first part), but also the parking behavior including the duration of each stop between two routes (second part) as well as the charging and discharging behavior of the EV by analyzing the specific features like the state of charge, charge cycle and charging period in combination with the time (third part).

Table 4.2 on page 75 summarizes and shows the four-step-structure and the various academic issues in the form of research questions. However, all this data gives information about the behaviors and actions of the driver and the vehicle. Most data from the study is split into a daily, weekly and a weekend analysis and is the basis of further spatial investigation in this paper (see also page 37). For this analysis, the data of 60 EVs is used.

For the study of their behavior, the selected users had to fulfill different criteria to

guarantee the comparability between each other and generate usable data. The different user groups are listed in table 4.4 on page 78. This subdivision enables a view from different perspectives and allows the comparison of the different behaviors and demands of various user groups. In respect to a charging infrastructure, the usage of different user groups at different times and locations completes the overall perspective and compensates for the use of one vehicle model.

1. The time window of the study was from April 13th, 12 AM to April 26th, 12 AM 2015. This recording period covers two weeks, including two weekends (CW 16 - 17). The studied user should drive at least 10 days to receive representative results.
2. All vehicles feature an average growth of 400 km in the mileage indicator during the recording period.
3. To ensure that drivers experienced a *learning curve* (see below), daily rental vehicles are excluded from the study.
4. The radius of action is the Province of Beijing. This restriction had to be made due to the GIS vector maps which only cover this region. Zinoro, which fulfills the above criteria but is located in Shanghai, Shenzhen or Shenyang is excluded from the spatial analysis but is still studied in the statistical analysis to get more data.

Not all end-users of the vehicle can be determined if the EV belongs to a rental company. Due to the fact that most Zinoro vehicles belong to an intermediate dealer and the small overall amount of vehicles, all vehicles are analyzed in one group. A user group differentiation is not valuable in this case.

The term *learning curve* of EV drivers denotes the change in driving attitude. Out of the MINI E study, drivers of electric vehicles need a period of approximately six weeks to get to know the vehicle and adapt their driving style to battery-powered cars. The drivability of ICE vehicles is different due to the power train and gearbox as well as range and refueling time. The familiarity with the EV can be measured by comparing the distance covered per day and distance covered between two charging processes. Expectedly, these parameters will rise while the quantity of charging processes per week and the consumption of kWh per 100 km will decrease.

The database for this software is the RTM log files that each vehicle sent to a server in a sequence of 10 seconds. By picking up a monthly report in Excel format, the actual analysis was done by the free program called *QlikView* (Qlik Technologies Inc., 2014). This multi-dimensional database is memory-based and allows the combination of different kinds of data. By selecting attributes (e.g. in this case the time or VIN), tables and charts can be visualized by using expressions and definitions. These codes are put in the subsections to match them with each academic question, whereas the

source code (script) for the whole analysis is listed in the appendix (see page 155).

Table 4.1 lists all used terms and attributes of the EV analysis. The definitions have been chosen with a simple and effective creation of a program-code in mind. The definitions are as close as possible to the actual EV usage and reflect reality. The minimum duration for a stop as well as the minimum speed for a route are included to guarantee suitable data and exclude faulty measurements recorded by the RTM.

Term	Attribute	Definition
Interval	Morning:	6 AM - 12 PM
	Afternoon:	12 PM - 6 PM
	Evening:	6 PM - 12 AM
	Night:	12 AM - 6 AM
Charging Process	Charging\Discharging status:	CHARGING
	Gear position:	P
	Vehicle speed:	$= 0 \text{ km}\backslash\text{h}$
Stop	Gear position:	P
	Vehicle speed:	$= 0 \text{ km}\backslash\text{h}$
	Duration:	$\geq 5 \leq 30 \text{ minutes}$
Parking	Gear position:	P
	Vehicle speed:	$= 0 \text{ km}\backslash\text{h}$
	Duration:	$\geq 30 \text{ minutes}$
Trip	Gear position:	D
	Vehicle speed:	$\geq 2 \text{ km}\backslash\text{h}$
	A track can include many stops, but ends with a parking event	

Table 4.1: Defined terms for the RTM analysis; a further subdivision of the parking process can be find on page 94

The visualization of the RTM data is based on the *QlikView* results in the form of excel tables. The geo-processing tools in *ArcMap* and the database in *ArcCatalog* again, refer to these tables.

Driving analysis

1. How many kilometers the drivers travel per day?
 2. How long is the duration of the track traveled per day and per vehicle?
 3. How far is the distance of the longest, shortest and average track distance traveled per day and per vehicle?
-

Parking analysis

4. How often a vehicle is stopping per day?
 5. How often a vehicle is parking per day?
 6. How long a vehicle is parking per day, week and weekend (parking classes, cf. table 4.9 on page 94)?
-

E-drive analysis

7. Whats the average Start-SOC at the beginning of the first track of the day?
 8. Whats the minimum, maximum and average Start-SOC at the beginning of each track?
 9. Whats the average End-SOC at the end of the last track of the day?
 10. Whats the minimum, maximum and average End-SOC at the end of each track?
 11. How big is the average Δ SOC (electrical consumption) per day and track?
-

Charging analysis

12. How often the user charge the EV and per week?
 13. How long is an average charging process?
 14. What is the average SOC growth per charging process?
-

Table 4.2: Methodology and research questions for the analysis of the user patterns

4.4 Initial conditions

This section deals with the analysis of EV user behavior and represents one of the main parts of this dissertation. As a quantitative study of driving, parking and charging manners of real users of electric vehicles within a period of one month in Beijing, this data constitutes a novelty by visualizing them on maps and combining them with vector data. First of all, the frame conditions of the assessment are listed and described. Then the vehicle, user groups and technical equipment, the methodology as well as the fault analysis require particular attention.

4.4.1 The Reference vehicle: Zinoro E1

The EV used for the field test is the Zinoro E1 (see figure 4.2). It is a pure BEV and a product of the Joint Venture BMW Brilliance Automotive Ltd. (BBA) (BMW Brilliance Automotive Ltd, 2014) The car has an electrical range of 150 km and a battery capacity of 24 kWh. A GB/T type 2 socket is built into the vehicle and allows charging currents of up to 16 A. Fast charging with direct current, as well as fast charging with three-phase current, are not feasible with this EV. All Zinoro E1s have the same battery pack and electronic components installed, which simplifies a comparison between the vehicles.



Figure 4.2: The Zinoro E1 from BMW Brilliance Automotive Ltd.

One feature of the E1 is the energy recuperation. By transforming the kinetic energy of the vehicle into electrical energy, the electric motor becomes a generator during

braking. This procedure is not recorded as a charging process in the data logger (see the subsection "The Real-time-monitoring device" on page 78). A recuperation during driving with the gears position *D* is treated as discharging. A pure coasting mode, which means the electrical motor is disconnected from the axis and the vehicle trundles, is not possible. Instead, a *one-pedal-feeling* affects the driving. After removing the foot from the accelerator pedal, the vehicle immediately slows down. These design specifications are reasons for the driving attitude change in drivers who are used to driving an ICE vehicle in the past. The battery capacity in the EV represents a state of charge (SOC) in percentage points (0% is an empty battery; 100% is a full battery). If the SOC falls under 30%, the driver gets an optical warning; if it falls under 10%, the driver gets another acoustic warning.

Attribute	Value
Doors/Seats	4/5
Luggage capacity [l]	306
Engine	Electric motor
Maximum Performance [kW/hp]	125/170
Maximum Torque [Nm]	250
Charging Time (up to 80% SOC) [h]	7,5 (at 16A Wallbox)
0-50 km/h [sec]	5,5
Top Speed [km/h]	130
Range [km]	150

Table 4.3: Product data sheet of the Zinoro E1. (BMW Brilliance Automotive Ltd, August 2014)

The business model for the Zinoro E1 is a pure rental distribution to private or commercial customers. Most rental companies offer contracts for daily rental or long term rental with a time frame of one, two or three years. But not all rental companies have these kinds of contracts. Others have their own distribution models for their customers. A clear subdivision of the customer intra-market of the rental companies was not feasible. This constellation is unfavorable because it is not possible to generate different user groups. However, some rental companies have focused on short term rental models (days and weeks); others focused on long term rental models (months and years), confer to table 4.4. Attention should be paid to the fact that drivers are only consistent for long term private customers. This fact cannot be guaranteed for commercially used vehicles because the drivers could change inside the company (in this case the end user). Considering the market launch of the Zinoro brand and product in 2014, brand awareness was not established in the beginning. This had impacts on user groups as well because mainly market mavens know the brand. However, the first Zinoro users reflect the early adopters, like technology-affiliated customers (see section "Customer Groups of Electric Vehicles" on page 70).

User group	Quantity
Private long term	3
Commercial long term	11
Commercial short term	46
Total	60

Table 4.4: User groups of analyzed Zinoro E1 driver; all rental cars belong to local rental companies in Beijing

4.4.2 The real-time-monitoring device

The real-time-monitoring device (RTM) is the government's requirement for all subsidized EVs in China. The aim of this device is the tracking and observation of the vehicle's usage. This includes all vehicle data as well as battery-specific data. The user is informed about the installation in the car within the purchase contract. For the government, the RTM device has two advantages: The battery and vehicle specific data serve to develop new generations of EVs and the overall amount of data can be used for a traffic analysis in the each respective city.

Figure 4.3 shows the main components of the system. Immediately after switching the vehicle on, the CAN logger taps the signals every 10 seconds off the BUS-system and the integrated SIM card transmits the data to an antenna. Via a UMTS signal, the data is sent to a database server. A LED-box in the windshield displays the status and function of the RTM. Although this technology allows live tracking of the vehicles, this study is based on retrospective user data. The RTM data are not connected to the driver's personal data.

The RTM-signals used for this study are listed in table 4.5. These signals are listed in the Excel sheets, which are the data basis for *QlikView* and further processes by *ArcGIS*.

There are four gear positions in the Zinoro E1's automatic transmission which are visible and feasible for the user: *P* for the parking gear, *D* for the driving gear, *R* for the reverse gear and *N* for neutral. In addition to these four positions, the RTM device sends a fifth signal called *6*. It is generated when the CAN-Bus-signal² is invalid and no other gear position (*P*, *D*, *R* or *N*) is engaged. The signal *6* always occurs after the parking gear *P* and is a precursor for the sleep-mode of the whole vehicle. Furthermore,

²A CAN Bus is an internal message broadcast system in a vehicle. In a CAN network, many short messages like temperature or RPM are broadcast to the entire network, which provides for data consistency in every node of the system. (Texas Instruments, Incorporated)

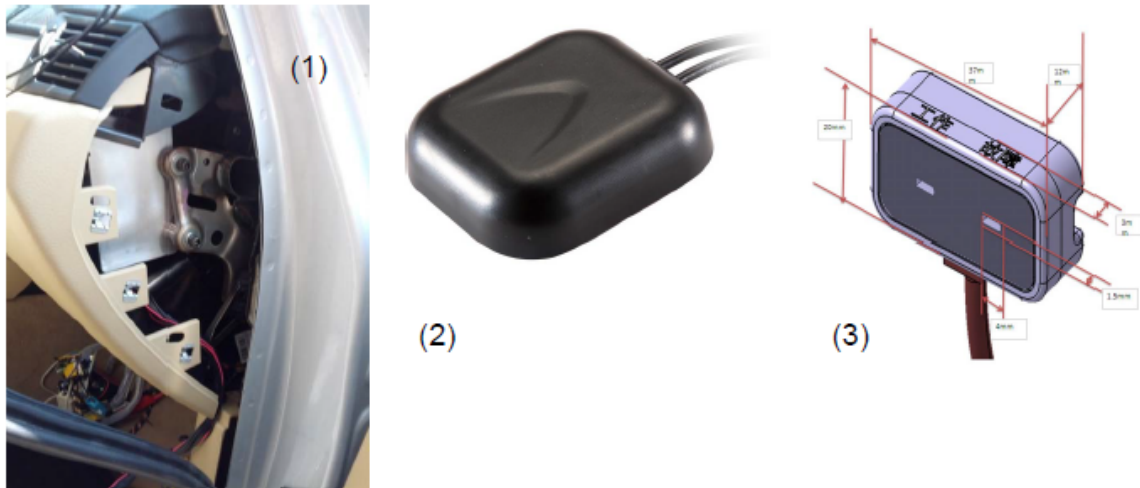


Figure 4.3: Real-time-monitoring device (RTM) for the Zinoro E1: (1) CAN logger with GPS receiver, mobile connection and battery, (2) Antenna and (3) LED-box

the engine is off and the vehicle is locked. After charging, when the SOC has reached 100%, the vehicle needs 12 minutes to activate sleeping mode and the RTM device needs 3 minutes to go to sleep. This time is defined as 6 in the database. After 15 minutes the vehicle is in sleeping mode, does not generate any more signals and the RTM device does not emit anything. When the car is next turned on, the system switches to *P* as a first task.

4.4.3 Fault tolerance

The results of the user behavior analysis depend on the precision of the technical devices on the one hand and human faults on the other. The following overview lists all possible error sources and their effects on the result.

GPS Breakdown The signal of a GPS device is subject to variations. Especially in downtown Beijing with its skyscrapers, underground parking lots and tunnels, the signal can be interrupted for an indefinite period of time. This breakdown results in invalid tickets, which indicate 0 for the geographic coordinates.

GPS Deviation The RTM device generates the longitude and latitude signal as decimal degrees coordinates with a six decimal places after the comma (e.g. 121.164922 East, 31.282014 North). To minimize the fluctuation, *QlikView* rounds after five decimal places after the comma. Whereas a value in decimal degrees to a precision of 6 decimal places is precise to around 11 centimeters at the equator; a precision of 5 decimal places is precise to around 1 meter at the equator.

Signal	Unit	Explanation
Serial number	numeric	Automated sorted signal number
VIN number	numeric	Vehicle identification number
Acquisition Time	[mm/dd/yyyy] [hh:mm]	Date and time of the recorded signal
Longitude	Decimal degrees	GPS position
Latitude	Decimal degrees	GPS position
Mileage	Kilometers [km]	Aggregate number of miles traveled
Gear position	D, P, R, N or 6	Automatic transmission modes
Vehicle speed	Kilometers per hour [km/h]	Vehicle speed, not tapped from the GPS device
Charging Status	Charging/Discharging	Indicates if the battery is charged
SOC	Percent [%]	Battery status
Air Temperature	Degrees Celsius [°C]	Measurement for outside temperature

Table 4.5: Used signals from the data logger

Measuring Inaccuracy of Sensors As all sensors in a vehicle can be susceptible to defects, an unlikely possibility for incorrectly measured values is generated all the time and can influence other devices and generated data.

Transmission Failure of the Data Signal The RTM device uses a stationary SIM card which sends the signal via telephone frequency to the server. Incorrect settings or radio interferences can be potential software sources of error. Defective wiring or mechanical damage are potential hardware faults.

Programming Error in QlikView The source code of the analysis tool is listed on page 155. Although the code was written with accuracy and was tested with small values and verifiable outcomes; transposed numbers, logical mistakes or error propagation to the nested levels can't be excluded.

Visualization in ArcGIS The visualization technology in a geographical information system like ArcGIS is diverse. This also holds for the visualization of classification methods. For example, the three traffic-light colors indicated critical values which are based on personal experiences; such called geoprocessing tools like *Kernel Density* or a *buffer* are subjectively selected for a better presentation on the map.

Quality of Maps The maps in this study include the vector-data and a base map of

Beijing from 2014. This includes all kinds of points (POIs), lines (streets) and polygons (areas and grounds). All data was purchased from an official vendor, but this makes no claim of being complete.

Interpretation of Results The retrospective analysis of the data during a short time-frame is not representative. This snapshot allows a basic orientation of the user patterns.

4.5 General travel patterns in Beijing

The quantity of charging pillars and the demand for public charging infrastructure is mainly based on the user patterns of EV drivers. Next to the battery size and the resulting e-range, the daily trips and trip chains play an important role for the installation of charging facilities. The following paragraphs deal with the general traveling patterns of private transport users in Beijing. With a literature review of existing scopes in the field of travel behaviors, universal travel behaviors are presented. Thereby, not all of the scopes have a connection to the e-mobility or to China. Although driving behaviors of private transportation and passenger cars has been extensively explored from many aspects, this part provides an overview of user patterns in the field of private transportation in Beijing. Investigations of travel diary surveys, tour types and trip characteristics related to the land-use in Europe and the USA yield fundamental knowledge: Higher residential density is associated with more home-based tours with fewer stops and shorter trips, while mixed land use at workplaces having higher density and accessibility is associated with more stops within one work tour, or a more complex tour pattern. (Ma et al., 2014) (Gather et al., 2008) (Boarnet and Crane, 2001) (Lee et al., 2009)

The foundation of this study are BEV drivers, however, the patterns from ICE drivers are of particular interest as well because the attitude change between both groups is not yet clarified. Both groups share similar daily routes and mileage, as well as parking behaviors. On the one hand, BEV drivers *have to* change their behavior because the e-range in the BEV is limited and the drivers have to approach destinations with public chargers which are out of his regular scope. On the other hand, users buy a BEV only when they can still cover their present destinations with a battery vehicle. This study can't give an answer to this question but uses current academic sources from other studies. The main comparative study is from Ma, Mitchell and Heppenstall who dispensed over one thousand questionnaires to high-income workers and households with children in Beijing. The goal of their study was to combine social-demographic attributes, urban form characteristics and a tour-based travel decision process. Although this study has social-demographics, includes several transportation modes but no spatial data such as distances, it can be integrated into this paper because the question of

alternative routes is presented. Table 4.6 lists all home-based work tours and home-based non-work tours of the interviewees. Concerning the charging network, the parking events and quantity of non-home or non-work locations are of greater interest.

Home-based work tour			Home-based non work tour		
Tour type	Frequency	Percent	Tour type	Frequency	Percent
H – W – H	376	47.9%	H – L – H	61	48.4%
H – X – W – H	27	3.4%	H – S – H	29	23.0%
H – W – X – W – H	210	26.8%	H – F – H	15	11.9%
H – W – X – H	57	7.3%	H – P – H	12	9.5%
H – X – W – X – W – H	34	4.3%	H – O – H	4	3.2%
H – X – W – X – H	9	1.1%	H – 2 stops – H	1	0.8%
H – W – X – W – X – H	65	8.3%	H – 3 stops – H	1	0.8%
H – X – W – X – W – X – H	7	0.9%	H – 4 stops – H	0	0.0%
Single-purpose work tour	376	47.9%	Single-purpose non-work tour	121	96.0%
Multi-purpose work tour	409	52.1%	Multi-purpose non-work tour	5	4.0%
Total	785	100.0%	Total	126	100.0%

Table 4.6: Tour classification borrowed from Ma, Mitchell and Heppenstall (Ma et al., 2014)

H represents home; W represents work;

X represents any non-work activities; L represents leisure activity;

S represents shopping activity; F represents family obligation;

P represents personal business, like eating out;

O represents other non-work activity

For later analysis, these home-based tours are essential because private EV drivers use their home as their charging base. Although most of the Zinoro E1 drivers do not fall into this category, in 50% of the home-based work tours the travelers have more than one destination, whereas non-work tours have mainly just one destination. Complex tours do not occur during non-work tours, although complex trip chains could reduce total vehicle mileage and total vehicle trips (Noland and Thomas, 2007). In the framework of a charging network, multi-purpose tours are predestined for public charging (provided that EV drivers have a private charging station at home). As table 4.6 integrated all user groups (see page 70), different types of NEVs had to cover these tours.

These daily routes are characterized by routines and most users do plan their journeys

before driving. But not all of the outcomes are suitable because the urban spatial development and individuals' daily travel behaviors are not the same in developing countries and transitional economies like China (Pan et al., 2009). In addition to the above information, just a few inquiries have been focused on the city of Beijing. Thereby, the spatial view for private passenger cars has not been studied so far. Again, this data is based on general vehicle studies and can be used for a comparison later.

- The commuting period is from 6:00 AM to 9:30 AM and 4:30 PM to 7:00 PM (Beijing Transportation Research Center, 2009)
- The average distance of public transportation travel is 9.5 kilometers at an average speed of 14 kilometers per hour, which takes 66 minutes to travel during rush hours (Beijing Transportation Research Center, 2009)
- The average distance of car travel is 14 kilometers at an average speed of 22 kilometers per hour, which takes 39 minutes during peak hours (Beijing Transportation Research Center, 2009)
- A quarter of the travel time is spent waiting at traffic lights while another quarter is spent in traffic jams.(Beijing Transportation Research Center, 2009)
- The commuting range for car users in Beijing is 9.4 km (Zhou et al., 2014)
- The distance between commuters' homes and their most frequently visited shop is between 2 km and 5 km (Wang et al., 2011)
- The distance between commuters' homes and their most frequently visited entertainment area is between 2 km and 6 km (Wang et al., 2011)

4.6 Case Study

The structure of this section is equal to the academic questions that can be found in table 4.2 on page 75. For better clarity, the consecutive ordering was borrowed. Where necessary and feasible, maps or tables will highlight and visualize the data. Adduced literature completes the results as well. Although most of the results are solved in *QlikView*, additional calculations or diagrams were made in *MS Excel*. The general layout of the following tables contains the maximum values to reveal the peak values. The minimum values were excluded because their value is always 1 or 0, e.g. for the minimum kilometers driven per day. However, the focus is on the statistical median of the data. In contrast to the statistical average, the median does not consider outliers. Input errors or incorrectly transferred signals were smoothed out. All values, numbers, charts and diagrams have taken an amount of 60 vehicles as a basis ($n = 60$).

This section only analyzes the RTM data in an objective way and does not correlate them to the spatial POIs or the charging infrastructure. Concerning the final outline, this part can be seen as a further influencing factor. For a subsequent integration, the statistical vehicle data is useful and should be used as another source. However, because only a small amount of vehicles and user groups are selected here, this is just an example of how to do it.

4.6.1 Driving analysis

Overall route analysis

One of the most important key indicators is the daily and weekly overall distance covered by the drivers (Research Question 1: How many kilometers do drivers travel per day and week?). The total amount of kilometers gives information about the general usage of the cars and their spatial distribution within Beijing. Although this mileage data includes all trips (a trip is the mileage between two parking stops), the first part excludes this fact to get a comprehensive overview. Table 4.7 features the median and maximum distance and travel duration of all 60 vehicles during the two week recording period. The daily median distance during the investigation period amounts to under 20 km. This is higher than the median distance during work days (Monday to Friday), but shorter than the median distance per weekend. Figure 4.4 illustrates the distribution of these traveled distances. Distances over 100 km were driven less often than shorter distances. Observable is the decrease of distances higher than 70 km. The maximum distance per day of 233 km is obviously high. To make this mileage possible, a full recharge of the battery is necessary. It can be assumed that the vehicles are used more frequently during the weekends than on workdays. However, under the best conditions, the e-range of the Zinoro E1 is 150 km. So, most of the drivers underachieve the potential of the vehicle most of the time.

		Median	Maximum
Per day (Monday to Sunday)	Distance [km]	19	233
	Driving time [min]	54	302
Per working day (Monday to Friday)	Distance [km]	11	132
	Driving time [min]	57	263
Per weekend (Saturday and Sunday)	Distance [km]	43	233
	Driving time [min]	64	302

Table 4.7: Mileage and driving time analysis per vehicle per day and weekend for CW 16-17; $n=60$

The driving time can be relevant for the charging infrastructure and can give clues

regarding the usage of the vehicle. Depending on the distance traveled, the average speed of the EV and the outside temperature, an estimation of the battery consumption is feasible. This again influences the quantity of charging processes. During the two week recording period, the duration of driving was about one hour per day per vehicle. Consequently, the car was parked the rest of the day. Again, this number just represents the median and is not transferable directly to all drivers. But this serves as a reference point for the operation of a car and indirectly for the operation of charging stations.

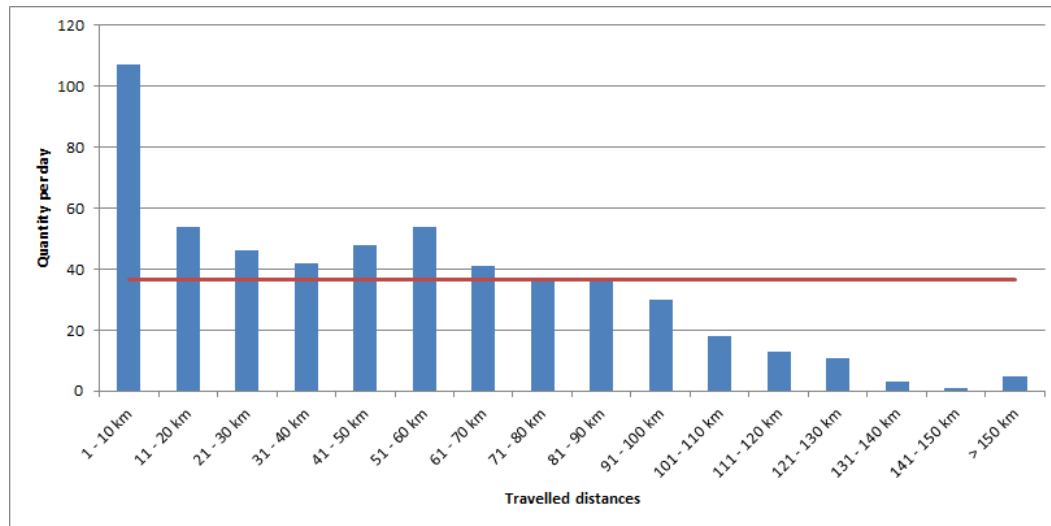
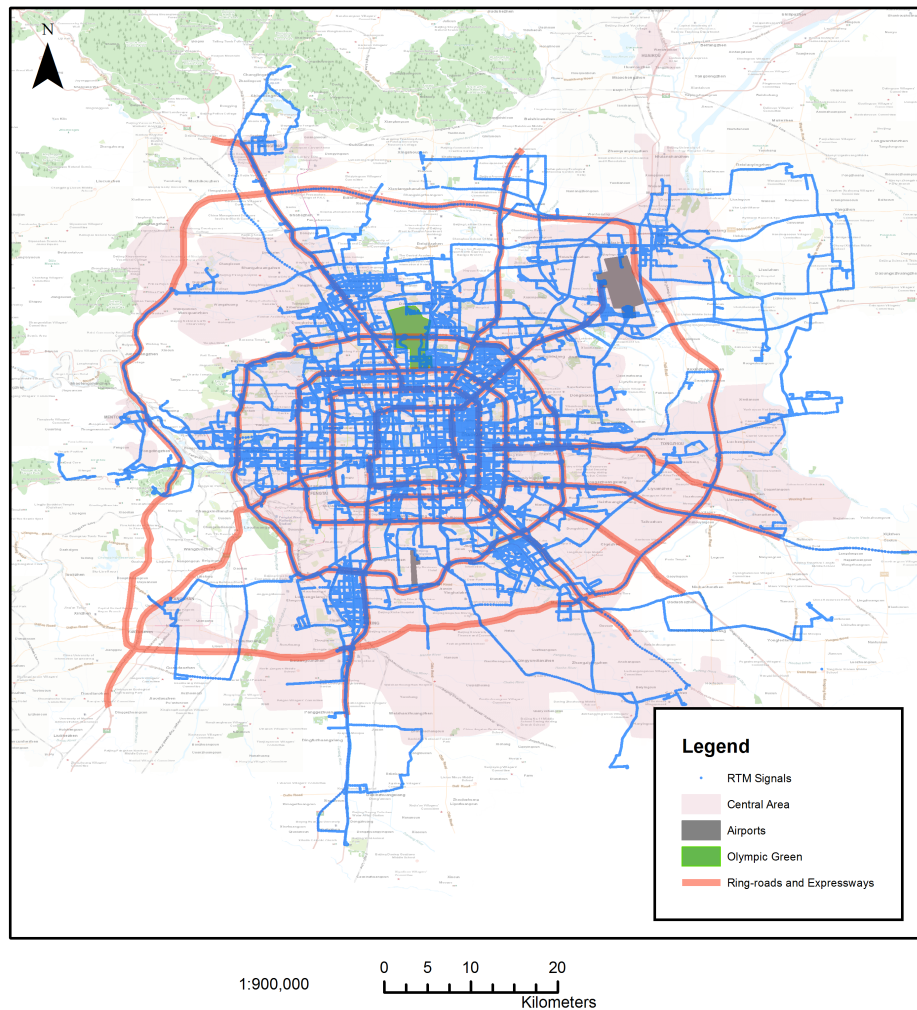


Figure 4.4: Classification of traveled distances; the red line represents the median

Map 10 illustrates the driving profiles of the 60 Zinoros in the metropolitan area of Beijing during the recording period. Like the topographic base map, the map contains the official Central Area of Beijing, the two airports and the main road network. The radial expressways are not entirely highlighted, but show the driving routes in relation to the city and its six Ring-roads. The blank area in the south and east of the map is the Hebei province and not part of the maps used for this study.

During the recording period, the EVs were driven up to 60 km from Tiananmen Square, which represents the center of Beijing. These routes were outside of the sixth Ring-road; and some of them were not even within the official Central area of Beijing. Outstanding is the highly frequented usage of the Ring roads and expressways because of the high density of points on this lines.

A hotspot analysis of the driving analysis is shown on map 11. Compared to map 10 where the signals overlap, this map highlights the areas with more traffic. From the overall traffic of the Zinoro, $\frac{2}{3}$ of it was within the 5th Ring road; respectively 40% within the area of around 500 km² between the 3rd and 5th Ring road. Within the 5th Ring road the north, northeast and east districts were clearly more frequented. The Chaoyang district, which includes the CBD and the embassy area, features a higher usage of side roads than in other districts, at least for the area inside the fifth Ring

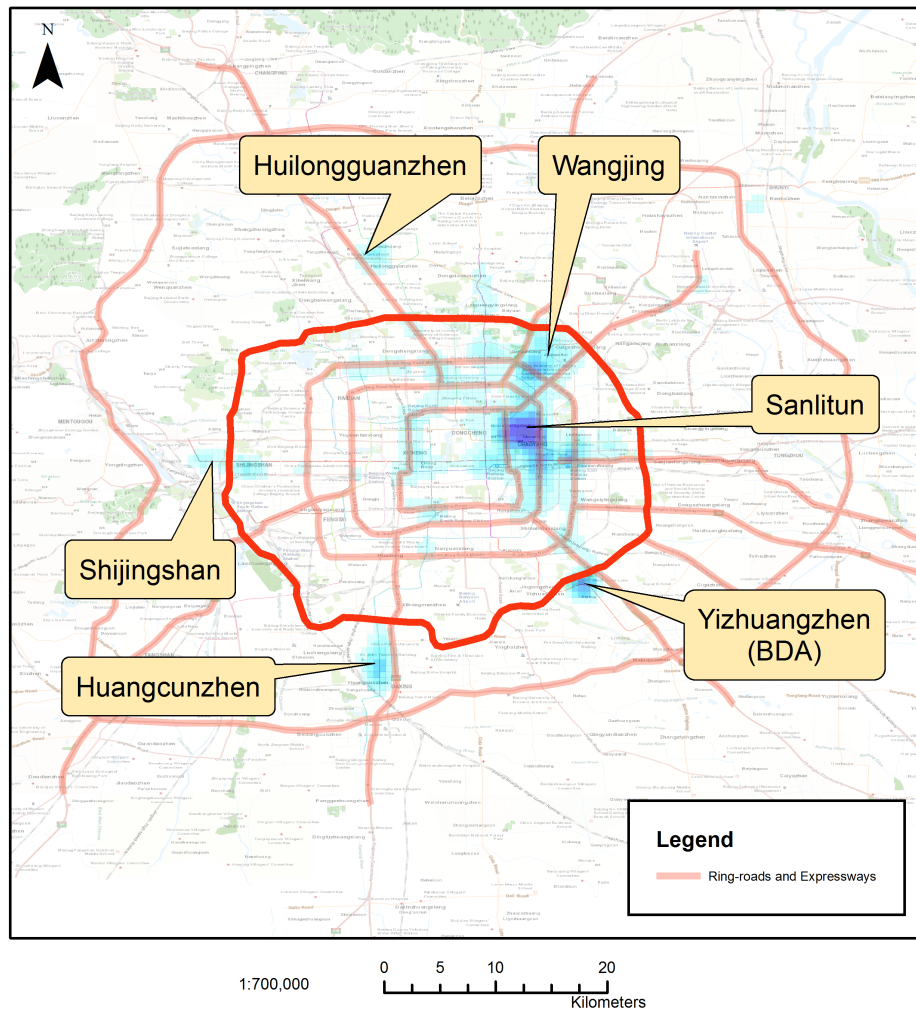


Map 10: Overall driving routes of 60 Zinoro E1 in CW 16 and 17 in 2015

road. The districts in the southwest and south have less traffic, although these areas still belong to the Central area. Outside the 5th Ring road are six areas with a higher amount of road usage: Huilongguanzen, Wangjing, Sanlitun, Yizuangzhen (BDA), Huancunzhen and Shijingshan. All of them are within the official Central Area of Beijing, and close to the 5th Ring road. With the exception of Shijingshan, these areas are located next to expressways. Together with the CBD, five "core areas" were generated by the Zinoro drivers and stand out. Concerning the RTM data, these areas became ROI because the drivers spend more time and travel longer distances in these areas.

Track analysis

This paragraph deals with the trips and answers the research questions 2 and 3 (cf. page 75). The analysis of trips and trip chains is another essential part of the study. The



Map 11: Hot spot analysis of driving routes of 60 Zinoro E1 in CW 16 and 17 in Beijing (generated with a *Kernel density tool* in *ArcMap*)

drivers' behavior is revealed by representing the start and end of a journey. Additionally, the distances and the spatial relation of the trip in the city can provide information about where potential charging stations are necessary. Parking (and potential charging) locations are included when the drivers stop during a trip. However, for various reasons, different parking locations can't all be a charging location at the same time: Structural conditions might prevent the installation a charging facility, the time of the parking event might be outside of business hours of the POI, other EVs could be occupying the existing charging pillars or drivers simply might not need a charging event.

In relation to the charging infrastructure, the median quantity of trips is an important indicator for the daily driving behavior and can represent recurring activities. For the current calculation, only routes with the gear box position *D* and a duration of over five minutes are used. Hence, shorter reverses or routes with many stops, e.g. in slow-moving traffic or stops in front of traffic lights, are excluded. Table 4.8 lists the

		Median	Maximum
Per day (Monday to Sunday)	Quantity	3.3	4.2
	Distance [km]	9	69
	Duration [min]	22	183
Per working day (Monday to Friday)	Quantity	4	8
	Distance [km]	9	56
	Duration [min]	29	160
Per weekend (Saturday and Sunday)	Quantity	2.1	5
	Distance [km]	11	69
	Duration [min]	21	183

Table 4.8: Track analysis per vehicle per day and weekend in CW 16-17; $n=60$

trip quantity, distance and duration within the two-week recording period of the 60 Zinoros. The median quantity is about three trips per day per vehicle during the whole week. This is spread across three trips per day and car on working days and two trips per day and car during the weekend. Conspicuously low is the distance of the trips during the recording period. Although there are outstanding maximums of around 70 km, the drivers usually drive around 10 km per trip. Again, most of the trips per day are feasible with the e-range of the Zinoro.

This trip analysis does not provide an answer to the trip motivation of the driver. The reasons to start the trip can't be identified by analyzing the GPS data. However, as seen from the perspective of the charging infrastructure, three kinds of trips are feasible:

Trips Without Charging A driver starts a route without charging the EV before or after the trip. Sense and purpose of the journey are detached from the field of charging. In this case the SOC is high enough to reach the destination without charging. Detours or changes in the driving patterns are not necessary.

Trips with Feasible Charging Options This kind of trip does not yield a change in the driving behavior either. The driver charges the EV in advance to ensure sufficient charge to reach the destination. The drivers use the EV routinely without the stringent necessity to use public charging facilities. However, if a charging location is on the route, drivers could use the possibility to recharge the battery (even if the return trip or further trips are guaranteed).

Trips to Approach a Charging Station EV users cannot arrive at their final destination without a detour to recharge the battery. This compulsive behavior generates complex trips and requires a charging facility to complete the trip chain.

The last option results in the fact that drivers could choose POIs outside of their daily route to recharge the battery. Drivers hazard the consequences of detours to

arrive at the proposed destination even if there exists no need to park at a POI under normal conditions. The more (public) charging facilities are installed in an area, the less complex the trips become.

By generating a trip chain of the previous and subsequent trips before and after the parking event, more feasible charging locations can be provided to the driver. So, the spatial track analysis becomes relevant for a charging infrastructure build up. Therefore, this methodology is more necessary for suburban areas or areas outside of the inner city because it can be assumed that the public charging pillar density is higher in the inner city. Underlying the driving patterns of map 11, a spatial track analysis is applied in order to understand the inclusion of these areas in the urban context and the *necessity of public charging stations* in these areas. If EV drivers are travelling to one of the five "core areas" (Huilongguanzen, Shijingshan, Huancunzhen, Majuqiaozen and Sanlitun) outside the 5th Ring road, the need to charge could be lower when drivers can charge the battery before or after the trip. The maps on page 90 ("Map 12") visualize trips to and from the "core areas". The dashed lines symbolize the linear distance between the areas as well as the starting point or end point. The maps show that there are connections between each of the areas. The highest travel was between the Sanlitun and the BDA. The distance between these two areas is about 10 km and hence the shortest of all, followed by the traffic between the Zongzhuang area and Sanlitun. The whole Chaoyang district was also frequented very often. In summary, it can be stated that, in addition to the International airport in the northeast, most of the Zinoro traffic happens between these five areas of Beijing.



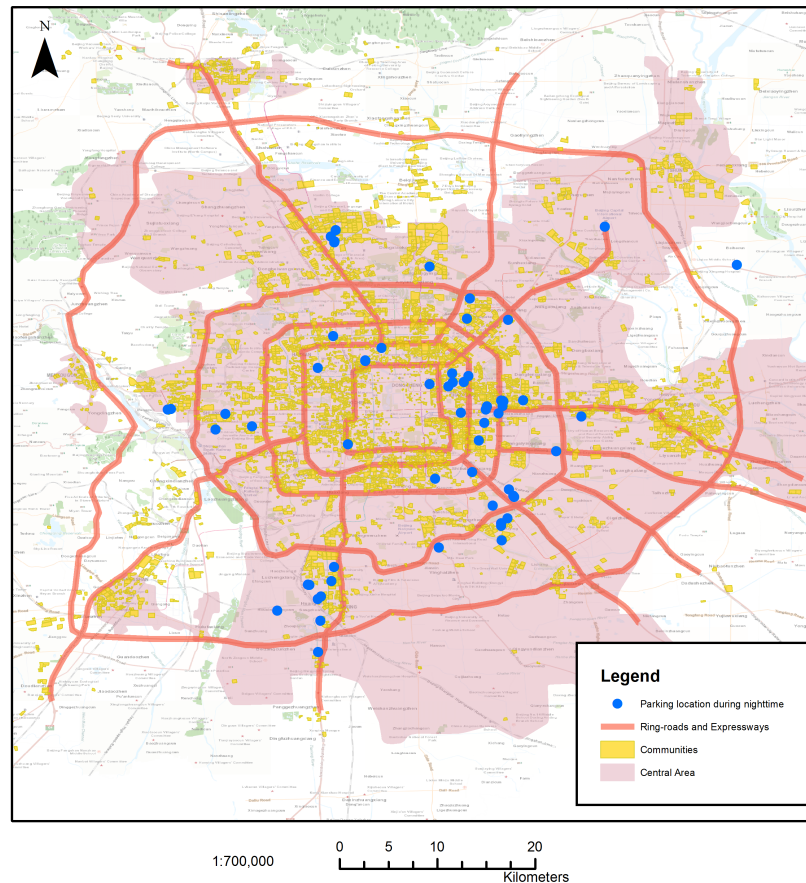
Map 12: Tracks from and to Shijingshan, Huilongguanzhen, Huangcunzhen, BDA and Sanlitun

4.6.2 Parking behavior analysis

The parking analysis is also part of the user's pattern. Concerning the charging infrastructure, the parking locations give information about potential charging locations, too. But, as long as the battery is full, a charging process is not necessary, but only desirable for the user. Consequently, the battery status (SOC) provides more information when it is connected with the parking event. Hence, this section focuses on the duration of the parking event because it is essential for the type of charger. As described on page 26, the charging times are essential for the build up of a public network. A charging event which runs with direct current or three-phase alternating current can charge the battery up to an SOC of 80% in 30-40 minutes (see page 28). This short charging time enables an energy input even during shorter parking events. As a fast charging option for the Zinoro E1 is not feasible, yet, but easily conceivable in the future, stopping events under 30 minutes will characterize potential fast charging locations. But, as most of the time vehicles are parked for longer periods, these places are perfect for normal chargers. Thereby, the parking lots can be the user's home for privately used EVs, the company parking lot of the rental companies or a parking lot at office buildings for vehicles used as company cars. So, a distinction between *stopping* and *parking* simplifies the study of the parking process for daytime parking events (cf. table 4.1 on page 74). Parking events over 30 minutes are especially highlighted in this study. However, an economically reasonable charging process with a simple AC, one-phase connection for the Zinoro begins at about 4 hours. Consequently, the parking processes are divided into five classifications (see table 4.9).

This subsection deals with the city-wide analysis and distribution of the parking events and deals with research questions 7 and 8. As before, where necessary and helpful, maps will be added for a more precise clarification. For this subsection, it is understood that the stopping of a car is defined as a vehicle standstill between 5 and 30 minutes. As stopping less than 5 minutes can be due to waiting time at traffic lights, durations shorter than 5 minutes are excluded. Although this analysis is not relevant in relation to the charging infrastructure, it is part of this paper for the sake of completeness. A closer neighborhood analysis that combines user patterns with the urban geography is described in chapter 5.1 on page 104.

The focus is on daytime parking events, because these locations will be potential locations for public or semi-public charging stations. However, the nighttime parking locations provide the main parking lots for the user. A first look at the night parking locations generated by the 60 EVs within the recording time gives map 13 on page 92. The number of 67 night parking events show that the nighttime parking locations do not change for most users. Excluding one location, all parking events took place in the official Central area of Beijing, whereas 48 parked within the 5th Ring road. All places overlap with the "core areas" of the driving routes (cf. map 11 on page 87). Most of these locations are also the start or end points for the drivers' trips. Thereby, around

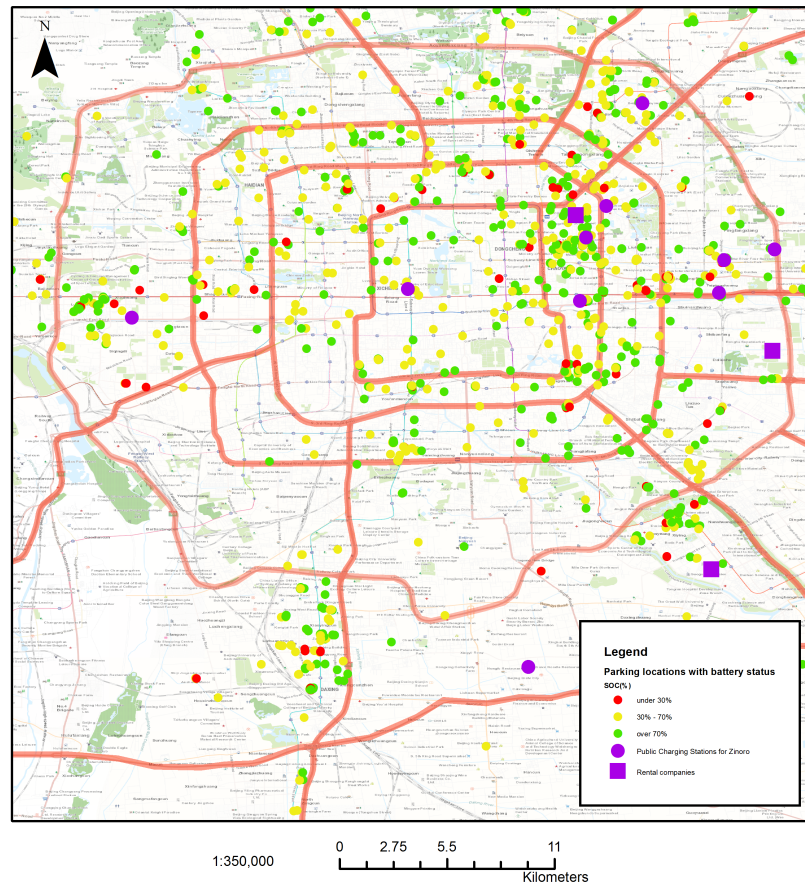


Map 13: Night time parking locations for 60 EVs in CW 16-17

40% of the parking events take place in a compound. This is just an indicator for the usage of the vehicle because some office buildings and shops are also located inside a compound. These vehicles, again, can be used as company cars instead of private cars.

Map 14 on page 93 visualizes the daytime parking locations of the Zinoro drivers. The map indicates the distribution of the parking events and their spatial relation to the public chargers, as well as the battery status at the beginning of the parking event. Thereby, here SOC data is the most important factor, respectively the deduced consumption and quantity, as well as the quality of charging events. The battery of the Zinoro E1 has a usable capacity of 24 kWh. A fully charged battery corresponds to a state of charge of 100%. This represents the maximum e-range of the vehicle. The driver is informed about the e-range via a display of four blocks (where each block represents 25%) and the remaining e-range in kilometers. At a SOC of 30%, an acoustic signal warns the driver for the first time. A second visual signal is generated at a SOC of 10%. However, the calculation of the remaining e-range is dynamic and depends on the previous driving behavior. So, at all times the driver is clear on the current energy in the battery and its e-range.

Starting with the distribution, again, most of the parking events took place within the



Map 14: Daytime parking locations (duration over 30 min.) with battery status and charging facilities of 60 EVs during CW 16-17

"core areas". Scattered parking events also happened mostly within the fourth Ring road. Other parking events took place within a 1 km radius of feasible charging facilities. 20% of the parking events during the day were at a compound. Concerning the battery status at beginning of the parking event, the users with a low battery (SOC under 30%) are of particular interest because they could need a charging spot. Out of all recorded parking events 21% of them started with a low SOC. Out of these, 53% parked at a compound. But 87% took place in one of the "core areas" and, consequently, next to a home charger.

Table 4.9 points out the detail diversification of the daytime parking events. The short-term parking events ("stopping") under 30 minutes are the most frequent, whereas the long-term parking events ("parking") of over 240 minutes are frequent as well. However, in the median a Zinoro is parking around one to three times per day during daylight hours. Especially the *stops* over two hours are of particular importance because, during this time, the Zinoro can be charged with a reasonable amount of electrical energy.

Duration	Median	Maximum	Quantity
< 30 min.	2.5	202	2134
30 - 60 min.	2.3	6	189
60 - 120 min.	3.0	6	238
120 - 240 min.	1.2	4	59
> 240 min.	3.8	5	487

Table 4.9: Parking analysis per vehicle per day during daytime in CW 16-17; $n=60$

4.6.3 E-drive analysis

The e-drive analysis focuses mainly on the state of charge of the battery. The electrical consumption per trip and per day are presented in table 4.10 and answer the research questions 9 through 13. Conspicuous is the generally high percentage of the SOC before and after the trips, as well as before and after the first and last trip of the day. Almost all users charge their EV during the night and start their trip with a high SOC. Furthermore, they generally drive with a high SOC, although the minimum SOC before a trip was under 10 %. The consumption per day and per trip was quite low. The maximum of 146 % is accounted for by several full charging processes per day.

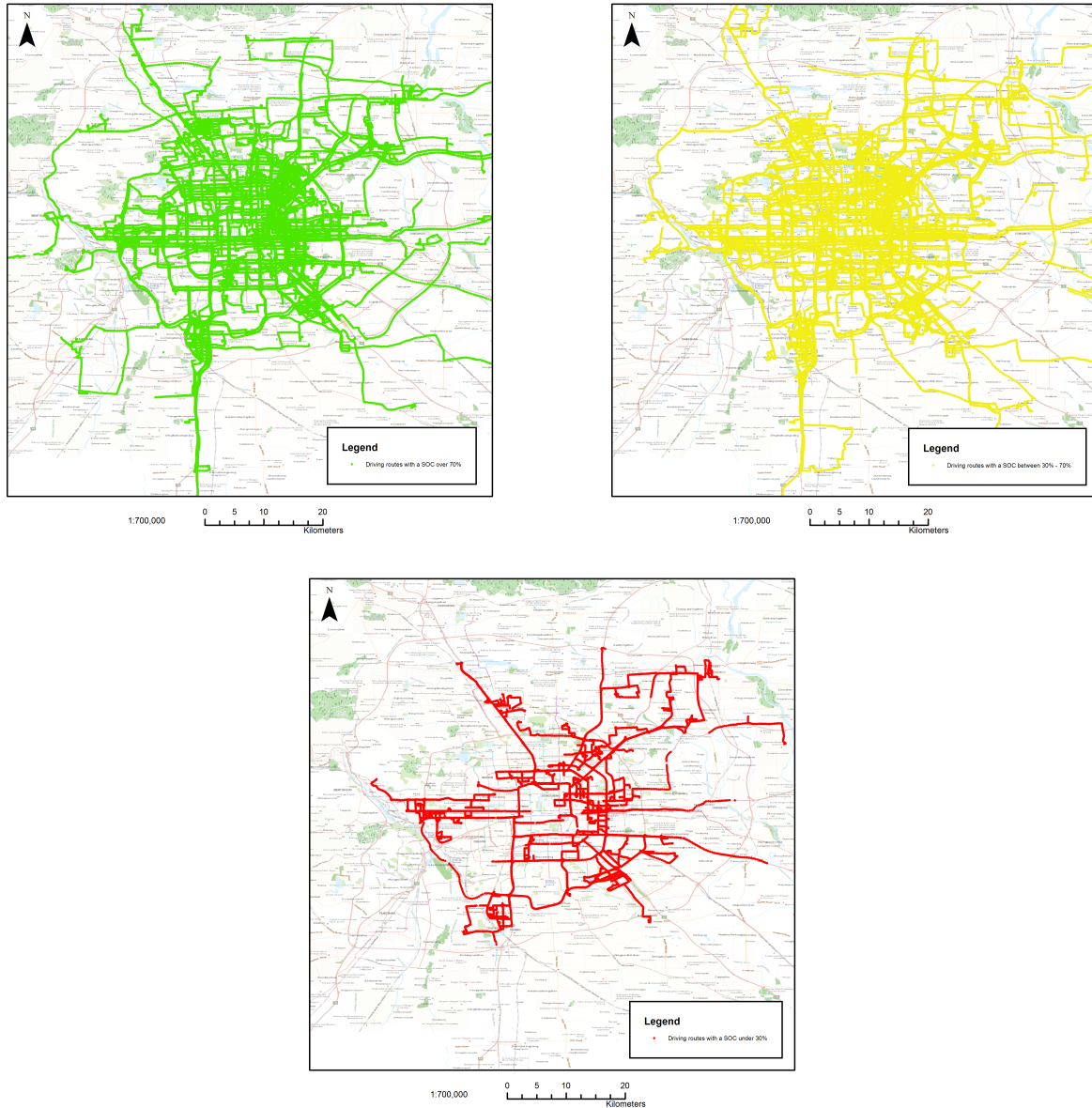
During the recording period of two weeks, 18 parking events combined with a charging event took place at a Zinoro fitted public charger.

	Median	Minimum	Maximum
Before the first trip of a day	98.6 %	94.5 %	100.0 %
After the last trip on a day	65.4 %	19.3 %	89.3 %
Beginning of a trip	70.4 %	8.4 %	100.0 %
End of a trip	48.2 %	4.3 %	98.3 %
Consumption per day	-28 %	-1 %	146 %
Consumption per trip	-11 %	-1 %	33 %

Table 4.10: The battery status (SOC) at the beginning and end of a trip as well as a day in CW 16-17; $n=60$

Map 15 illustrates the driving routes of map 10 (page 86) with different SOC values. This spatial analysis of the battery usage gives information about *where* the EVs drive with high or low battery status. With very long recoding times and a high quantity of vehicles, these maps can be used for further sources. In this example, the mileage driven with an SOC over 70 % and between 70 % and 30 % covers almost the same area and reach outside the sixth Ring-road, the distances driven with a SOC under 30 % are restricted to inside the sixth Ring-road. Thereby, areas where several EVs

are driving with low batteries are of particular importance. The areas in which the Zinoros drove with a low SOC are the same as the "core areas" detected in map 11 (see page 87). This insight suggests that drivers stay in areas near their home chargers or in areas where they know the location of charging stations and do not drive too far away.



Map 15: Driving routes of the Zinoro with a full battery (green, SOC over 70%), a SOC between 30% and 70% (yellow) and an empty battery (red, SOC under 30%)

The consumption of EVs is not the focus of the current discussion as it is for ICE vehicles, instead the e-range is discussed more. However, the efficiency of EVs is important and another influencing factor for the charging infrastructure. This is independent from the

battery capacity. Less consumption means less charging processes.³

4.6.4 Charging analysis

The charging behavior of the EV drivers provides information about quantity, frequency and duration of charging events. As the Zinoro E1 is only equipped with a 1-phase AC charging socket, the analysis for fast charging options is not investigated in this study. Rather, the understanding of the current charging patterns have priority. An important key indicator are the number of charging events per week. The assumption that EV drivers charge their car every night could not be confirmed in this study (see table 4.11).

		Median	Minimum	Maximum
Daytime	Quantity of charging processes per week	2.3	1	11
	Duration of a charging processes	2.2 h	0.1 h	15.6 h
	Δ SOC during a charging processes	41%	5%	97%
Nighttime	Quantity of charging processes per week	2	2	8
	Duration of a charging processes	3.6 h	0.1 h	17.3 h
	Δ SOC during a charging processes	53%	3%	95%

Table 4.11: Quantity and duration of Charging processes per week for daytime and nighttime in CW 19-17; $n=60$

As nighttime charging is more related to home charging and daytime charging is more related to public and semi-public charging, a distinction was made between the times of day. In view of the fact that this paper introduces a guideline, this distinction can help to identify detailed patterns in the future. However, during the recording time in this study, the quantity of 2 charging processes per week during the daytime is the same as nighttime charging. The minimum charging events per week are expectably low, whereas the maximum numbers are very high. Figure 4.5 illustrates the distribution of charging events into classes. In general, shorter events are the rule. Thereby, a higher frequency of charging events can be an indicator for a higher mileage and a more frequent usage of the vehicle. The median of the duration shows how short most of

³A conversion into kWh / 100 km is described in the following way:

$$\text{Consumption [kWh / 100 km]} = \frac{\Delta \text{ SOC [\%]} \times \text{Battery capacity [kWh]}}{\Delta \text{ millage [km]}} \times 100$$

the charging processes are. However, the maximum duration, with more than 15 hours during daytime and over 17 hours during nighttime, is quite high. These numbers result from vehicles which were connected to the charging station even after they were fully charged. This long time also shows that the cars were used less because most of the time these vehicles were not moved.

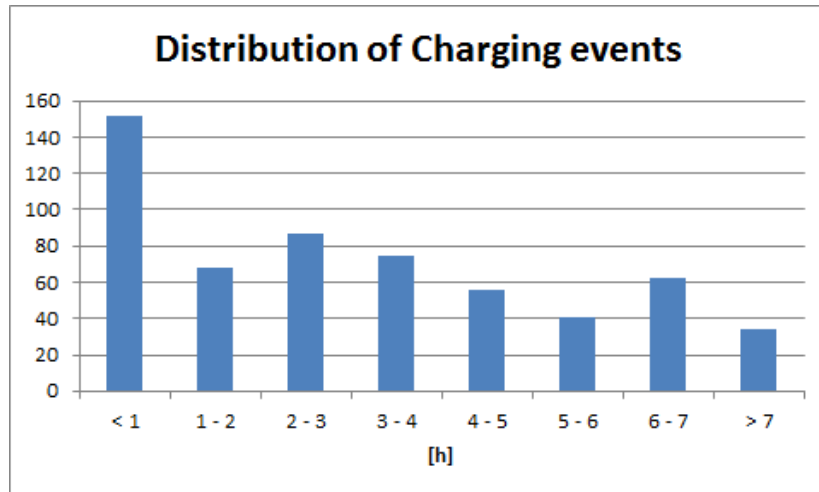


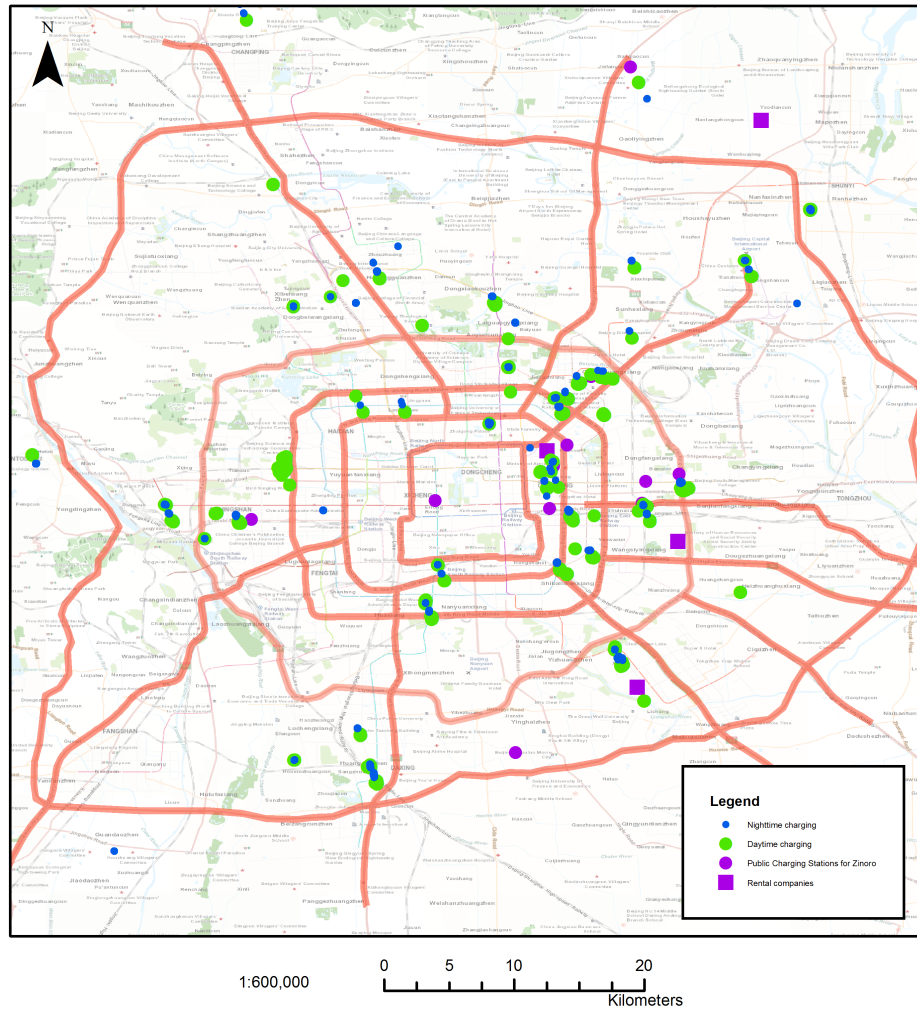
Figure 4.5: Distribution of the charging events in CW 16-17, $n=60$

The SOC lift (Δ SOC) gives information about how much energy was transferred during the charging processes. Although some of the drivers had charged the battery from almost a one-digit percentage, most of them just had to charge half of the battery. Very low SOC lifts can be an indicator for trial charging, whereas, in general, low SOC lifts are indicators for charging during short parking times. This analysis also shows that most of the drivers do not need the whole capacity of the battery because their delta SOC is around 50 %.

Map 16 visualizes the locations of the events: Both daytime and nighttime charging processes happened in the same areas. This fact is not surprising because of the general lack of public chargers and the small amount of vehicles. So, a spatial distribution is not visible. The charging processes near the rental companies were also not visible. But again, the charging process took place in the same areas which were identified above (see page 87).

4.7 Conclusion of user behavior analysis

This chapter of the user behavior analysis should be seen as a further influencing factor regarding the build up of a charging infrastructure for EVs. Because the driver's patterns influence the location of charging spots, it is important to know how and where the car is used. However, the study of the user patterns was gathered during a



Map 16: Nighttime and daytime charging locations for 60 vehicles in CW 16-17

short-term period of two weeks. The routes and frequented areas were derived from 60 vehicles, which are, again, composed of different user groups. Most of them were EVs from rental companies. The drivers of these EVs (customers of the rental companies) are different from the drivers who opted for a private long-term rental model. First of all, they do not have a lot of EV-driving experience. Compared to a higher amount of cars and users with a longer driving experience, different outcomes would be and were generated. Altogether, it can be summarized that the drivers park and charge in the same areas. However, the reason behind this couldn't be detected. A lack of EV-experience was responsible, or the recurring daily activities took the drivers to the same locations. Another indicator for the lack of experience could be the short distances and low consumption.

The spatial limitation of most of the traffic is an indicator for the general demand for the first charging stations in Beijing. Although the battery status and single route distances are excluded in this sub-analysis, frequented areas represent potential installation spots

for charging pillars. The reasons that some areas are not even passed once are diverse. Assumptions can be general ROIs without any needful POIs or areas that are not used to arrive at final destinations. A lack of current public charging infrastructure is also conceivable. However, the routes outside of the sixth Ring road clarify the possibility to reach areas in the suburbs of Beijing.

The reasons why the users do not approach the public charging stations can't be clearly answered in this study without a survey of the users. However, some assumptions could be:

- No clear labeling or road signs of the charging facilities
- No information about the nearest charging station in the EV navigation system
- The distance between the charging facility and the destination is too far.
- The charging station was blocked/occupied/had a defect

A categorization into user groups was difficult due to the small amount of vehicles. But, generally, there exist two kinds of users. The first group is the early adopters. These people deal with e-mobility and know their daily behavior and their driving patterns. Most of them use the EV privately. Some fleet managers have a long-term plan to integrate EVs into their company. In the end, this group is prepared for the EVs. The charging events occur at regular intervals, mostly in the same location(s). Rather at home and/or at the destination of their daily commute. Consequently, these people have worked out a charging plan, or know exactly where to charge if they have a low battery. The second group is the customers of the rental companies. These drivers have different reasons to rent an EV for a short time. Thereby, the short time can be one day or two weeks. This group uses the vehicle for testing, during a business trip in Beijing, or for other specific reasons. However, this second group has not prepared in advance like the first group. As the drivers charge more frequently than the first group, they cannot gain experience with e-mobility.

Finally, the radar charts on page 101 show the SOC history of six typical EVs and represents the battery status during the day. An operator of a charging network is able to use this information to generate business cases and specify the timing of demand. The chart has to be read as follows: The circle itself represents one day (24 h). However, it is not like a typical clock. Midnight is at the top, 12 PM is at the bottom. The line represents the battery status during the course of the day. The inside of the diagram is red and stands for an empty battery (under 30 % SOC). A battery with a SOC between 30 and 70 % is marked in yellow. A full battery is visualized as the green belt in the margin. All values in these radar charts are rounded and represents guide values. That's why the end of the day is connected to the beginning of the day at midnight. However, the closer the line is to the inner part of the diagram, the emptier the battery is. This type of radar chart generates various types of "figures".

A line profile of a typical EV driver looks a bit like an "egg", where the bottom of the egg is in the top right corner. This means a full battery during the night. The peak is on the opposite end of the diagram, the bottom-left. This means, the user is charging in the evening and driving, without any charging event, during the daytime. This "egg" is typical for a commuter who charges at home. A commuter who charges at work is shown in the second diagram. Here, the bottom of the egg shifts to the opposite end of the diagram. It is clearly evident that the user drives from 7 AM until 10 AM and from 6 PM to 9 PM.

The "rental EV" shows typical usage of a single trip with a subsequent charging event. On the other hand, a "family EV" has two parking events during the daytime. The term family EV was chosen because these long-term parking events can be shopping stops. A rapid decrease and increase shows an EV with high consumption. The "shuttle service" is characterized by many parking, charging and discharging events. Summarizing, most of the vehicles are charged in the evening and have a full battery during the night. Furthermore, most of the drivers stay in the yellow area but try to prevent driving under a SOC of 30 %.

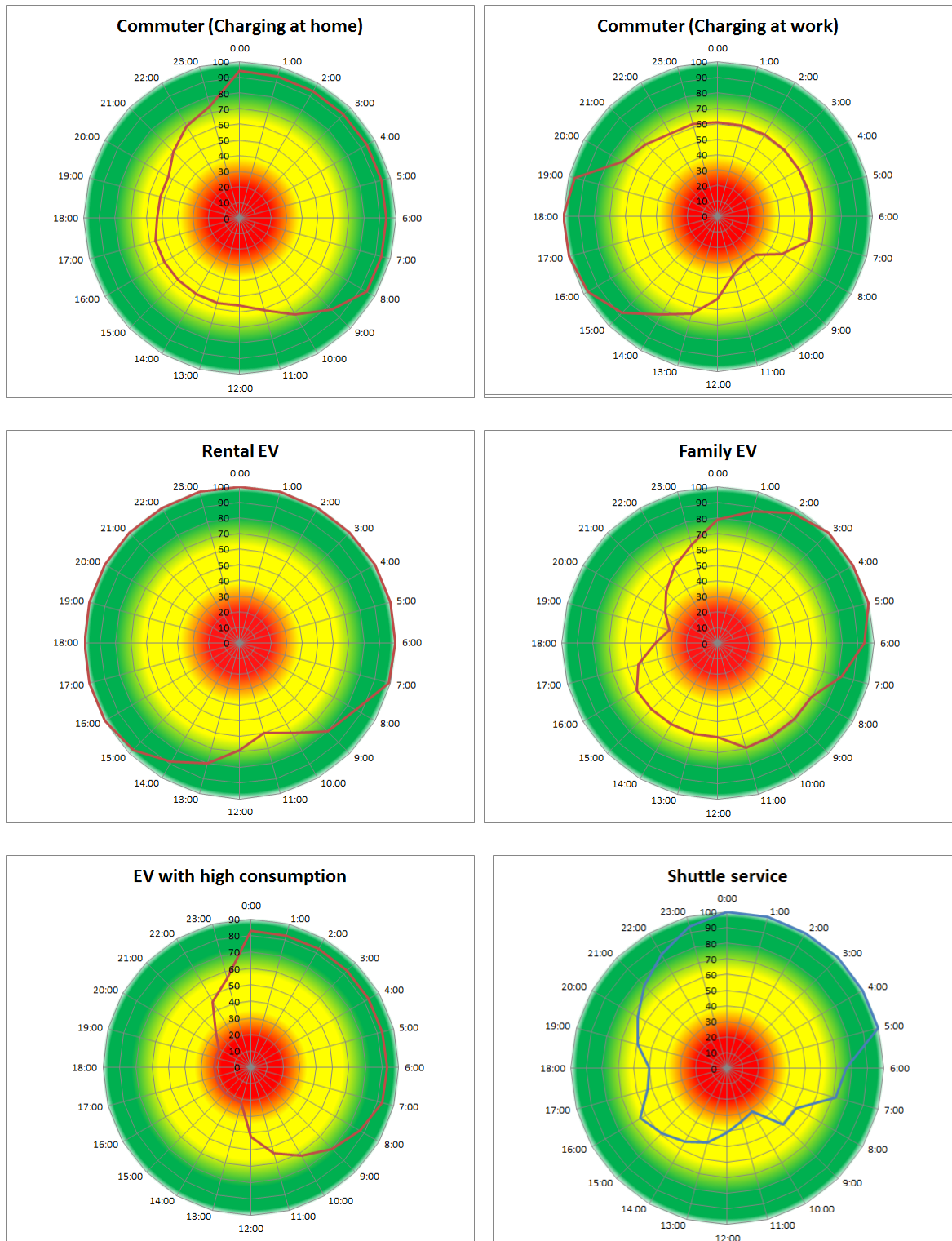


Figure 4.6: Radar charts of typical EV drivers during the recording time

5 Guideline for a Charging Infrastructure installation

This chapter deals with the question of how to build up a charging network in Chinese cities mainly based on driving, parking and charging patterns of electric vehicle users on the one hand and the analysis of the urban geography on the other. Political and technical aspects, as well as the profitability, are only marginally highlighted because this guideline is both a summary of the previous chapters and constitutes the combination of the spatial aspects of chapter 3 and the user aspects of chapter 4. The following guideline is from the *perspective of a charging station operator* (following just "*the operator*"). It is irrelevant whether the operator is state-owned, private or organized in a private public partnership (PPP).

On one hand, the success of a charging network can be achieved through a positive business case for charging facilities. Especially private investors would archive this goal to earn money. On the other hand, the coverage of a specific area with charging stations is an objective for public authorities. They could support e-mobility in general by increasing publicity as a kind of state subsidy. In both cases, an infrastructure is always open for the public and has no restrictions on users (Hisatomo Hanabusa and Ryota Horiguchi, 2011). Furthermore, it is need-based and has to follow market trends (Speidel and Bräunl, 2014). This applies to almost all kinds of infrastructures, e.g. streets, bus stations or even telephone boxes. Associated with a charging infrastructure for EVs, the need-based implementation of charging pillars is only partly correct because the decision to purchase an EV can be depending on the quantity of charging stations. Too many chargers endanger a sustainable economic success of the charging network. Consequently, the operator has to carefully place the stations based on the user needs and the urban structure to overcome the often mentioned chicken-and-egg problem. At the same time, design and structure of the charging pillars has to be open with free access to reach many customers. If the hardware and location are chosen carefully, a full-value charging net can be established.

The operator's task is to take all factors of influence into account. Beginning with the implementation of efficient hardware, the statutory provisions are affected by the laws. Here, the analysis of spatial surroundings and the user's patterns constitute the main spadework. Finally, an elaboration of a business plan is based on these findings

(cf. figure 5.1). All of these aspects can effect and greatly change the design of the charging infrastructure. In the end, all determining factors have to harmonize. Since just one factor can be the reason a user refuses a charging network, the interaction of all different aspects with is important and necessary for success.

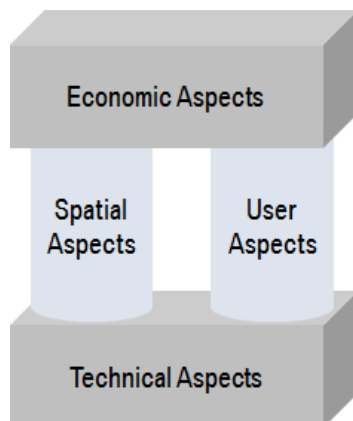


Figure 5.1: The four priorities of how to build-up a charging infrastructure. The higher they are, the more important the task is

As of 2016, the EV car market is split into two factions. While Chinese OEMs are using the GB AC standard (simple one-phase AC chargers) or the Chinese DC fast charging standard, foreign OEMs are focusing only on the AC standard. From the view of an operator, this situation is challenging. The strategic focus on one or both standards is possible, but always excludes one user group. And by integrating the DC charging standard a *parallel infrastructure* is automatically generated because the EVs with AC plugs are not able to use charging stations with DC sockets. Each of the charging stations has to be equipped with its own plugs and communication systems. In the end, that specific feature hampers the build up of a charging station network. For this purpose, the nationwide distribution of both AC and DC standards is desirable because an appropriate solution for a charging network can consist of the distribution of normal and fast charging stations. Taking Beijing as an example, the feasibility of private AC home chargers with the combination of AC semi-public chargers is encouraging. These technical specifications are a basic requirement for implementing charging facilities. Additionally, standardized booking and payment systems have to come into use. Intelligent solutions guarantee quick and easy applications, whereas unpractical solutions will be avoided by the customers.

Normally, the generation of a business plan is the last step of the guideline, but here it is anticipated even though this aspect will not be elaborated in detail. The operator's task is to ensure profitability and efficiency by integrating all use cases into one booking and payment system. The connectivity between home, public and semi-public charging stations is of the highest significance. While the focus is on private and semi-public charging facilities, smart phone apps and cashless payment transactions are essential preconditions as well. If an operator decides to focus on private charging stations, these

tools are not necessary, unless the private home chargers serve as semi-public chargers during the time the owner is not using them. However, the most important feature of a business plan has to be the simplicity of switching between private home chargers and semi-public chargers for the users. The system shall allow an easy accounting system and guarantee a system-wide interoperability.

The first pillar of the deep-rooted analysis is to understand the spatial structures (cf. figure 5.1 on page 103). The operator's goal is to present a tailor-made network by including local circumstances, such as the driver's parking conditions as well as the distribution and relation of critical POIs within the planned geographical area of operations. The following paragraph will describe this approach.

The operator of charging facilities can decide to focus on private chargers or on public and semi-public chargers or on all three kinds of charging stations (private, public and semi-public). Focusing on private charging stations would be only meeting the users' basic needs. Whereas focusing on the public and semi-public charging stations would be meeting the users' needs during a lack of e-range. But by integrating both networks with each other, the operator could offer an added value to the drivers because the user can decide where to charge. Thus, a network is not defined as the amount of all chargers from an operator. As some regions, cities or districts are focusing on different priorities, a displacement of home, semi-public or public chargers is possible. The reasons for a focus on (semi-) public chargers can be a lack of private parking lots, an unstable electricity grid in private housing areas or a higher utilization of public parking spaces during night-times. The authorities can focus on private chargers due to a lack of parking lots in public or the lack of opportunity to reserve parking spaces for NEVs. However, the operator always has to have in mind that tethered, home-based AC charging solutions, with a normal home performance of electrical power outcome, is sufficient to cover the daily recurring mobility of the users (Busk and Warrenstein, 2014). Whereas, the public chargers have to cover a huge area to reduce range anxiety and enable emergency charging. The higher the quantity of public chargers in a city, the lower their workload will be. Consequently, the entire system becomes more expensive. Therefore, a low ratio between EVs and public chargers is required. In doing so, the user's acceptance determines a further strategic orientation on the quantity of public chargers (Michael A Nicholas et al., August 1, 2011).

5.1 Alignment with the spatial surroundings

For an intelligent combination of home chargers, semi-public chargers and pure public chargers and the ratio of normal and fast chargers, the spatial surroundings have to be understood by the operator. The visible lack of public space within Beijing and the far too few parking lots within compounds yields to develop a tailor-made solution for

Beijing.

As the parking lot is never the final destination of a user, but the POIs around them, a detailed neighborhood analysis gives a first indication of where to install charging stations. As the charging pillars are physically small objects and covers just a small radius around them, it is important for the operator of a charging network to understand the structural circumstances and the spatial characteristics of the city. Based on the three different charging possibilities, private, semi-public and public, different kinds of POIs can be covered by the charging stations. Thereby, the kind of POIs is important for a high workload for the charging pillar, during day and night as well as easy access for the customers.

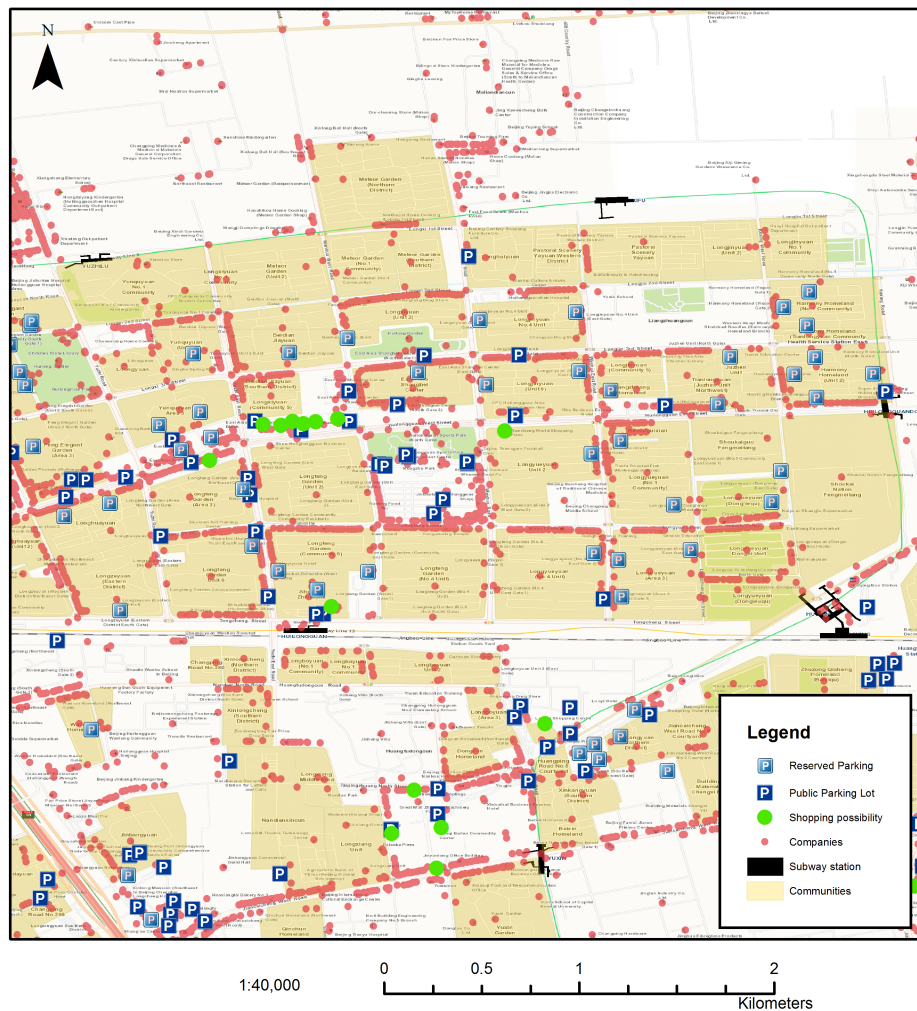
The most important POIs for charging infrastructure are the accommodations in Beijing. This point serves as the start and destination of nearly all private used EVs. As presented in chapter 3, most of the residential dwellings in Beijing are compounds. But their parking conditions represent a main challenge for the operator because of a lack of parking management and a general lack of space. It is, however, important to underline that private home charging stations create almost perfect circumstances for the EV user: The user is free to charge whenever he wants, for however long he wants and how often he wants. Generally, in this case, one user can steer the complete workload. The e-mobility user has its own energy supply station, irrelevant to whether it is at home or somewhere else, e.g. at work places. Avoiding the issues of business hours or other restrictions allows the user to optimize the charging strategy and gear it toward their own needs.

These circumstances give the user an advantage over users who are linked to infrastructures outside of their properties. At this point, it should be noted that normal EV users have their own parking lot to charge at home. It does however become problematic when, for whatever reason, several EV users need to charge at the same time where there is a lack of parking spaces. Here the question of sharing charging stations becomes another option for users. Commuters and occasional drivers who only use the car once a week to go shopping can share charging facilities as long as enough stations are available for all dwellers of e.g. compounds.

In this case of home charging, the following neighborhood analyses give an answer on where to charge instead. Generally, all (residential) areas in Beijing can be classified into two kind of regions: a *mono-centric region* or a *poly-centric region*. Both are characterized by different properties, different types of POIs and public infrastructure and cover all kinds of living conditions on one hand and all kinds of private and public parking conditions on the other. Consequently, these zones cover all use cases of the charging infrastructure. This includes the different installation cases, the different types of chargers and customer needs.

5.1.1 Charging locations in mono centric regions

Mono-centric regions can be composed of accommodations, commercial areas, industrial complexes or green spaces. The decisive factor is a lower mix of POIs inside these regions. This engenders a focus on space utilization. Services, goods and other needs have to be supplied into this region or the people have to leave the region to get them. In relation to the charging infrastructure for EVs, mono-centric regions can generate different types of charging events. In a residential neighborhood, for example in Huilongguanzhen (see map 17), most dwellers are probably leaving the area because there are few office buildings or factories. This assumption is also based on the high frequency of long distances out of this subdistrict (see map "Tracks from and to Huangcunzhen" on page 90).



Map 17: Huilongguanzhen, a mono-centric area in the north of Beijing

The area of Huilongguanzhen is surrounded by subway line 8 in the north and east, line 13 in the south and the Changping line in the west. Moreover, the Jingzang Expressway (G6) is running in the west of the sub-district. The access to the area is open for public,

however, the access to some properties is restricted by guards and boom gates.

The structure of Huilongguanzen is characterized by compounds and smaller side roads. The companies in this area provide goods and services to meet daily needs and are located in the basements of the buildings or in the lower floors (see figure 5.2). However, most of them do not have their own parking lots for customers because they are located inside a compound.

These kind of regions feature pertinent travel patterns. During rush-hours, most dwellers are leaving the area in the morning while most are coming back in the evening. The quantity of vehicles is much lower during daytime than during nighttime. This has consequences on charging infrastructure as well. Providing that the amount of EVs is high and that the owners of the EVs have equipped their parking lots with home charging stations, these parking spaces and charging facilities are empty during the day.

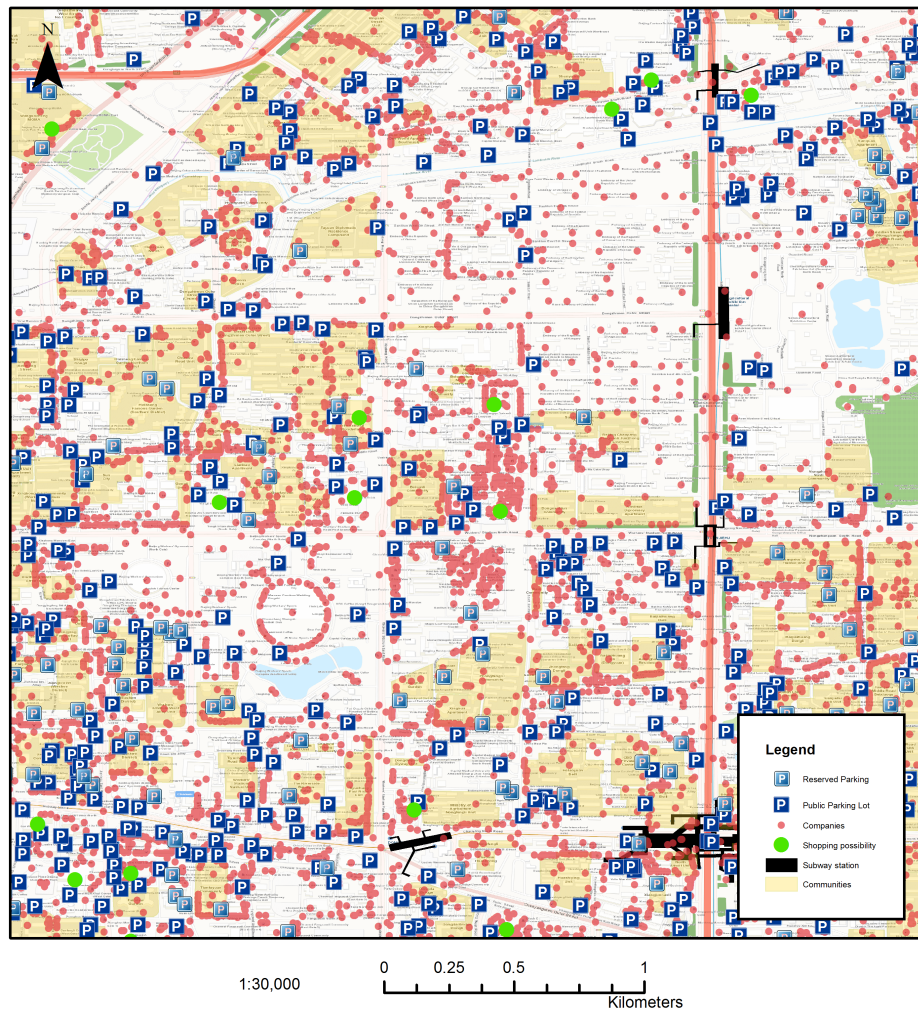


Figure 5.2: The access to a typical Compound in Beijing: A guard is verifying the license plates and registering visitors (left photo); a post office with commercial vehicle and electric three wheeler (right photo)

With reference to a charging infrastructure, mono-centric regions, whether residential or working regions, require their own charging structure. A high pendular movement at certain times ensures that parking lots and the attached charging stations have periods of peak activity. This uneven workload is insufficient for the operator because the usage of charging stations has to be as high as possible. Because mono-centric areas have a limited variety of POIs, attractive offers for other EV users are missing. Most of the charging stations would be used by dwellers or workers in these regions. The lack of transit traffic makes a regular workload during the whole day and night time difficult. A higher workload can be generated by involving POIs and properties around the mono-centric area. As the map shows, the surrounding area is less developed with compounds but has different kinds of properties. These locations can become potential charging spots if the parking conditions are better than in the compound (see paragraph 5.1.3 on page 109). These POIs serve as an alternative if too few parking lots are within the compound or visitors of these POIs can use the compound's chargers reversely.

5.1.2 Charging facilities in poly-centric regions

The second kind of regions are poly-centric areas. As an example, the Sanlitun sub-district was chosen to reveal the difference from the mono-centric area. Map 18 shows the mixed area of Sanlitun. This subdistrict features many different building types, grounds and POIs. The map highlights the reserved parking and public parking lots, companies, shopping possibilities, the subway stations for line 10 in the west and line 6 in the south, as well as the communities/compounds. First of all, the density and distribution of the accommodation areas is not that high and narrow as in the mono-centric areas. This is the main difference and characterizes Sanlitun. However, conspicuous is the high quantity of parking lots. Most of them are smaller ones and belong to a compound, a shopping mall or are public building. The smaller parking lots are a result of the generally smaller properties, compared to the compounds and shopping malls in the suburbs.



Map 18: Sanlitun, a poly-centric area in the north-east of Beijing

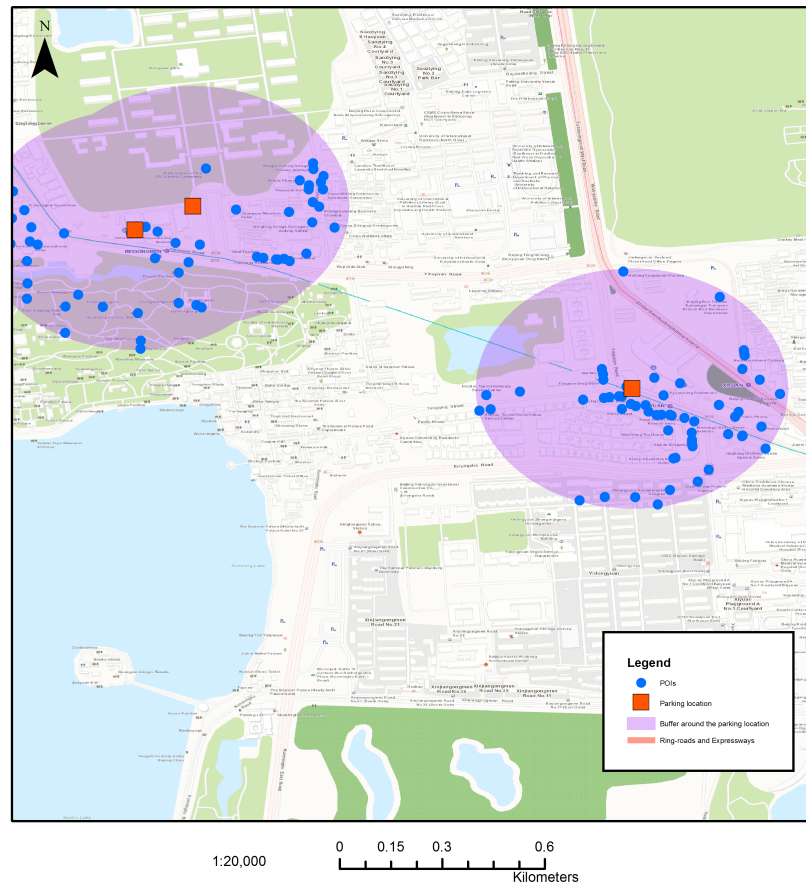
Concerning a charging infrastructure, the inefficient doubling of parking facilities yields

to more potential options for chargers. The huge amount of vehicles are distributed to more, smaller parking lots instead of a few big ones. The distribution of public and semi-public chargers has to be adjusted as well. Based on the fact that a fixed percentage of parking lots must be equipped with charging facilities in the future, many charging locations are distributed throughout this area. This is different when compared to the mono-centric area where a few big parking lots cover the entire compound. As the parking lots are smaller, just a small absolute quantity of chargers could be installed at each one. Consequently, these EV charging stations can't satisfy the demand and EV drivers have to fall back on other parking spaces. One option for these areas would be the installation of some parking lots with a higher amount of chargers to pool the e-mobility into a few parking facilities.

5.1.3 POIs near Parking locations

An operator of charging stations relies on the distribution and quantity of parking lots. Hereby, the POIs next to parking facilities are of peculiar interest. In this study, the parking behaviors of the drivers are based on the parking analysis on page 91 and are associated with the urban geography of Beijing. The following analysis is based on selected parking lots but, generally, the operator is able to use any selection of parking facilities. This procedure of the investigation is highly dependent on map quality and the currency of the vector data because the outcome of this sub-study gives information about the most approached POIs. The basis of this work are the parking locations of the 60 vehicles during CW 16 and 17. The parking locations themselves are defined as parking events with a duration of stay of minimum 30 minutes. These long-time parking events are visualized as an orange square in map 19. A buffer of 500 meters was layered around this point to mark the surrounding neighborhood. The SGEVCP has found out that the distance between the final destination and a charging station should not be more than 5 minutes walking distance (SGEVCP, 2015). By taking a walking speed of 5-6 km/h as a basis, this duration corresponds to a distance of about 500 meters.

After selecting all matching POIs of all buffers in the map, a categorization was done by the POI list from Esri China (see appendix on page 156) (Esri, 2014) which lists all POIs in one of 20 categories (see figure 5.3 on page 111). Firstly, the POIs around the parking events were evaluated by using this general list from the map supplier. Generally, three kinds of POIs groups emerged. (1) High frequented locations where over 10% of the parking events happened. Food and beverage POIs, shopping facilities, daily service companies and business points are included in this group. (2) Occasionally frequented POIs like commercial/housing, transportation, science and finance POIs where about 4-10% of the parking events took place. (3) Less frequented POIs like tourist spots, sport leisure services, health care services and automobile services represented under



Map 19: Sample for the POIs around parking events

4%. These groups reflect the parking behavior of all vehicles during the two weeks recorded. An installation of charging facilities near properties of the most frequented POIs is obvious. It stands out that these POIs have mostly private parking lots for their customers/visitors. This isn't the case for transportation POIs (subway and bus stations).

Table 5.1 on page 112 captures the categorization from subsection 3.2.1 (POIs related to the charging infrastructure) on page 46 and associates the POIs with the absolute quantity of parking events. The results are more detailed and are only focused on charging relevant POIs¹. Some of them are sub-categories of the main groups on page 111, others are directly assumed. Although all kind of POIs were studied, the two main groups are the POIs for public and semi-public charging stations. What stands out in this study are the health care services, restaurants, education spots, government institutions and companies. However, although these POIs are providing parking lots, not all of them are fit for the charging of a Zinoro. This is based on the fact that the

¹The POIs in this table were selected by expert discussions.

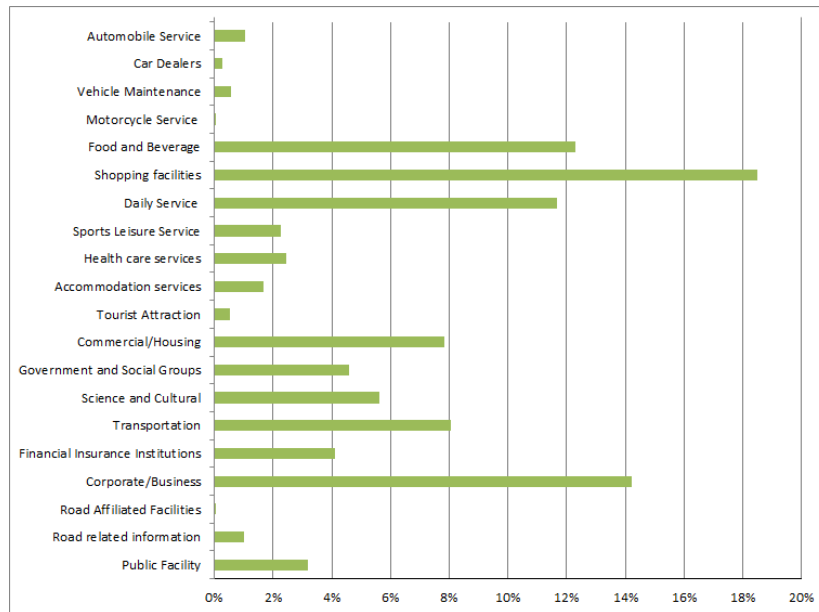


Figure 5.3: POIs around a 500 meter buffer of the parking locations categorized in 20 main groups

Zinoro can only be charged with alternating current which makes the charging process longer. The parking duration is crucial for this issue (cf. page 94).

Particular attention should be placed on the long-distance routes. Areas like Gaolingzhen in the northeast of the province are up to 100 km away from downtown Beijing. The distance between towns in the north of the municipally and the center can be covered by an EV when just one way, e.g. an outbound trip, is driven. Consequently, a charging event is needed at the destination point to cover the way back. Whereas inhabitants of towns closer to the city can manage their round trips without an additional charging event. The commuting flow changes when inhabitants go away for the weekend. As the west of the province becomes a recreation area in the broadest sense, the usage and time of use of the (public) charging stations can be lower than in the east. This leads the operator to the question whether to focus on *intercity* or on *intra-city* travel. The latter means a charging network inside one city with an eventual constraint of limited access for only residents of this city. Thereby, the limitation is linked to the different access or payment systems rather than with technical requirements for non-residents. An intercity network was built by the American OEM Tesla. Because this infrastructure is tailor-made just for one EV with a huge battery capacity, relatively fewer charging facilities would suffice to cover entire cities or even provinces. An intercity network with normal AC chargers would need significantly more facilities. In the case of Beijing, a quantitative statement on this fact can't be done because the EVs in the study didn't travel this far.

	Detailed POI category	Absolute quantity of parking events
POIs for public charging (short time parking)	Recreation spots	122
	Museums	23
	Tourism spots	182
	Sport courts	452
	Cinemas/Theaters	80
	Parking spaces	4412
	Gas stations	55
	Subway stations	269
	Health care services	1426
POIs for semi-public charging (daytime parking)	Convention centers	26
	Hotels	784
	Shopping centers	233
	Supermarkets	394
	Restaurants	7182
	Education	1093
	Embassies	73
	Research institutions	516
	Government institutions	1374
POIs for private charging (long time parking)	Compounds	3258
	Office buildings	1119
	Industrial parks	22
	Villas	18
	Companies	8003

Table 5.1: Approached POIs around a 500 meters buffer of the parking events: The parking events are cumulative of 60 EVs during two weeks. For example, 1426 parking events were done in total of all EVs within 500m around health care services POIs.

5.2 Alignment with the needs of the user

The following analysis constitutes the user behavior and represents the second pillar of the guideline (see figure 5.1 on page 103).

Drivers of EVs are able to purchase the kind of EVs that best fits their daily routine. Additionally, a (home) charging station is perfectly matched to the EV and the size of its battery. As it is evident that users routinely repeat their travel behaviors during a normal week, these actions recur at different locations at a certain time. As these actions are different for all users but regulate the lifestyle of most users, the charging strategies have to be tailor-made. Insofar, EV users will not fundamentally change their behavior during their normal work life, as most of the ICE drivers wouldn't either. Potential users of EVs know their daily mileage, the e-range of their future EV as

well as their behavior before the purchase of the vehicle. Even if one full battery just covers one way of the route, the driver knows or will find a location near or at their final destination to recharge the battery. Again, always provided that the EV user has a charging station at their night parking location. All these considerations were made before the purchase. Consequently, the user can handle most trips and routes for everyday life.

For now the demand and supply for a public charging and a semi-public charging infrastructure has to adjust. The majority of drivers in this study have parked the car with a high SOC and were able to complete their trips without public charging infrastructure (this is also based on the fact that there is a lack of public chargers). However, a considerable portion of drivers remain convinced that public charging sites are essential because if they deviate from their travel routine, and drive out of range from their home and/or destination charger, additional charging facilities have to be added to the routes (Azadfar et al., 2015). So, in addition to the *home charging* and/or *destination charging*, another option has to be implemented for these cases: *on-the-go charging*. This can be coherent to semi-public charging, public charging or even private charging in some cases. These charging spots are not made to be base chargers for one person, but as sharing facilities and thus become a public good. Besides offering energy to all EV users who are unable to reach their final destination without on-the-go chargers, public charging stations can still potential user's fears regarding *range anxiety*. This aspect must be kept in mind and must not be underestimated because it can be an indirect promotion of e-mobility. Even if the EV drivers never use the public chargers, a feeling of security is generated and can incite users to drive more often or for longer distances.

5.2.1 Satisfying the need for energy

A charging infrastructure for electric vehicles is mainly based on the urban geography of cities in a country. The location of a city or agglomeration within the region, its structure and its size are fundamentally important for the quantity and density of (semi-) public chargers. Depending on the location of the city within the region, commuters are traveling from the surrounding cities/villages into the city. As mentioned above, most commuters can handle the trip to their final destination with a single charging process if they live close to their destination, but others need another charging process at their destination point to reach home again. So, the amount of long-distance commuters is one indicator for the quantity of public chargers. Another influencing factor is the quantity of rental and car sharing companies with EVs. Users of these services are less experienced with EVs and are not familiar with the charging infrastructure either. Depending on the fleet size and quantity of vehicles that are reserved for daily rental models, the public charging network has to be adjusted to meet charging demands.

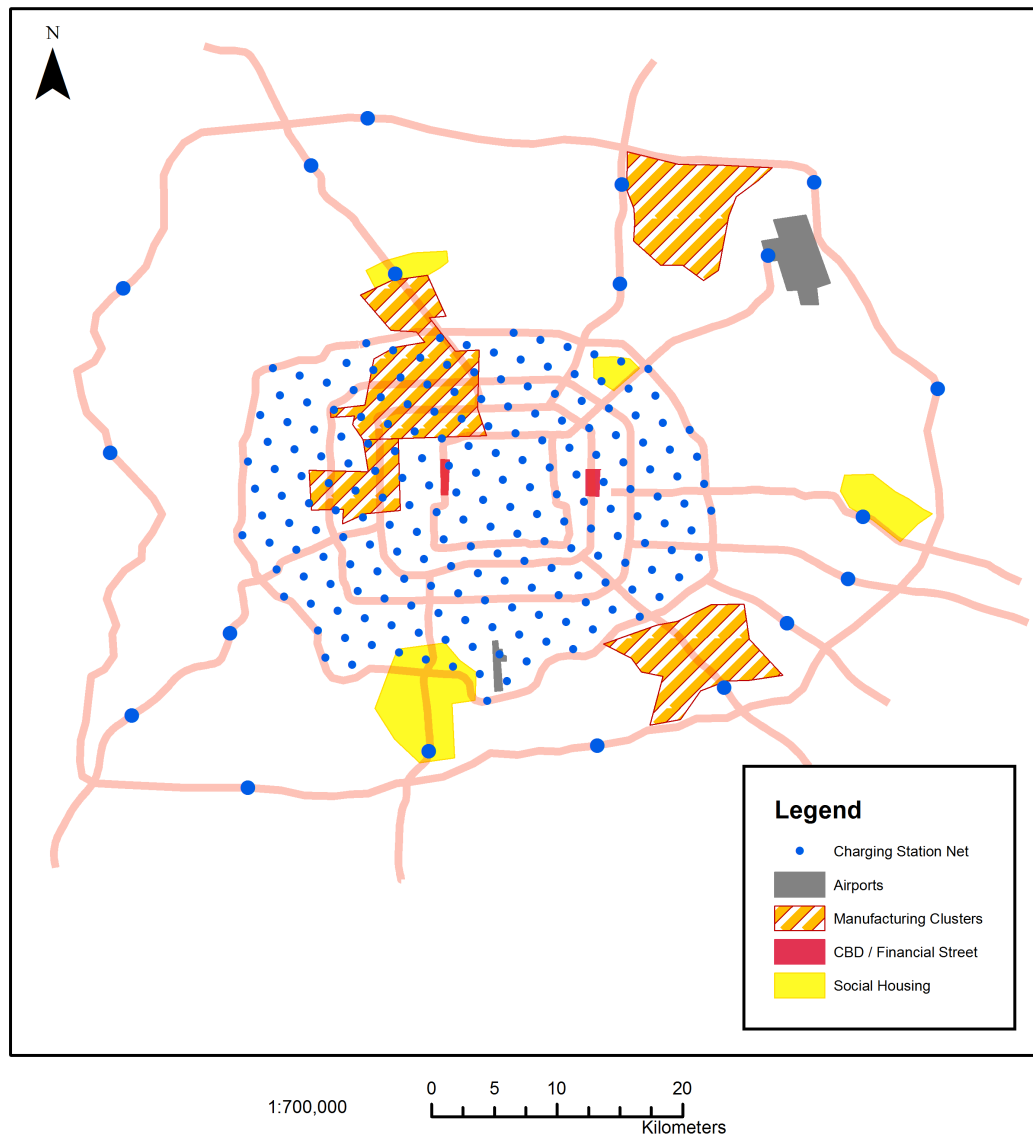
According to expectations, this demand is higher because the drivers have no charging plan or strategy for their trips and routes. Also, the amount of EVs used as shuttle cars are of interest, e.g. if hotels offer their customers EVs for airport service or for trips to tourists spots. Thereby, this strategy becomes profitable for the operator: the installation of semi-public chargers ensure the mobility around the hotel and the facilities for destination charging at tourists spots or main transportation hubs ensure the way back.

Besides the fact that public charging stations have the task to calm the range anxiety of drivers and promote e-mobility in general by being installed at prominent locations, public chargers have to supply energy to drivers who really need it. The reasons for this can be diverse: drivers forgot to charge, are visitors in the city and do not know charging locations or do not know the e-range of the EV. In these cases, public chargers have to meet the basic need of public energy supply. They can be seen as an emergency or back-up plan for people with a low SOC. Consequently, the workload of these stations will not be as high as that of stations at home or at office buildings.

Map 20 visualizes a model for a public charging infrastructure in Beijing. It consists of two different layers. The inner part of the city is equipped with a close-meshed net of chargers. These chargers cover the basic needs of public facilities and are spread in equal relation to each other. By contrast, the suburbs are connected to the public charging net with charging stations at the Ring roads and expressways. Thereby, the density and amount is changeable. This model only illustrates approximate values. Clusters or heavy-traffic areas outside the inner city can assemble a higher density of chargers as well to absorb the demand in these areas. Again, this concept assumes that all EV users have access to a private (night) charger.

5.2.2 Satisfying the indirect demand for charging

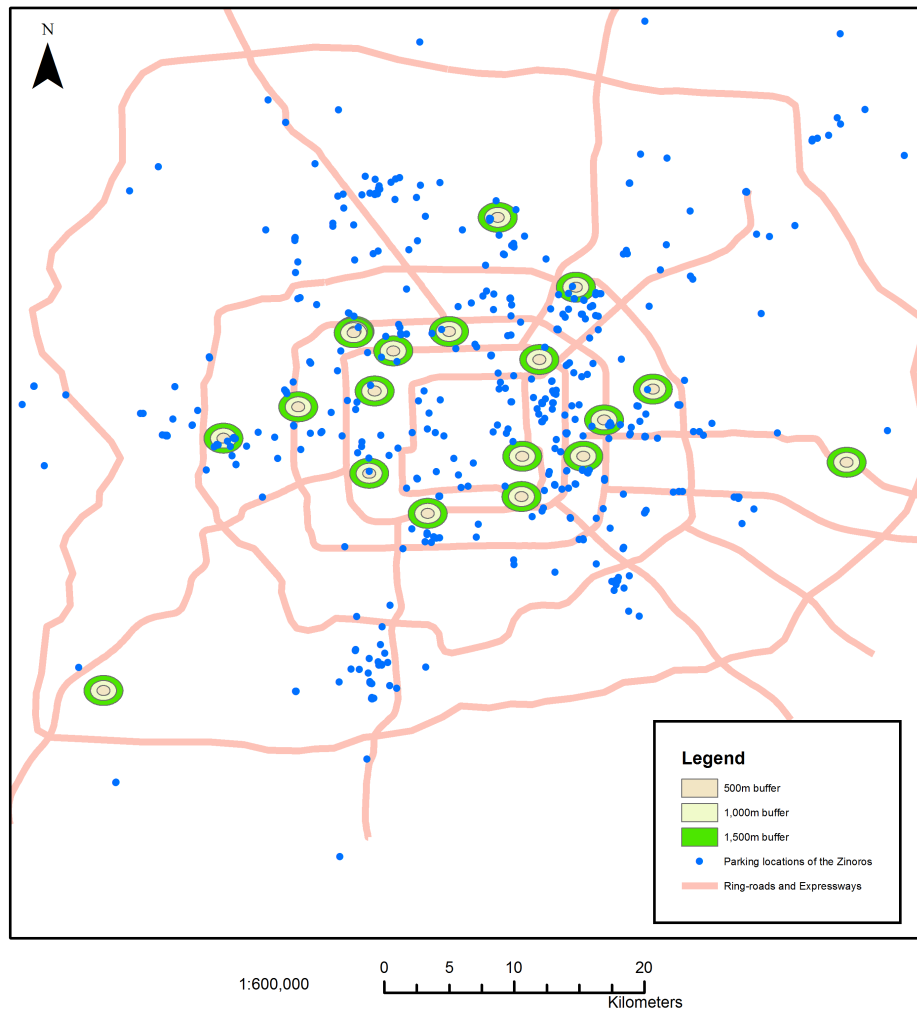
The demand of charging stations is not always connected to the location where the vehicle has a low SOC. Qualified POIs with a charging station can be approached because of the need of the POIs and not because of the charging station. The charging event itself has a lower priority but will be part of the journey because electricity for the EV can be offered next to other needs of the user. For example, fitness studios, hotels or supermarket chains fulfill the above mentioned requirements. Furthermore, they are distributed all over the city. But on the other hand not all EV drivers have a need for these kinds of POIs. Therefore, these POIs can be close to POIs users really have a need for. The goal of an operator should be to combine these needs (the direct need to visit a POI and the indirect need to charge the EV). For example, the French retailer Carrefour has 18 supermarkets in Beijing. Map 21 illustrates their locations. During the recording time of two weeks just two Zinoros parked directly at the supermarket, but five Zinoros parked within 500 meters of the supermarkets; 41 parking events were



Map 20: Concept of a charging infrastructure build up in Beijing

within 1,000 meters and 59 parking events were inside a 1,500 meters buffer around the Carrefour market. As mentioned before, the preferred walking distance is about 500 meters from the parking lot/charging station to the final destination. So, these drivers could be customers of Carrefour. However, the direct *catchment area* for charging events has a bigger potential. The operator has to "collect" the drivers and lead them to approach the supermarket instead of the surrounding area.

To reach this goal, the drivers must not have a real need for charging. A free and secured parking lot could be the main reason to drive to Carrefour and the optional charging event is not the ulterior motive of the driver. The operator's company and the supermarket could create an incorporation and generate a win-win situation. However, the drivers of the EVs need to know about the possibility of charging at the supermarkets.



Map 21: Carrefour supermarkets with attended buffer of 500m, 1000m and 1500m

This can be done by integrating the charging locations into the navigation system, by road signs within a radius of 1 km or by mobile phone apps. The advertisement for these charging facilities does not need a direct link to the supermarket. If the chargers are installed next to their entrance, customers will have another benefit. This methodology can also be adopted to compounds. But in this case, the PMO has to allow access to the property. In both cases, the opening hours of the gate have to guarantee permanent access to the chargers as well.

This approach is also reflected by the user's behavior which is analyzed in this paper and, of course, instead of Carrefour, other POIs can be used. Because the median of the weekly amount of charging processes with 2 events is relatively low (cf. table 4.11 on page 96), *on-the-go chargers* have a high potential. Especially in frequently driven areas where drivers have an empty battery (cf. maps on page 95), the combination between a spatial and user analysis can help generate new charging points.

5.3 Expansion of a charging network

A charging network operator has plenty of opportunities to build up an infrastructure in Beijing. First of all, home chargers with AC standards can be the basis for EV users in the whole city. It can be assumed that almost all EV drivers will use these stations during night time and their destinations can be reached. The user behavior's analysis Users who are living "one battery capacity" away from their destination can be supported with *destination chargers* at their work places. During the time these users charge at work, their home charger can become a semi-public charging station. While the users charge at home during the night, the charger at the work place can become a semi-public charging station. In this model, the user always has first priority to charge. However, by sharing stations, a higher workload is generated. Furthermore, the operator does not need to place more charging facilities as necessary. Along with these charging points, *on-the-go chargers* can complete the network in densely populated areas. Parking lots of supermarkets, malls or POIs for daily life could achieve significant additional revenues for the operator as long as the operator is able to re-route the EV traffic towards the *on-the-go chargers*. Furthermore, these *on-the-go chargers* can be used for the surrounding dwellers during the night. As a result of high investment costs, fast public *on-the-go chargers* make most sense at highways. In this model the operator has to space out all kind of chargers evenly in the operating area to guarantee short distances between the charging point and the destination POI of the user.

The whole network can be focused on the most important districts or ROIs to meet the customers' needs. The main belts and axes in Beijing and respectively the biggest accommodation, shopping and office areas should be covered by the network first to supply energy to the most relevant customer groups. The analysis of the customer data in this paper show that most night parking locations don't change and only three charging events per week can cover the customers' needs. Furthermore, three parking stops per day per EV driver can be seen as constants for the operator. Combined with the locations of these user's actions, an overall build up plan can be created. However, most of the difficulties of the actual pillar installations are on-site: uninterested PMOs at compounds and semi-public grounds have to be convinced one by one and tailor-made contracts as well as installation cases for compounds which do not fulfill the criteria have to be worked out (cf. Compound criteria on page 56).

6 Conclusions, critical appraisal and outlook

Conclusions

The goal of the work in hand was to analyze the political, economical and technical aspects with the combination of a spatial analysis and user patterns. Based on one EV model and its drivers patterns in Beijing, a first guideline for charging station operators was created. An important insight becomes apparent here: The complexity of a charging network is based on the principle of a perfect interplay between all influencing factors. Optimal political frameworks, sophisticated technology, an intelligent distribution of charging locations and a respective business concept have to cover all user patterns. If even one of these pillars is inconsistent, the charging infrastructure fails. Because of the extensive subjects, this dissertation contributed empirical findings in the fields of spatial aspects and user patterns; and marking the remaining influencing factors. While some of the influence factors are given and fixed, e.g. the general user behavior or the urban geography of Chinese cities, others succumb to modifications in the form of subsidies for charging facilities, a quantitative increase of NEVs or non-monetary incentives for drivers of NEVs could change the entire system fundamentally.

A charging infrastructure in Beijing is subjected to some restrictions. First of all, the urban structure of the city predetermines limitations in terms of public space. Unlike in western countries, space is rare on sidewalks, side roads and parking lots. With this in mind, the placement of charging pillars needs to adapt to local conditions. As most of Beijing's residents are living in compounds, the private parking situation isn't better. Too few parking spaces for more and more vehicles make an implementation difficult. Therefore, existing space has to be used efficiently for all users. The concept of sharing not only parking lots but also charging stations has to be in public as well on private ground. Of course, the common pattern of home charging is still in use in Beijing. But this only applies at night. This means every EV user has its own home charging station for satisfying its basic needs. During the night time, the battery can be fully charged to guarantee the maximum e-range during the day because the user has chosen an EV with the battery which fits their personal needs best. This means the EV's e-range covers its daily recurring travel behavior. This *home-charging* can be seen as the basic infrastructure model for Beijing. Because the parking time is sufficient, a normal AC

charging station can handle this work. Furthermore, the user gets the perfect station which connects the battery from the OEM together with the EV. Third party charging stations may also be used; however, this doesn't mean the ownership is always owned by the user itself.

The above mentioned model will be enlarged when one way of the user's route already consumes one battery capacity. For this case, *destination-charging* is an option. As the suburbs of Beijing are up to 100 km far away from the inner city and the city's diameter is more than 80 kilometers, this model may be applied more often. If the EV is used privately, a charging station at work can offset the lack of energy, while a company EV can use a home-charger as a destination-charger. This extension will be taken on by commuters to guarantee return. It has to be taken into account that charging event takes place during night time and during daytime. These two private charging stations can help to cover most of the use cases in Beijing. The study shows that most Zinoro drivers did not park with an empty battery. There are multiple reasons for this but it shows that home chargers can meet the basic needs of users.

A second extension of the model will come up if there are EVs on a route with a state of charge which is too low to reach their destination. This happens to users of rental EVs or drivers with less EV experience as well as drivers who could not charge their EV before the trip. These groups of people need a charging infrastructure to satisfy their need of energy. Here, for the first time, semi-public or public *on-the-go-chargers* are relevant for users. The implementation of this common term is a challenge for the operators of charging stations in Beijing. As mentioned above, public space is a precious resource. The placement of pillars in the inner city is not possible because it has been occupied by other goods or has no parking management. The difficulty is to interrupt the user's route as little as possible but charge as fast as possible because the Zinoro can only be charged with a normal voltage and not with higher voltage. As charging in Beijing with normal voltage makes the charging event quite long, the idle time for the driver is long as well. This problem is solved in this thesis by integrating relevant POIs next to charging events. The generation of an added value for the user is necessary to bridge the time until the charging process is over. In contrast, in the periphery, this model is difficult because the user has no associated POIs. However, the placement of *on-the-go-chargers* next to POIs with parking lots enables a new business case for the operator and an enjoyable idle time for the user. Thereby, a direct need for energy does not have to be the only reason for parking and charging at semi-public on-the-go-chargers. By adding intelligent marketing and advertisement, users accept detours to combine necessary daily actions with the need for charging. Beijing's densely populated area offers perfect conditions. Additionally, the already installed home-chargers and destination-chargers can be used as on-the-go-chargers as well, as long as access is possible without any restrictions. Most compounds offer enough parking space during the daytime and are able to absorb EVs with empty batteries.

Critical appraisal

This paper is only based on the screening of EVs; ICE vehicles and PHEVs were not part of the study. The reasons for this approach was a lack of access to qualified data of vehicles with other drive concepts. However, the present data of the Zinoros has a strong validity and provides enough data for a high-quality result. This is mainly based on the fact that during daily recurring actions under 150 km, the driving behaviors of ICE vehicle drivers and EV drivers are the same. Regarding the lesser EV experience which induces drivers to travel and charge more carefully at the beginning, only after 150 km is the EV driver dependent on a charging facility. A second reason why ICE vehicles were not part of the study is because ICE vehicles do not need a charging infrastructure. Their range is high enough to travel long distances and a refueling process several times a week is not necessary, whereas EVs need a recharge of energy more often because their e-range is significantly smaller. A driver of an ICE vehicle does not have to refuel the car every night or every second day even though the car has traveled the same distance as an EV. Consequently, the drivers of EVs *inevitably have* different behavior compared to ICE drivers because of the limited e-range (after a distance of 150 km). As potential customers of EVs know these circumstances before purchase, they readjust their behavior to the smaller e-range (more likely to happen) and choose a nearer supermarket in their neighborhood, under certain conditions with a charging facility, or the users retain their old driving behavior, which they had with an ICE vehicle. Then, especially the latter, need a charging infrastructure to guarantee the preservation of their familiar behavior patterns. In summary, it can be said, therefore, that a charging net is only dependent on the driving patterns of ICE drivers if these patterns exceed a distance that is higher than that of EVs. However, the methodology of just studying EVs had some limitations. Although this dissertation attempted to cover most aspects, a few frame conditions had to be made.

1. The data collection only took place in the municipal area of Beijing. The outcomes of the analysis are tailor-made to this city and difficult to apply to other regions. Furthermore, commuter flows to and from the nearby city of Tianjin couldn't be studied because of missing users and maps. These long distance trips could change the charging behavior completely.
2. Only conductive AC charging was part of the investigation. Although DC charging was established in Beijing during the study, the users were not able to use it because the Zinoro did not support this technology. If so, more public charging stations could be approached by the drivers and could enable charging behavior like that observed in Europe or the U.S.
3. Most of the EVs studied belonged to rental companies and were driven by customers with a short-term contract. By contrast, long-time drivers acquire more experience and use the EV in different ways than drivers with less experience. The amount

of charging events per week, the SOC lift, the minimum SOC and the location and usage of public chargers are key figures.

4. During the study no consistent business model and payment system were rolled out in Beijing. Some charging stations offer electricity for free, whereas the driver has to pay for electricity at other charging facilities with different payment options. An extensively harmonized environment simplifies the handling and usability for the user and could change their entire patterns.
5. The data was collected from one electric vehicle model. A comparison between EVs with various battery sizes could cover all use cases and enable a comprehensive view on the charging system. Adding PHEVs with very small batteries and EVs with battery sizes over 80 kWh could show their real need for public charging. The e-range of these vehicles could change the workload of the chargers. Furthermore, a mix of EVs can generate better statistical averages and medians for the parking and charging duration. These results would give better information for the implementation of a network open for different kinds of EVs. Whereas the current EV model, the Zinoro E1, gives only information about the usage for a customized charging infrastructure.
6. The outcome of the spatial analysis was highly based on the quality of the maps. Especially in Chinese cities, the urban form is changing rapidly. New parking lots, shopping malls or compounds are constructed all the time. This changes the user patterns as well. Spatial social demographic data, like population density, or meta data of the parking lots like absolute parking spaces per lot could generate more detailed results regarding the need of charging stations.
7. The short recording period of two weeks could not cover all use cases. Seasons like winter or public holidays have a large influence on the battery and user patterns. A long-term investigation could also compare charging behaviors during different temperatures. The heating and cooling system have a big impact on the e-range of the car.

Outlook

E-mobility in China will be growing on more than a temporary basis. Environmental concerns, as well as sustainability, force the government and society to change their thinking about individual mobility. China wants to make up leeway in car manufacturing by investing resources in EVs and their periphery. This relentless process changes the way people, especially in mega cities like Beijing, change the way they travel. To reach this goal, many *fine details* have to be aligned. First of all, technical standards are an important topic. Extensively harmonized standards like the CCS (Combined charging standard) will remove the current mix of plugs and communication signals in the future. Although this engenders high costs for the conversion of the charging facilities and

EVs, simplicity helps all participants. The political focus on e-mobility will also yield privileges for NEV users. Be it monetary by less taxes or physical by special e-lanes on roads or reserved parking spaces. Ultimately, these new surroundings should not prompt people to adapt their driving patterns. The charging facilities have to follow the user, not the other way round. Beijing's urban characteristics differ from the European cityscape and the city planners, as well as operators of charging facilities, should use this given condition. A waste of (parking) space in mega cities is not only desirable but absolutely essential. By installing an intelligent parking management now, cities lay the foundation of future development.

One future in relation to the charging infrastructure can look like this: Whereas the short-term goal of a charging network is the intelligent distribution of charging stations within cities, suburbs and intercity areas, the e-range of batteries will be higher in every EV generation. This development is the first challenge in the technology aspect and can lead to less charging events overall. This fact must always be kept in mind. Simultaneously, the highly autonomous driving for EVs will be introduced by the OEMs. This step will change the whole mobility of residents. The need for finding a parking lot, finding a charging station or route choices will be handled automatically by the car. If the car is an EV, even the charging process will happen automatically. Thereby, the EV will seek out the best charging time and location which fits customers patterns best. The sharing of EVs within the family, the company or with other people will be simplified. The users mobility will be reduced to moving from point A to point B, while other activities relating to the car retreat into the background. If users order an autonomous driving electric vehicle in the future, the car will pick up the passenger in front of their doors and drop them off in front of their work or a supermarket. As long as the EV is not needed during this time, it can just park and wait, pick up and drop off other passengers or charge the batteries. In the beginning, people will inform the EV how long they will be absent and do not need the car, but after a while the computer will know the user's patterns and it will have learned the regularly recurring appointments. This algorithm will integrate all spatial circumstances like the missing parking lots in compounds or missing parking management in the inner city because parking lots can be placed in the suburbs of the city or at locations where users have no additional value. Driving time spent searching for charging stations or parking lots is irrelevant as long as the charging event will be autonomous as well. In the end, a self driving EV is the ultimate game changer in the established mobility net. From this perspective the build up of a charging infrastructure is just an interim solution with human beings as actors.

Bibliography

- Ahrend, Chrstine. Analyse Nutzerverhalten und Raumplanung regionale Infrastruktur, 2011. URL https://www.ivp.tu-berlin.de/fileadmin/fg93/Mitarbeiterbilder/2011.09._Schlussbericht_Nutzerverhalten_und_Raumplanung_Regionale_Infrastruktur.pdf. visited on 01/15/2017.
- Azadfar, Elham; Sreeram, Victor, and Harries, David. The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour. *Renewable and Sustainable Energy Reviews*, 42:1065–1076, 2015. ISSN 13640321. doi: 10.1016/j.rser.2014.10.058.
- Barfod, Jakob. 2 mated plugs and wall-mounted sockets, 2006. URL http://en.wikipedia.org/wiki/File:20061007_3P_N_PE_CEE_connections.jpg. visited on 01/15/2017.
- Basic Beijing, . Sanlitun, 2015. URL <http://basicbeijing.com/beijing-area-guide/sanlitun/>. visited on 01/15/2017.
- Beck, Marc. "Park and Ride" model coming to Beijing subways, 2010. URL <http://www.thebeijinger.com/blog/2010/06/08/park-and-ride-model-coming-beijing-subways>. visited on 01/15/2017.
- Beeton, David A. North east electric vehicle roadmap, 2011. URL http://e-mobility-nsr.eu/fileadmin/user_upload/downloads/info-pool/NorthEast_EV_Roadmap.pdf. visited on 01/15/2017.
- Beijing Municipal Commission of Transport, BMCT, . Government report, 2015. URL <http://www.ebeijing.gov.cn/Government/reports/default.htm>. visited on 02/13/2015.
- Beijing Municipal Commission of Urban Planning, . Beijing master urban plan for 2004–2020, 2005.
- Beijing subway, . General information about the subway network, 2015. URL <http://www.bjsubway.com/>. visited on 01/15/2017.
- Beijing Transportation Research Center, . Research on beijing's public transportation commuting transit network, 2009.
- Benysek, G. and Jarnut, M. Electric vehicle charging infrastructure in Poland. *Renewable and Sustainable Energy Reviews*, 16(1):320–328, 2012. ISSN 13640321. doi: 10.1016/j.rser.2011.07.158.

- Blakely, Edward and Snyder, Mary. *Fortress America: Gated Communities in the United States*. Brookings Institution Press, 1997. ISBN 978-0815710028.
- BMCT, . City parking information summary for second quarter of 2014, 2014. URL <http://www.ebeijing.gov.cn/Government/reports/default.htm>. visited on 01/15/2017.
- BMW Brilliance Automotive Ltd, . Zinoro: Product information, 2014. URL <http://www.zhinuo.com.cn/cn/en/product/index.html>. visited on 10/09/2015.
- BMW Brilliance Automotive Ltd, . Zinoro E1 product manual: The new brand of BMW Brilliance, August 2014.
- Boarnet, M. and Crane, R. The influence of land use on travel behavior: Specification and estimation strategies. *Transportation Research Part A*, pages 823–845, 2001.
- Bogenberger, Klaus. E-Plan München, 2014. <http://hwk-muenchen.de/viewDocument?onr=74&id=8969>, visited on 01/15/2017.
- Boland, Alana and Zhu, Jiangang. Public participation in china’s green communities: Mobilizing memories and structuring incentives. *Geoforum*, 43(1):147–157, 2012. ISSN 00167185. doi: 10.1016/j.geoforum.2011.07.010.
- Botsford, Charles and Szczepanek, Adam. Fast charging vs. slow charging: Pros and cons for the new age of electric vehicles, 2009. URL <http://www.cars21.com/assets/link/EVS-24-3960315%2520Botsford.pdf>. visited on 01/15/2017.
- Brand, Marius; Loleit, Martha, and Braun, Steffen. Szenarios zur Elektromobilität 2025, 2012. <http://wiki.iao.fraunhofer.de/images/studien/szenarios-elektromobilitaet-2025.pdf>, visited on 01/15/2017.
- Busk, Andrey and Warrenstein, Arvid Joellson. *Market analysys for electric vehicle supply equipment: The case of China*. PhD thesis, Royal Institute of Technology, Stockholm, 2014.
- BYD Auto, . e6: Power and performance, 2014. URL <http://www.byd.com/la/auto/e6.html>. visited on 01/15/2017.
- Campbell, Amy R.; Ryley, Tim, and Thring, Rob. Identifying the early adopters of alternative fuel vehicles: A case study of Birmingham, United Kingdom. *Transportation Research Part A: Policy and Practice*, 46(8):1318–1327, 2012. ISSN 09658564. doi: 10.1016/j.tra.2012.05.004.
- CHAdEMO Association, . Chademo technological strengths, 2014. URL <https://www.chademo.com/technology/technology-overview/>. visited on 01/15/2017.
- China Daily. Cities’ car plate policies, 2014. URL http://www.chinadaily.com.cn/bizchina/motoring/2014-01/06/content_17217042.htm. visited on 01/15/2017.

- China Knowledge Online, . Beijing economic-technological development area (bda), 2015. URL <http://www.chinaknowledge.com/Manufacturing/IndustrialPark.aspx?province=31&content=31>. visited on 01/15/2017.
- City of New York, . Privately owned public space, 2014. URL https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/active-design-sidewalk/active_design.pdf. visited on 01/15/2017.
- Dallinger, David; Doll, Claus; Gnann, Till, and Held, Michael. Gesellschaftspolitische Fragestellungen der Elektromobilität, 2011. URL http://www.isi.fraunhofer.de/isi-wAssets/docs/e/de/publikationen/elektromobilitaet_broschuere.pdf. visited on 01/29/2015.
- Dang, Yunxiao; Liu, Zhilin, and Zhang, Wenzhong. Land-based interests and the spatial distribution of affordable housing development: The case of Beijing, China. *Habitat International*, 44:137–145, 2014. doi: 10.1016/j.habitatint.2014.05.012.
- Deutschen Gesellschaft für Internationale Zusammenarbeit, . Elektromobilität im Privatkundensegment stellt nach wie vor Herausforderungen. In DEInternational, , editor, *Econet monitor*, pages 7–10. Beijing, China.
- Dong, Jing; Liu, Changzheng, and Lin, Zhenhong. Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data. *Transportation Research Part C*, 2014(38):44–55. doi: 10.1016/j.trc.2013.11.001.
- Eakin, Chelsea. Air quality in Beijing, 2015.
- Edelstein, Stephen. China extends electric-car incentives as Shenzhen caps registrations. URL http://www.greencarreports.com/news/1096094_china-extends-electric-car-incentives-as-shenzhen-caps-registrations. visited on 01/15/2017.
- Edelstein, Stephen. Beijing’s privileged electric-car registrations fail to attract interest, 2014. URL http://www.greencarreports.com/news/1095462_beijings-privileged-electric-car-registrations-fail-to-attract-interest. visited on 01/15/2017.
- ElBanhawy, Eiman; Dalton, Ruth; Thompson, Emine Mine, and Kotter, Richard. A heuristic approach for investigating the integration of electric mobility charging infrastructure in metropolitan areas: An agent-based modeling simulation.
- Elm EV Ltd., . Rapid charge: The quicker the charge - the more custom generated., 2014. URL <http://www.elmev.co.uk/rapid-charge/>. visited on 01/15/2017.
- Engel-Yan, J.; Hollingworth, B., and Anderson, S. Will reducing parking standards lead to reductions in parking supply? *Journal of Transport and Land Use*, (1):102–110, 2010.

- Environment Bureau, Hong Kong. Guidelines for building your EV charging infrastructure. URL https://www.clponline.com.hk/EV/Pages/ChargingSystem_Guidelines.aspx?lang=EN. visited on 01/15/2017.
- Esri, . Arcgis Desktop Help 9.3 - an overview of map projections. URL http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=An_overview_of_map_projections. visited on 01/15/2017.
- Esri, . Vector-maps of Beijing for Arcmap 10.2.2, 2014.
- European Parliament, . Legislative resolution: Alternative fuels infrastructure: P7_taprov(2014)0352, 2014-04-15.
- EV charging management service platform for the city of Beijing, . Public charging stations - map query. URL <http://evvehicle.cn/cdssChngElecServerQueryAction!initDeivceInfo.cs?partNo=BM14001>. visited on 01/29/2015.
- EV Zone, . Shanghai ev international pilot city, yearly report, 2012. URL www.evzonechina.com. visited on 01/15/2017.
- EVConnectors Ltd., . Innovative power connectors for electric vehicles, 2014. URL https://evconnectors.com/EV_brochure.pdf. visited on 01/15/2017.
- eVgo, . Terms and conditions of the evgo services contract, 2014. URL <http://www.nrgevgo.com/terms-conditions/>. visited on 01/15/2017.
- Fulton, Mark. 12th five year plan: Chinese leadership towards a low carbon economy, 2011. URL https://institutional.deutscheam.com/content/_media/China_12th_Five_Year_Plan.pdf. visited on 01/15/2017.
- Gallego, Esteban. Electric car rebates and tax credits: Los angeles electrician installs ev chargers, 2012. URL <http://www.theelectricconnection.com/electric-car-rebates-tax-credits-los-angeles-electrician-installs-ev-chargers/>. visited on 01/15/2017.
- Gather, Matthias; Kagermeier, Andreas, and Lanzendorf, Martin, editors. *Geographische Mobilitäts- und Verkehrsforschung*. Gebrueder Borntraeger Verlagsbuchhandlung, Berlin, 2008. ISBN 9-783443-071431.
- Geinitz, Christian. Wie china die deutschen Autobauer vorführt. *Frankfurter Allgemeine Zeitung*, (8):14, 2014-01-10.
- General office of Beijing Municipal People's Government, . 2013-2017 beijing city motor vehicle emission pollution control program, 10/8/2013.
- Grant, Jill and Mittelsteadt, Lindsey. Types of gated communities. *Environment and Planning B: Planning and Design*, (31):913–930, 2004. doi: 10.1068/b3165.

- Greive, Shane and Hon, Michelle. The "compound house", 2005.
- Hassenpflug, Dieter. *The Urban Code of China*. Birkhauser Verlag, 2010. ISBN 978-3-0346-0572-4.
- Hatton, C. E.; Beella, S. K.; Brezet, J. C., and Wijnia, Y. C. Charging stations for urban settings: The design of a product platform for electric vehicle infrastructure in Dutch cities. *World Electric Vehicle Journal*, (3), 2009. URL www.evs24.org/wevajournal/php/download.php?f=vol3/WEVJ3-1230095.pdf. visited on 01/15/2017.
- Hecker, Andreas. Factors of influence on the charging infrastructure in China. Recorded tape, 2014-10-29.
- Heineberg, Heinz. Stadtgeographie. In *Grundriss Allgemeine Geographie*. Schoeningh UTB, 2006. ISBN 978-3-8252-2166-9.
- Hisatomo Hanabusa, and Ryota Horiguchi, . A study of the analytical method for the location planning of charging stations for electric vehicles. In Koenig, A.; Dengel, A.; Hinkelmann, K.; Kise, K.; Howlett, R.J, and Jain, L.C, editors, *Knowledge-based and intelligent information and engineering systems*, volume 6883 of *Lecture notes in computer science*. Springer, Berlin and Heidelberg, 2011. ISBN 978-3-642-23853-6.
- Honda Worldwide, . Honda unveils micro-sized electric vehicle "micro commuter prototype", 2012. URL <http://world.honda.com/news/2012/4121113Micro-EV-Commuter-Prototype/index.html>. visited on 02/22/2015.
- International Electrotechnical Commission, . Plugs, socket-outlets, vehicle connectors and vehicle inlets - conductive charging of electric vehicles -, 2010.
- Ji, Wei; Wang, Yong; Zhuang, Dafang; Song, Daping; Shen, Xiao; Wang, Wei, and Li, Gang. Spatial and temporal distribution of expressway and its relationships to land cover and population: A case study of Beijing, China. *TRansportation Research Part D*, 32:86–96, 2014. doi: 10.1016/j.trd.2014.07.010.
- Johnson, Lyndsey. Charging modes, 2015. URL <http://www.elmev.co.uk/tag/charging-modes/>. visited on 01/15/2017.
- Kane, Mark. Zap sparkee ev launches for city commuters in China: It's a smart fortwo clone, 2014. URL <http://insideevs.com/zap-sparkee-ev-china-launch/>. visited on 01/15/2017.
- Kley, Fabian. *Ladeinfrastrukturen für Elektrofahrzeuge: Entwicklung und Bewertung einer Ausbaustrategie auf Basis des Fahrverhaltens*. PhD thesis, Universitaet Karlsruhe, 2011.
- Kulke, Elmar. Wirtschaftsgeographie. In *Grundriss Allgemeine Geographie*. Schoeningh UTB, 2006. ISBN 978-3-8252-2166-9.

- Kuo, Iris. Why global companies like ABB plow millions into electric car charging startups, 2011. URL <http://venturebeat.com/2011/01/10/why-global-companies-like-abb-plow-millions-into-electric-car-charging-startups/>.
- Kwan, Amanda. Private space or public park? Revealing Toronto's in-between spots, 2013. URL <http://www.theglobeandmail.com/news/toronto/private-space-or-public-park-revealing-torontos-in-between-spots/article14315725/>. visited on 01/15/2017.
- Langezaal, Michiel and Bouman, Crrijn. Towards winning buisness models for the ev-charging industry: Who plays this game, what are the rules and why it is one of the most important competences in this industry., 2011.
- Lawson, Barrie. Electric vehicle charging infrastructure / ev battery charging, 2005. URL <http://www.mpoweruk.com/infrastructure.htm>. visited on 01/15/2017.
- Lee, Y.; Washington, S., and Frank, L. D. Examination of relationships between urban form, household ativities, and time allocation in the atlanta metropolitan region. *Transportation Research Part A*, 43:360–373, 2009.
- Lenz, Barbara. Elektromobilität im Verkehrs- und Mobilitätssystem, 2012. URL http://www.ivm-rheinmain.de/wp-content/uploads/2013/01/MasterplanEMKickOff_Lenz.pdf. visited on 01/15/2017.
- Li, Zhe and Ouyang, Minggao. The pricing of charging for electric vehicles in China - dilemma and solution. *Energy Policy*, (36):5765–5778, 2011. ISSN 03014215. doi: 10.1016/j.energy.2001.05.046.
- Liu, Jian. Electric vehicle charging infrastructure assignment and power grid impacts assessment in Beijing. *Energy Policy*, 51:544–557, 2012. ISSN 03014215. doi: 10.1016/j.enpol.2012.08.074.
- Liu, Wentao. Living conditions—the key issue of housing development in Beijing Fengtai district. *HBRC Journal*, 2014. ISSN 16874048. doi: 10.1016/j.hbrcj.2014.07.003.
- Liu, Yingqi and Kokko, Ari. Who does what in China's new energy vehicle industry? *Energy Policy*, (57):21–29, 2013. ISSN 03014215. URL <http://dx.doi.org/10.1016/j.enpol.2012.05.046>.
- Lo, Kevin and Wang, Mark. The development and localisation of a foreign gated community in Beijing. *Cities*, 30:186–192, 2013. ISSN 02642751. doi: 10.1016/j.cities.2012.03.005.
- Logan, John; Fang, Yiping, and Zhang Zhanxin, . Residence status and housing in urban China - the case of Beijing. *Espace, Populations, Societes*, (3):497–510, 2009.

- Long, Ying; Han, Haoying; Lai, Shih-Kung, and Mao, Qizhi. Urban growth boundaries of the Beijing metropolitan area: Comparison of simulation and artwork. *Cities*, 31: 337–348, 2013. ISSN 02642751. doi: 10.1016/j.cities.2012.10.013.
- Ma, Chunbo and He, Lining. From state monopoly to renewable portfolio: Restructuring China’s electric utility. *Energy Policy*, 36(5):1697–1711, 2008. ISSN 03014215. doi: 10.1016/j.enpol.2008.01.012.
- Ma, Jing; Mitchell, Gordon, and Heppenstall, Alison. Daily travel behaviour in Beijing, China: An analysis of workers’ trip chains, and the role of socio-demographics and urban form. *Habitat International*, (43):263–273, 2014. doi: 10.1016/j.jtrangeo.2011.03.008.
- Ma, Laurence J.C. and Wu, Fulong. *Restructing the Chinese City: Changing society, economy and space*. Routledge, 2005.
- Mak, Stephen; Choy, Lennon, and Ho, Winky. Privatization, housing conditions and affordability in the People’s Republic of China. *Habitat International*, (31):177–192, 2007. doi: 10.1016/j.habitatint.2006.11.003.
- Mayor of London, . London’s electric vehicle infrastructure strategy, 2009. URL <https://www.sourcelondon.net/sites/default/files/draft%20Electric%20Vehicle%20Infrastructure%20Strategy.pdf>. visited on 05/27/2014.
- Mennekes, . Intelligent charging stations as a key to electric mobility, 2011. URL http://www.mennekes.de/index.php?id=latest0&L=1&tx_ttnews%5Btt_news%5D=30&cHash=a3687acd859de36f6cbba65929f3a09f. visited on 01/15/2017.
- Michael A Nicholas, ; Gil Tal, ; Jamie Davies, , and Justin Woodjack, . Dc fast as the only public charging option? scenario testing from GPS tracked vehicles, August 1, 2011.
- Ming, An; Grabowski, Tanja, and Bongardt, Daniel. Transport demand management in beijing: Work in progress, 2012. URL <http://www.sutp.org/files/contents/sutp-archive/files/Work-in-Progress-TDM-Beijing-brochure.pdf>. visited on 01/15/2017.
- Minghing, Tan and Xiubin, Li. The changing settlements in rural areas under urban pressure in china: Patterns, driving forces and policy implications. *Landscape and Urban Planning*, (120):170–177, 2013. doi: 10.1016/j.landurbplan.2013.08.016.
- Ministry of Finance of the People’s Republic of China, . Notice about the demonstration work of promoting energy efficient and alternative fuel vehicles, 2009. URL http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/200902/t20090205_111617.html. visited on 01/15/2017.

- Ministry of Industry and Information Technology of The People's Republic of China, . Official internet site, 2015. URL <http://www.miit.gov.cn/n11293472/index.html>. visited on 01/15/2017.
- Muench, Barbara. Verborgene Kontinuitäten des chinesischen Urbanismus. *Archplus* 168, pages 44–49, 2004. URL <http://www.archplus.net/home/archiv/artikel/46,41,1,0.html>.
- Ng, W.; Schipper, L., and Chen, y. China motorization trends: new directions for crowded cities. *Journal of Transport and Land Use*, 3:5–25, 2010.
- Noland, R. B. and Thomas, J. V. Multivariate analysis of trip-chaining behavior. *Environment and Planning B: Planning and Design*, 34:953–970, 2007.
- Nuzzi, Bob. Electric vehicles in the state of connecticut, 2010. URL http://www.ct.gov/dcs/lib/dcs/office_of_education_and_data_management_files/sp11_electric_vehicles.pdf. visited on 01/15/2017.
- Pan, H.; Shen, Q., and Zhang, M. Influence of urban form on travel behaviour in four neighbourhoods of Shanghai. *Urban Studies*, 46:275–294, 2009.
- PHOENIX CONTACT, . E-mobility connectors, 2014a. URL https://www.phoenixcontact.com/online/portal/ca?1dmy&urile=wcm%3apath%3a/caen/web/main/products/subcategory_pages/Pre_assembled_charging_cable_P-29-03/df8e2122-37ca-4529-8a17-ed17e8eba258. visited on 01/15/2017.
- PHOENIX CONTACT, . AC and DC plug connector system according to GB standard, 2014b. URL https://www.phoenixcontact.com/online/portal/ca?1dmy&urile=wcm%3apath%3a/caen/web/main/products/subcategory_pages/AC_Charging_cable_P-29-03-02/e0a0cc39-78e9-458f-9271-1b7cfaf59108. visited on 01/15/2017.
- Qiang, Dou. Change and continuity: a morphological investigation of the creatio of gated communities in post-reform Beijing, July 10-13, 2008. URL <http://discovery.ucl.ac.uk/11630/1/11630.pdf>.
- Qiong, Yao and Wei, Wei. Gated community: the past and present in China. *Engineering and Technology*, 71, 2012.
- Qlik Technologies Inc., . Qlikview overview, 2014. URL <http://www.qlik.com/us/explore/products/qlikview>. visited on 01/15/2017.
- Radtke, Philipp; Krieger, Axel; Kirov, Sergei; Maekawa, Atsushi; Kato, Akitake; Yamakawa, Naomi, and Henderson, David. Profiling Japan's early ev adopters: A survey of the attitudes and behaviors of early electric vehicle buyers in Japan, 2012.
- Rey and Lenferna Ltd., . Mennekes industrial plugs and receptacles. URL <http://www.reylenferna.com/mennekes-introduction.php>. visited on 01/15/2017.

- Ried, Wolfgang. Entwurf einer "elektromobilen Quartiertypologie". In Bott, Helmut, editor, *Architektur und Stadtplanung*, pages 16–23. Städtebau Institut der Universität Stuttgart, 2013.
- Rui, Wang and Quan, Yuan. Parking practices and policies under rapid motorization: The case of China. *Transport Policy*, 2013(30):109–116, 2013. doi: 10.1016/j.tranpol.2013.08.006.
- School of the Built and Natural Environment Northumbria University, . A heuristic approach for investigating the integration of electric mobility charging infrastructure in metropolitan areas: An agent-based modeling simulation: Elbanhawy, eiman.
- Schroeder, Andreas and Traber, Thure. The economics of fast charging infrastructure for electric vehicles. *Energy Policy*, (43):136–144, 2012. ISSN 03014215. doi: 10.1016/j.enpol.2011.12.041.
- Sebastian Heilmann, , editor. *Das politische System der Volksrepublik China: 2., aktualisierte Auflage*. VS Verlag fuer Sozialwissenschaften, Wiesbaden, 2004. ISBN 3-531-33572-3.
- SGEVCP, . Electrify the future: How to meet China's challenges in NEV Infrastructure, 2015.
- Snyder, Jason; Chang, Daniel Erstad, Daniel, ; Lin, Ellen; Rice, Alicia Falken; Goh, Chia Tzun, and Tsao, An-An. Financial viability of non-residential electric vehicle charging stations, 2012. URL <http://luskin.ucla.edu/sites/default/files/Non-Residential%20Charging%20Stations.pdf>. visited on 01/15/2017.
- Speidel, Stuard and Bräunl, Thomas. Driving and charging patterns of electric vehicles for energy usage. *Renewable and Sustainable Energy Reviews*, 40:97–110, 2014. ISSN 13640321. doi: 10.1016/j.rser.2014.07.177. URL www.therevproject.com.
- Staiger, Brunhild; Friedrich, Stefan; Schuette, Hans, and Emmerich, Reinhard, editors. *Das große China-Lexikon: Geschichte, Geographie, Gesellschaft, Politik, Wirtschaft, Bildung, Wissenschaft, Kultur*. WBG (Wissenschaftliche Buchgesellschaft), 2009. ISBN 978-3534216277.
- Tesla Motors, . Model S specs: Powertrain, 2014. URL <http://www.teslamotors.com/models/specs>. visited on 01/15/2017.
- Tesla Motors, . Supercharger charging profile, 2015. URL <http://www.teslamotors.com/supercharger>. visited on 01/15/2017.
- Texas Instruments, Incorporated, . Introduction to the controller area network (can. URL <http://www.ti.com/lit/an/sloa101a/sloa101a.pdf>. visited on 01/15/2017.
- The Ontario Plan, . Floor area ratio example, 2013. URL <http://ontarioplan.org/index.cfm/27925/29188>. visited on 08/19/2014.

- Tian, Guanjin; Wu, Jianguo, and Yang, Zhifeng. Spatial pattern of urban functions in the Beijing metropolitan region. *Habitat International*, 34:249–255, 2010. doi: 10.1016/j.habitatint.2009.09.010.
- UC Davis, . The mini e study, 2011. URL <http://phev.ucdavis.edu/project/uc-davis-mini-e-consumer-study/>.
- Volkswagen Group China, . China ev charging infrastructure, 2012.
- Wang, Donggen; Chai, Yanwei, and Li, Fei. Built environment diversities and activity: Travel behaviour variations in Beijing, China. *Journal of Transport Geography*, 19: 1173–1186, 2011. doi: 10.1016/j.jtrangeo.2011.03.008.
- Wang, James J. and Liu, Qian. Understanding the parking supply mechanism in china: A case study of Shenzhen. *Journal of Transport Geography*, 40:77–88, 2014. doi: 10.1016/j.jtrangeo.2014.04.019.
- Wang, Y.; McElroy, M.; Boersma, K.; Eskes, H., and Veeffkind, J. Traffic restrictions associated with the sino-african summit: reductions of nox detected from space. *Geophysical Research Letters*, 34, 2007.
- Wang, Yuwei. Persistence of the collective urban model in Beijing, 2012. URL <http://projectivecities.aaschool.ac.uk/portfolio/yuwei-wang-beijing-collective/>. visited on 10/29/2014.
- Wang, Zhenpo; Liu, Peng; Cui, Jia; Xi, Yue, and Zhang, Lei. Research on quantitative models of electric vehicle charging stations based on principle of energy equivalence. *Mathematical Problems in Engineering*, 2013. doi: 10.1155/2013/959065. URL <http://www.hindawi.com/journals/mpe/2013/959065/>.
- Weinberger, Rachel. Death by a thousands curb cuts: evicence on the effect of minimum parking requirements on the choice to drive. *Transport Policy*, (20):93–102, 2012.
- Wiederer, Alfred and Philip, Ronald. *Poilcy options for electric vehicle charging infrastructure in C40 cities*. PhD thesis, Harvard Kennedy School, 2010. URL http://www.emic-bg.org/files/6.C40_CHARGINGINFRASTRUCTURE.pdf. visited on 01/15/2017.
- Wirges, Johannes and Linder, Susanne. Modelling the development of a regional charging infrastructure for electric vehicles in time and space. *European Journal of Transport and Infrastructure Research*, (12):391–416, 2012. URL http://www.ejtir.tudelft.nl/issues/2012_04/pdf/2012_04_03.pdf.
- Wu, Libo; Li, Changhe; Qian, Haoqi, and Zhang, Zhong Xiang. Understanding the consumption behaviors on electric vehicle in China: A stated preference analysis, 2013. URL <http://ageconsearch.umn.edu/bitstream/158729/2/NDL2013-079.pdf>. visited on 01/15/2017.

- Xiaolong, Ma; Xiaoduan, Sun; Yulong, He, and Yixin, Chen. Parking choice behavior investigation: A case study at Beijing Lama Temple. *Procedia - Social and Behavioral Sciences*, 2013(96):2636–2642, 2013. doi: 10.1016/j.sbspro.2013.08.294.
- Xu, Hao; Miao, Shihong; Zhang, Chunyong, and Shi, Dongyuan. Optimal placement of charging infrastructures for large-scale integration of pure electric vehicles into grid. *International Journal of Electrical Power & Energy Systems*, 53:159–165, 2013. ISSN 01420615. doi: 10.1016/j.ijepes.2013.04.022.
- Xue, Lulu. Beijing’s parking woes: Is there any end in sight?, 2013. URL <http://thecityfix.com/blog/beijing-parking-woes-end-sight-lulu-xue/>. visited on 01/15/2017.
- Yang, Jun; Liu, Ying; Qing, Ping, and Liu, Antung. A review of Beijing’s vehicle lottery: Short-term effects on vehicle growth, congestion, and fuel consumption. *Environment for Development*, 2014.
- Zeltner, Stefan. Netzanbindung von Elektrofahrzeugen, 2010. URL http://www.iisb.fraunhofer.de/content/dam/iisb/de/documents/veranstaltungen_messen/veranstaltungen/2010/jahrestagung_2010/zeltner.pdf. visited on 06/16/2014.
- Zeng, Ye; Changping, Liu, and Ning, Gui. Research on different parking supply in Beijing. *Journal of Transportation Systems*, 2009(9):47–51, 2009. doi: 10.1016/S1570-6672(08)60087-2.
- Zhang, Yale. China 12 cities EV demonstration project: Full report, 2011.
- Zhang, Yong; Yu, Yifeng, and Zou, Bai. Analyzing public awareness and acceptance of alternative fuel vehicles in China: The case of EV. *Energy Policy*, 39(11):7015–7024, 2011. ISSN 03014215. doi: 10.1016/j.enpol.2011.07.055.
- Zhang Peng, . Green drive: Beijing to turn ordinary street lamps into charging points, 2014. URL <http://english.cri.cn/12394/2014/10/17/3441s848348.htm>. visited on 01/15/2017.
- Zhen, Jie; Mehndiratta, Shomik; Guo, Jessica Y., and Liu, Zhi. Strategic policies and demonstration program of electric vehicle in China. *Transport Policy*, (19):17–25, 2012. doi: 10.1016/j.tranpol.2011.07.006.
- Zhou, Jiangping; Murphy, Enda, and Long, Ying. Commuting efficiency in the Beijing metropolitan area: An exploration combining smartcard and travel survey data. *Journal of Transport Geography*, 41:175–183, 2014. doi: 10.1016/j.jtrangeo.2014.09.006.
- Zhu, Guiping; Lu Zongxiang, , and Wang, ZANJI. Research on ev development and its impacts on power grid on China, 2013.

Zimmerman, Nicole and Bass, Robert. Impacts of electric vehicle charging on electric power distribution systems, 2013. URL http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1165&context=ece_fac. visited on 01/15/2017.

Appendix A

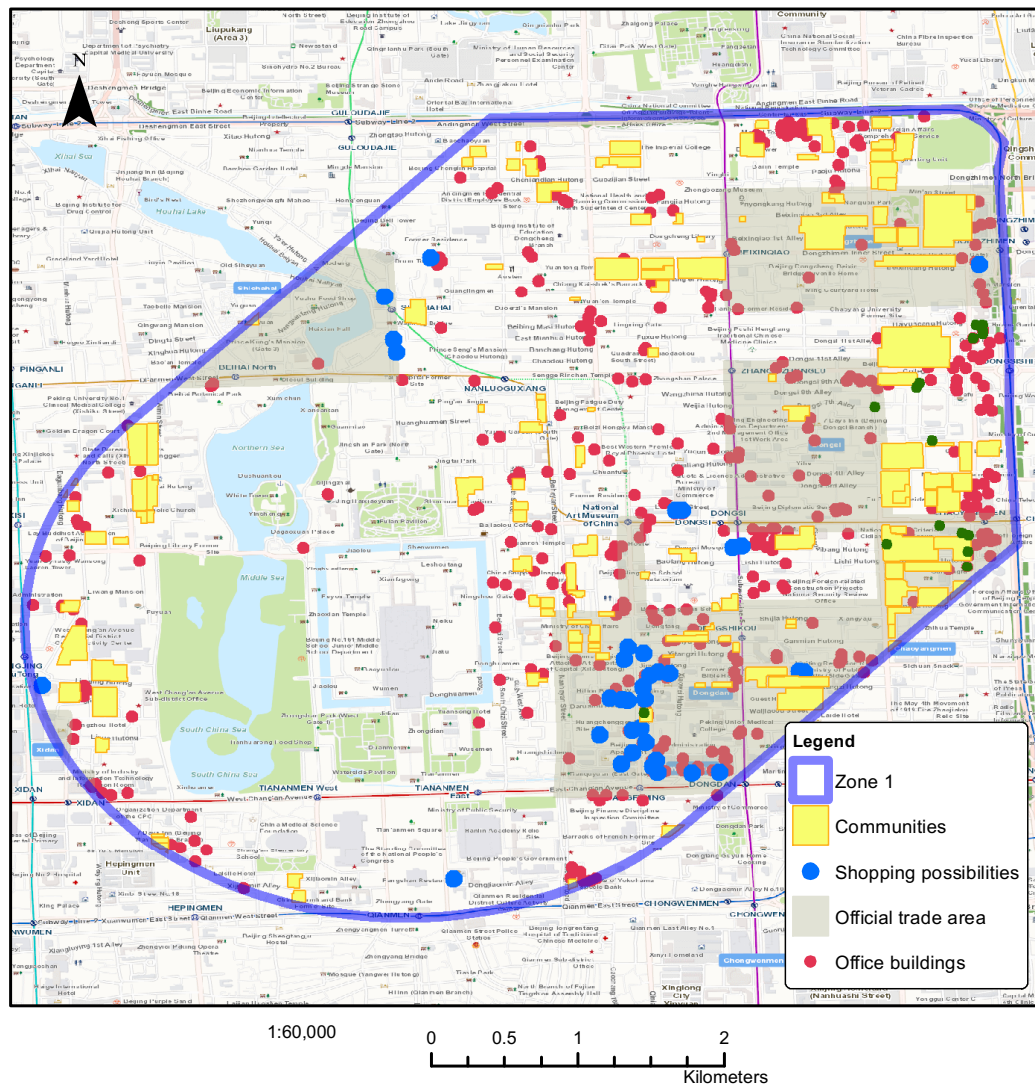
Interviewees of the expert discussion

Interviewee	Title\Company	Date
Yang, Wu (recorded)	Manager Business Development, BMW Brilliance Automotive Ltd.	September 30th, 2014
Liu, Jian (recorded)	Specialist, National Development and Reform Commission (NDRC)	October 12th, 2014
Wang, Xiaofeng (recorded)	Specialist, Potevio	October 12th, 2014
Heinen, Frank	General Manager Electric Vehicle and Hybrid Technology (BOSCH)	October 23rd, 2014
Tsang, Martin (recorded)	CEO and co-founder, Hong Kong EV Power Ltd.	October 25th, 2014
Hochfeld, Christian (recorded)	Program Director Sustainable Transport \Deutsche Gesellschaft für Internationale Zusammenar- beit (GIZ), Beijing	November 24th, 2014
Steinhauer, Stefan (e- mail)	Car2Go	October 24th, 2014
Prof. Zan (recorded)	Tsinghua University, Beijing	October 12th, 2014
Lankton, Cal (e-mail)	Tesla Motors, USA	December 8th, 2014
Kissel, Gery (recorded)	General Motors, Detroit	December 1st, 2014

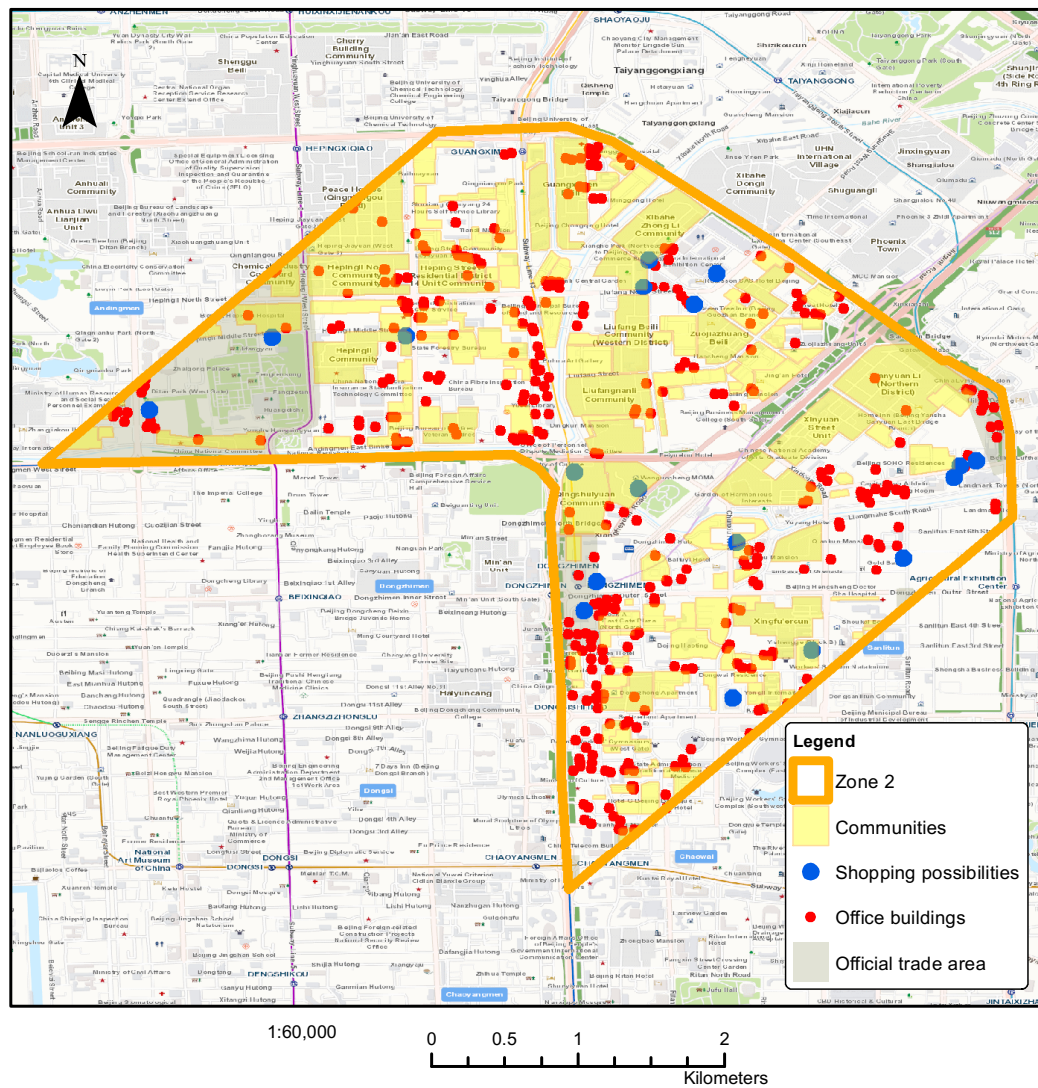
Table A.1: List of interviewees for the expert discussions

Appendix B

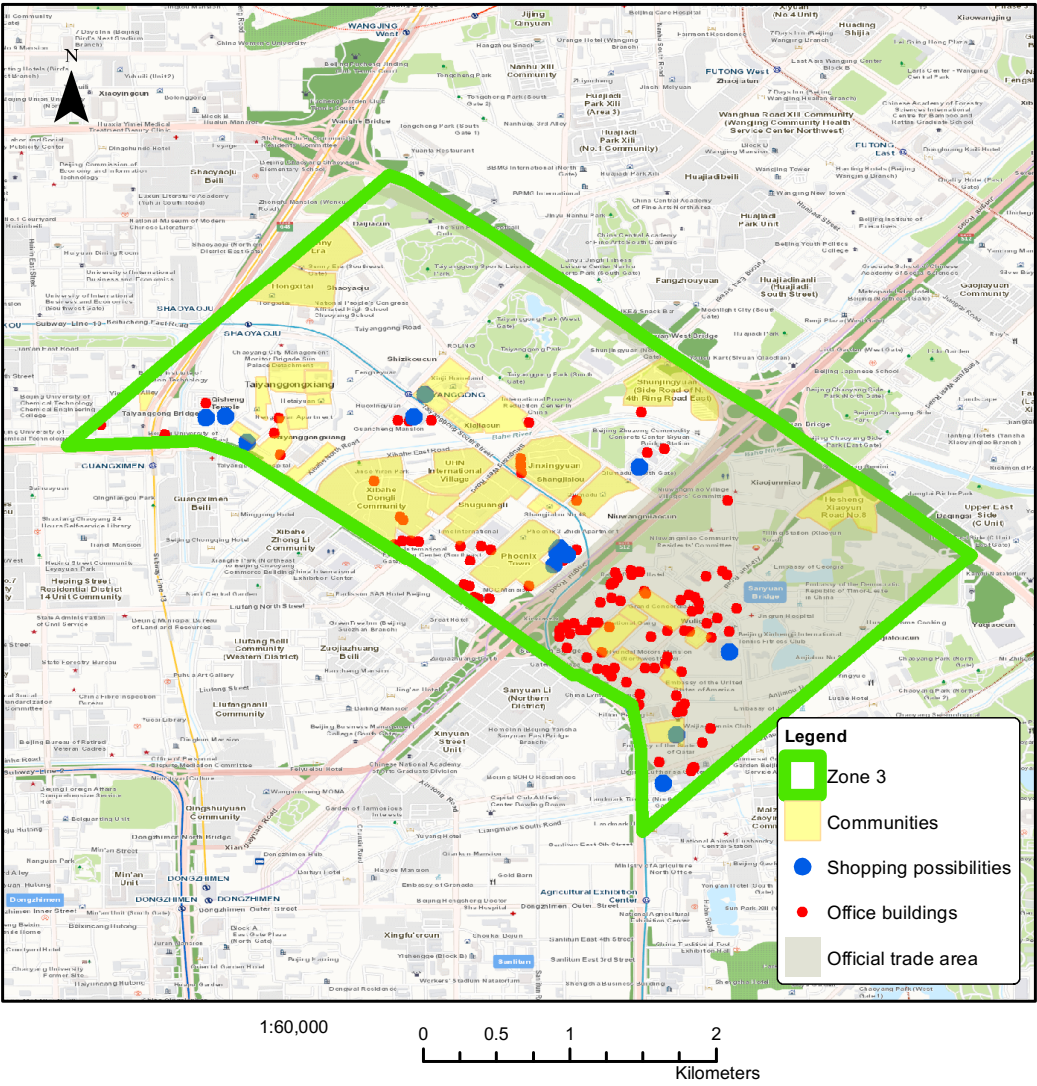
Detail maps of the six zones



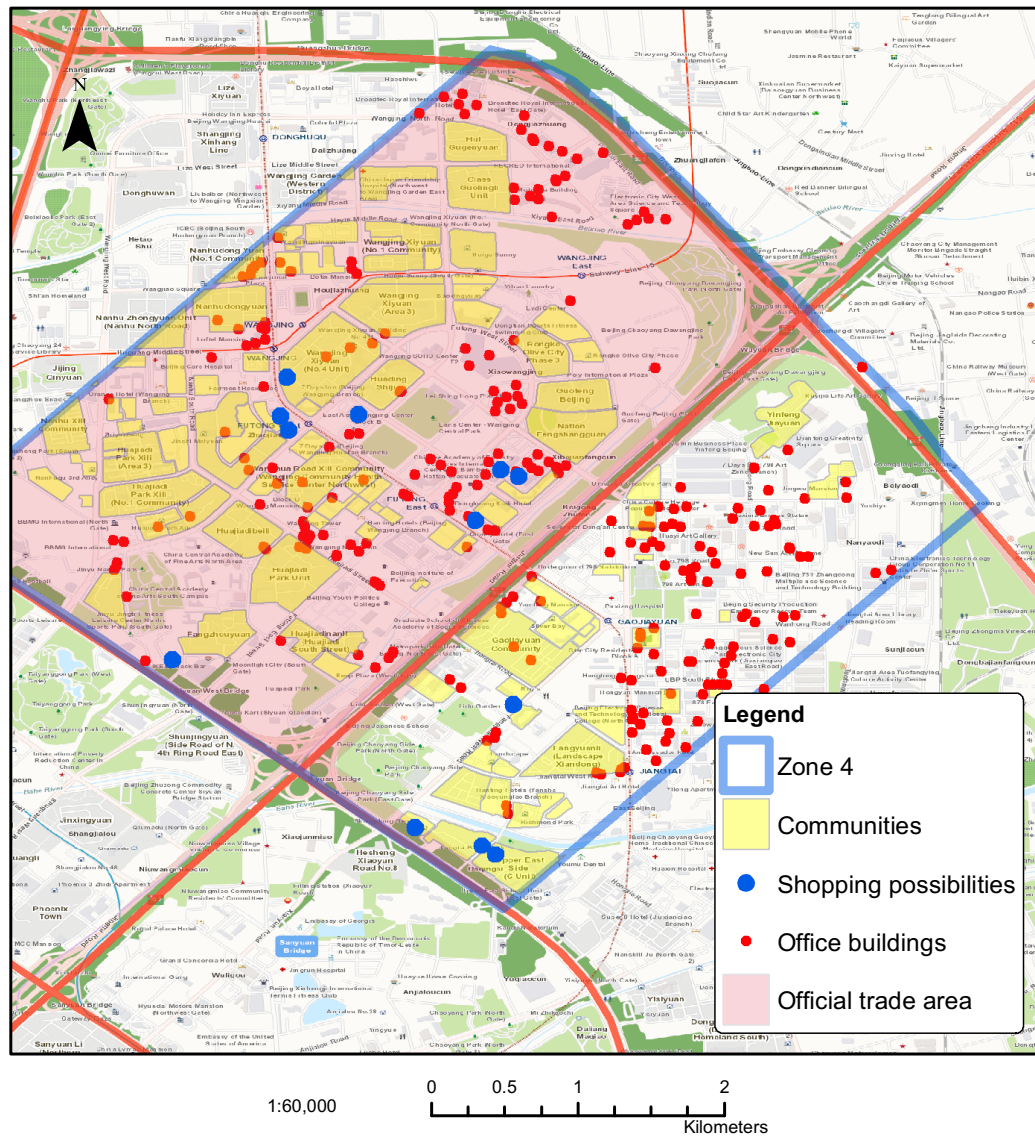
Map 22: Analysis of Zone 1 within the second ring-road;



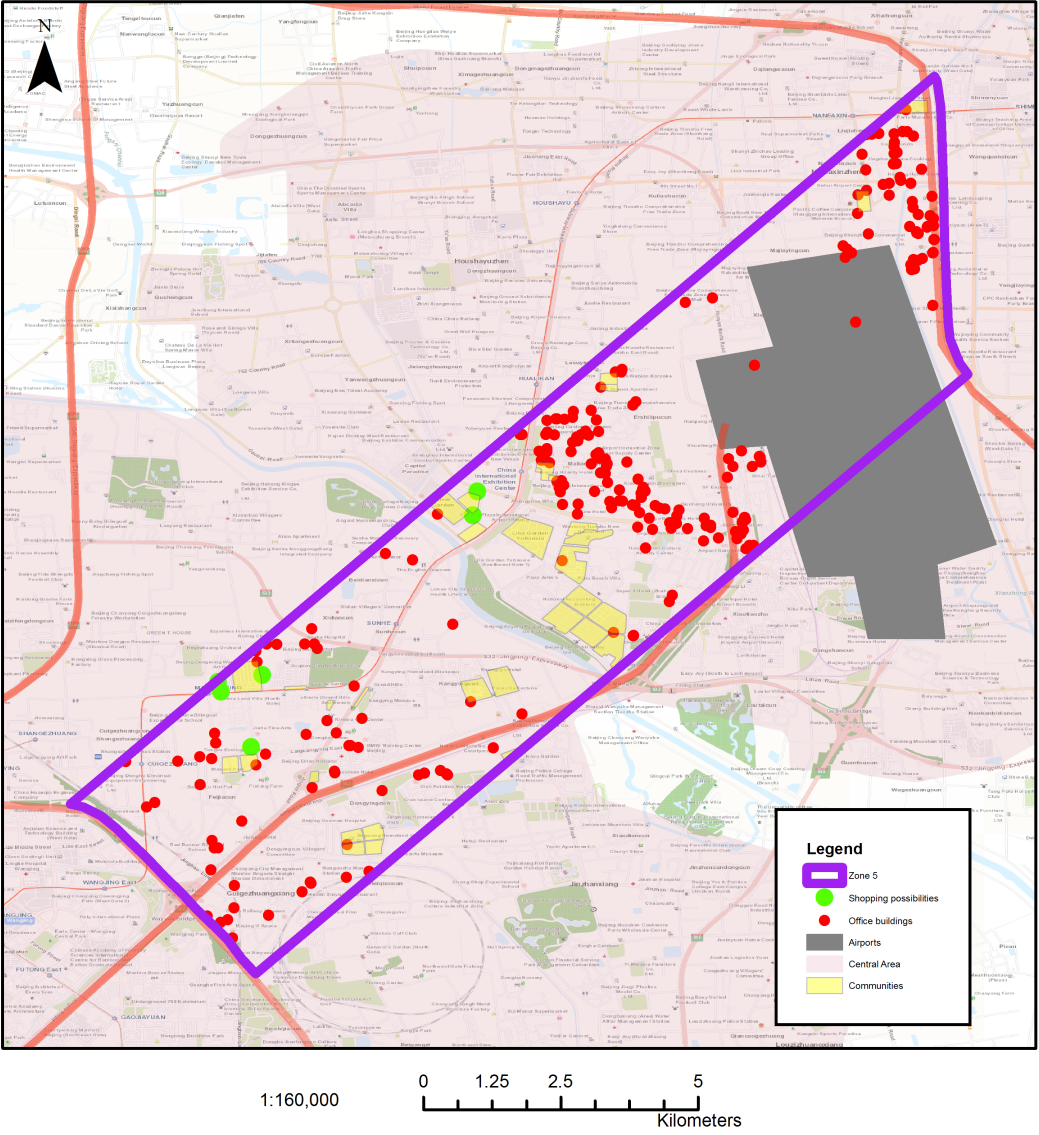
Map 23: Zone 2 between the second and third ring-road



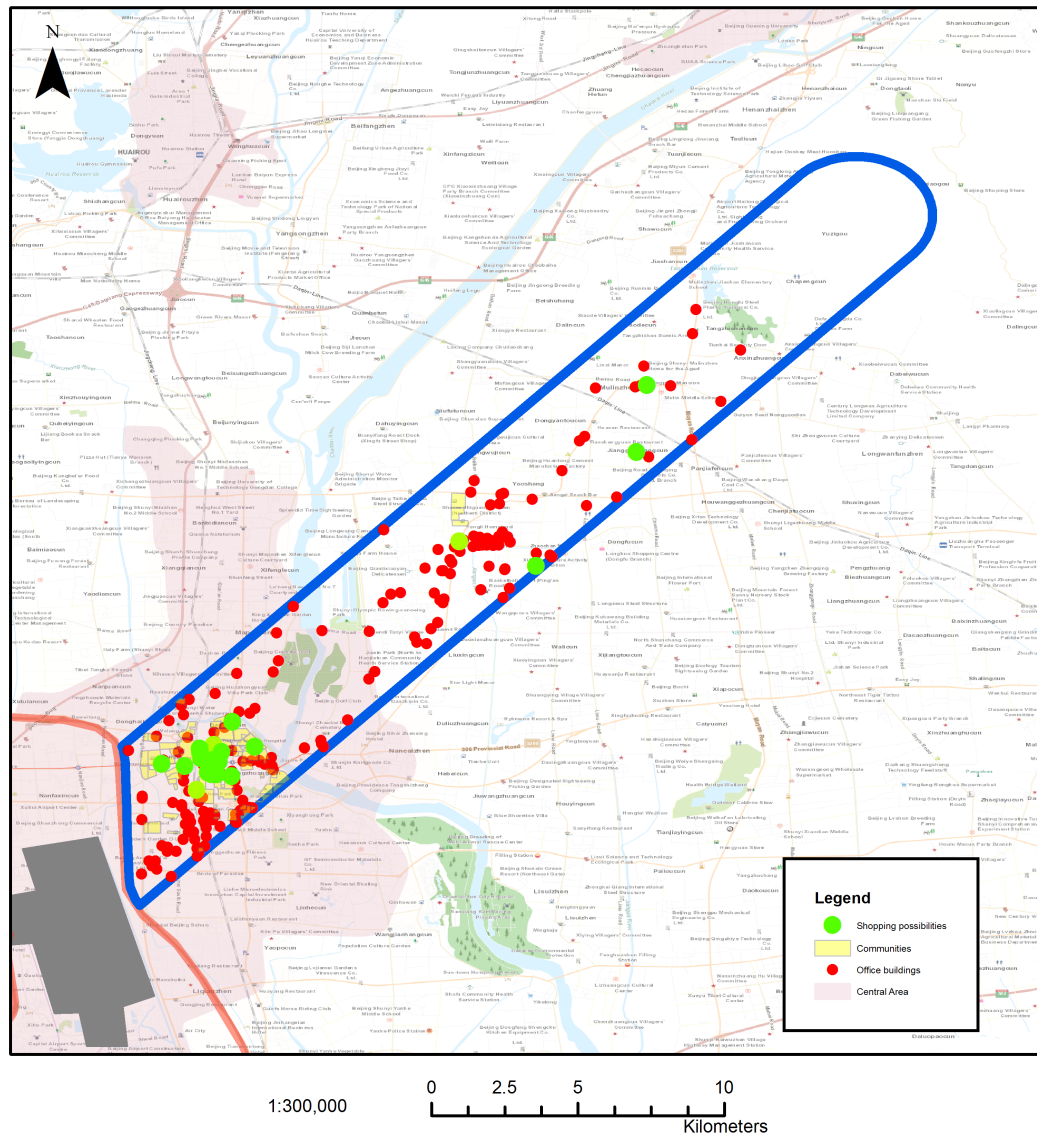
Map 24: Zone 3 between the third and fourth ring-road



Map 25: Zone 4 between the fourth and fifth ring-road



Map 26: Analysis of Zone 5 within the second ring-road;



Map 27: Analysis of Zone 6 within the second ring-road;

Appendix C

QlikView source code

```
1 \lstset{
2 xleftmargin=71pt
3 }
4 Data:
5 LOAD SerialNo,
6     VIN,
7     [Acquisition Time],
8     Longitude,
9     Round(Longitude, 0.00001) as Longitude_round,
10    Latitude,
11    Round(Latitude, 0.00001) as Latitude_round,
12    [GPS Speed(km/h)],
13    Direction,
14    [Eastern/Western Longitude],
15    [Southern/Northern Latitude],
16    [GPS status],
17    [Total No. Of Cells],
18    [Total PB Pack(Cells)],
19    [Total PB Pack Tem. Probes],
20    [Total PB Pack(Power)],
21    [Vehicle Speed(km/h)],
22    [Mileage(km)],
23    [Gears Position] as [Gears Position original],
24    // die originale Schalthebelposition
25    // beibehalten, um spaeter ggf. darauf
26    // zugreifen zu koennen
27    If([Gears Position] = '6' or [Gears Position]
28    = 'P' , 'P', 'D') as [Gears Position], //
29    Replace 6 mit 'P' da bei der Betrachtung '
30    Sleep' (=6) mit P gleichgesetzt werden kann
31    [Braking Validity],
32    [Drive Validity],
33    [Travel Of Accelerator Pedal(%)],
34    [Travel Of Brake Pedal(%)],
35    [Motor Torque(N*m)],
36    [Charging/Discharging Status],
```

```

31      [Motor Controller Tem.(Å;Å&C)],
32      [Motor Speed(r/min)],
33      [Motor Temperature(Å;Å&C)],
34      [Motor Voltage(V)],
35      [Motor Current(A)],
36      [Air Temperature(Å;Å&C)],
37      CRC,
38      [PB Packs No.with Max.Vol.],
39      [Cell No.with Max.Voltage],
40      [Max. Voltage Of Cells(V)],
41      [PB Packs No.with Min.Vol.],
42      [Cell No.with Min.Voltage],
43      [Min. Voltage Of Cells(V)],
44      [PB Packs No.with Max.Tem.],
45      [Probe No.with Max.Tem.],
46      [Max. Temperature(Å;Å&C)] as [Max. Temperature
      (Å°C)],
47      [PB Packs No.with Min.Tem.],
48      [Probe No.with Min.Tem.],
49      [Min. Temperature(Å;Å&C)],
50      [Battery Temperature(Å;Å&C)],
51      [Total Voltage(V)],
52      [Total Current(A)],
53      [SOC(%)]],
54      [Residual Energy(KW*h)],
55      [Insulation Resistance(kÅŠÅž)],
56      [Total Cell Of Max.Vol.],
57      [Total Cell Of Min.Vol.],
58      [Total Pro. Of Max.Tem.],
59      [Total Pro. Of Min.Tem.],
60      [Tem. Difference],
61      [Battery Post High Tem.],
62      [PB Pack Overvoltage],
63      [PB Pack Undervoltage],
64      [SOC Low Warning],
65      [Cell Overvoltage],
66      [Cell Undervoltage],
67      [SOC Too Low],
68      [SOC Too High],
69      [PB Pack Mismatch],
70      [PB Pack Poor Consistency],
71      [Isolation Fault],
72      WeekDay([Acquisition Time]) as WeekDay,
73      Week([Acquisition Time]) as CalendarWeek,
74      //Date(DayStart([Acquisition Time])) as Day,
75      //AutoNumber(VIN &'_'& [Acquisition Time] &'_'
      & If([Gears Position] = '6', 'N',[Gears
      Position])) as %Key,
76      AutoNumber(VIN
77      &'_'&

```

```

78         MakeDate(SubField(left([
            Acquisition Time], 10),
            '-', 1),SubField(
            SubField([Acquisition
            Time], ' ', 1), '-', 2),
            SubField(left([
            Acquisition Time], 10),
            '-', 3))
79         &'_'&
80         Time(MakeTime(SubField(
            SubField([Acquisition
            Time], ' ', 2), ':', 1),
            SubField(SubField([
            Acquisition Time], ' ',
            2), ':', 2),SubField(
            SubField([Acquisition
            Time], ' ', 2), ':', 3))
            , 'hh:mm:ss')
81         &'_'&
82         [Gears Position]) as %Key,
83         MakeDate(SubField(left([Acquisition Time], 10)
            , '-', 1),SubField(SubField([Acquisition
            Time], ' ', 1), '-', 2),SubField(left([
            Acquisition Time], 10), '-', 3)) as DATE,
84         Time(MakeTime(SubField(SubField([Acquisition
            Time], ' ', 2), ':', 1),SubField(SubField([
            Acquisition Time], ' ', 2), ':', 2),
            SubField(SubField([Acquisition Time], ' ',
            2), ':', 3)), 'hh:mm:ss') as TIME,
85         num(SubField([Acquisition Time], ' ', 2)) as
            TIME_NUM
86 FROM [Monthly-export_*.csv] (txt, codepage is 1252,
            embedded labels, delimiter is ',', msq)
87
88 Where [Mileage(km)] < 600000
89 and [Mileage(km)] > 0;
90
91
92 //Sort for delta calculations with previous()
93 Data_SORT:
94 NoConcatenate LOAD * Resident Data Order by VIN, [
            Acquisition Time] asc;
95
96 DROP Table Data;
97 %%%%%%%%%%%%%%%
98 Data_delta_km:
99 LOAD *,
100         if(VIN = Previous(VIN), [Mileage(km)] -
            Previous([Mileage(km)]), 0) as
            Mileage_delta
101 Resident Data_SORT;

```

```

102
103 DROP Table Data_SORT;
104
105
106 Data_delta_SOC:
107 LOAD *,
108     if(VIN = Previous(VIN) and [Charging/
        Discharging Status] <> Previous([Charging/
        Discharging Status]), 1, 0) as [Charging/
        Discharging Change],
109     if(VIN = Previous(VIN) and [Charging/
        Discharging Status] = 'Charging' and
        Previous([Charging/Discharging Status] = '
        Discharging'), 1, 0) as [Charging Begin],
110     if(VIN = Previous(VIN) and [Charging/
        Discharging Status] = 'Discharging' and
        Previous([Charging/Discharging Status] = '
        Charging'), 1, 0) as [Charging End]
111 Resident Data_delta_km;
112
113 DROP Table Data_delta_km;
114
115
116 Data_delta:
117 LOAD *,
118     if(WeekDay = 'Sat' or WeekDay = 'Sun', '
        WeekEnd', 'Week') as WeekEnd
119     //,AutoNumber(VIN &'_'& DATE &'_'& TIME &'
        _'& [Gears Position]) as %Key
120 Resident Data_delta_SOC;
121
122 DROP Table Data_delta_SOC;
123
124
125 //Sort for delta calculations with previous()
126 Data_SORT:
127 NoConcatenate LOAD * Resident Data_delta Order by
        VIN, [Acquisition Time] asc;
128
129 DROP Table Data_delta;
130 RENAME Table Data_SORT to Data_delta;
131 %%%%%%%%%%%%%%%
132
133 TMP:
134 NoConcatenate
135 LOAD \%Key,
136     VIN,
137     [Charging/Discharging Status],
138     [Acquisition Time],
139     if( (VIN = Previous(VIN) and [Charging/
        Discharging Status] = 'Charging' and

```

```

Previous([Charging/Discharging Status]
= 'Discharging') or (VIN <> Previous(
VIN) and [Charging/Discharging Status]
= 'Charging')), 1, 0) as
FLAG_CHARGE_BEGIN
140 Resident Data_delta
141 order By VIN, [Acquisition Time];
142
143 TMP1:
144 NoConcatenate
145 LOAD \ %Key,
146     VIN,
147     [Charging/Discharging Status],
148     [Acquisition Time],
149     FLAG_CHARGE_BEGIN,
150     if( (VIN = Previous(VIN) and [Charging/
Discharging Status] = 'Charging' and
Previous([Charging/Discharging Status]
= 'Discharging') or (VIN <> Previous(
VIN) and [Charging/Discharging Status]
= 'Charging')), 1, 0) as
FLAG_CHARGE_END
151 Resident TMP
152 order By VIN, [Acquisition Time] desc;
153
154 TMP2:
155 NoConcatenate LOAD * Resident TMP1 Where
FLAG_CHARGE_BEGIN <> FLAG_CHARGE_END;
156
157 //DROP Table TMP, TMP1, Data_delta;
158 //EXIT Script;
159
160 CHARGE_DURATION:
161 LOAD \ %Key,
162     if(FLAG_CHARGE_END = 1 and Previous(
FLAG_CHARGE_BEGIN) = 1, round(([Acquisition
Time] - Previous([Acquisition Time])) * 24
* 60 *60)) as CHARGE_DURATION,
163     1 as FLAG_CH
164 Resident TMP2
165 Order by VIN, [Acquisition Time];
166
167 DROP Table TMP, TMP1, TMP2;
168
169
170 // Drive Start
171 //DRIVE:
172 //LOAD VIN,
173 //    [Acquisition Time],
174 //    [Gears Position],
175 //    [Mileage(km)],

```



```

217 0.41597222222223, 0.70833333333332, "normal hour"
218 0.70833333333333, 0.83263888888889, "Rush hour"
219 0.832639, 0.99999999999999, "normal
    hour"
220 ];
221
222 // Intervalle
223 IntervalMatch(TIME_NUM)
224 Join(Data_delta)
225 LOAD von,
226     bis
227 Resident Rush_Hour;
228
229 Join (Data_delta)
230 LOAD von,
231     bis,
232     rushhour
233 Resident Rush_Hour;
234
235 DROP Table Rush_Hour;
236 DROP Field von, bis;
237
238 %%%
239
240 //Sort for delta calculations with previous()
241 Data_SORT:
242 NoConcatenate LOAD * Resident Data_delta Order by
    VIN, [Acquisition Time] asc;
243
244 DROP Table Data_delta;
245 RENAME Table Data_SORT to Data_delta;
246
247 %%%
248
249 // ----- DRIVE -----
250
251 // Drive Start
252 DRIVE:
253 LOAD VIN,
254     Longitude,
255     Latitude,
256     [Acquisition Time],
257     [Gears Position],
258     [Mileage(km)],
259     [SOC(\%)],
260     \%Key,
261     if( VIN = Previous(VIN) and [Gears
        Position] = 'D' and Previous([Gears
        Position] <> 'D') or VIN <> Previous(
        VIN) and([Gears Position] = 'D') , 1,
        0) as FLAG_STOP_BEGIN

```

```

262 Resident Data_delta;
263
264 // Drive End
265 DRIVE_02:
266 NoConcatenate LOAD VIN,
267     Longitude,
268     Latitude,
269     [Acquisition Time],
270     [Gears Position],
271     [Mileage(km)],
272     [SOC(\%)] ,
273     \%Key,
274     FLAG_STOP_BEGIN,
275     if(VIN = Previous(VIN) and [Gears Position
        ] = 'D' and Previous([Gears Position]
        <> 'D') or VIN <> Previous(VIN) , 1, 0)
        as FLAG_STOP_END
276 Resident DRIVE
277 Order by VIN, [Acquisition Time] desc;
278
279 DROP Table DRIVE;
280
281 // Drive Start & End
282 DRIVE_03:
283 NoConcatenate LOAD * Resident DRIVE_02 Where
        FLAG_STOP_BEGIN <> FLAG_STOP_END;
284
285 DROP Table DRIVE_02;
286
287 // Drive Duration
288 Duration:
289 LOAD \%Key,
290     if(FLAG_STOP_END = 1 and Previous(
        FLAG_STOP_BEGIN) = 1, round(([Acquisition
        Time] - Previous([Acquisition Time])) *
        3600 * 24)) as Duration,
291     if(FLAG_STOP_END = 1 and Previous(
        FLAG_STOP_BEGIN) = 1, round(([Mileage(km)]
        - Previous([Mileage(km)])))) as Distance,
        // example not tested
292     if(FLAG_STOP_END = 1 and Previous(
        FLAG_STOP_BEGIN) = 1, round(([SOC(\%)] -
        Previous([SOC(\%)])))) as Delta_SOC, //
        example not tested
293     if(FLAG_STOP_END = 1 and Previous(
        FLAG_STOP_BEGIN) = 1, [SOC(\%)] as SOC_END
        , // example not tested
294     if(FLAG_STOP_END = 1 and Previous(
        FLAG_STOP_BEGIN) = 1, Previous([SOC(\%)]))
        as SOC_BEGIN, // example not tested
295

```

```

296      //Track Start und ende
297      if(FLAG_STOP_END = 1 and Previous(
          FLAG_STOP_BEGIN) = 1, Latitude) as
          Latitude_END, // example not tested
298      if(FLAG_STOP_END = 1 and Previous(
          FLAG_STOP_BEGIN) = 1, Longitude) as
          Longitude_END, // example not tested
299
300      if(FLAG_STOP_END = 1 and Previous(
          FLAG_STOP_BEGIN) = 1, Previous(Longitude))
          as Longitude_BEGIN, // example not tested
301      if(FLAG_STOP_END = 1 and Previous(
          FLAG_STOP_BEGIN) = 1, Previous(Latitude))
          as Latitude_BEGIN // example not tested
302
303 Resident DRIVE_03
304 Order by VIN, [Acquisition Time];
305
306 DROP Table DRIVE_03;
307
308 %%%
309
310 // ----- PARK -----
311
312 // Parking Start
313 PARK:
314 LOAD VIN,
315      [Acquisition Time],
316      [Gears Position],
317      [Mileage(km)],
318      [SOC(\%)], //
319      if( (VIN = Previous(VIN) and [Gears
          Position] = 'P' and Previous([Gears
          Position]) <> 'P') or VIN <> Previous(
          VIN) and [Gears Position] = 'P' , 1,
          0) as FLAG_STOP_BEGIN
320 Resident Data_delta;
321
322 // Parking End
323 PARK_02:
324 NoConcatenate LOAD VIN,
325      [Acquisition Time],
326      [Gears Position],
327      [Mileage(km)],
328      [SOC(\%)], //
329      FLAG_STOP_BEGIN,
330      if((VIN = Previous(VIN) and [Gears
          Position] = 'P' and Previous([Gears
          Position]) <> 'P') or VIN <> Previous(
          VIN), 1, 0) as FLAG_STOP_END
331 Resident PARK

```

```

332 Order by VIN, [Acquisition Time] desc;
333
334 DROP Table PARK;
335
336 // Parking Start & End
337 PARK_03:
338 NoConcatenate LOAD * Resident PARK_02 Where
      FLAG_STOP_BEGIN <> FLAG_STOP_END;
339
340 DROP Table PARK_02;
341
342 // Parking Duration
343 Duration:
344 LOAD \%Key,
345         if(FLAG_STOP_END = 1 and Previous(
              FLAG_STOP_BEGIN) = 1, round(([
              Acquisition Time] - Previous([
              Acquisition Time])) * 3600 * 24)) as
              Duration,
346         if(FLAG_STOP_END = 1 and Previous(
              FLAG_STOP_BEGIN) = 1, round(([Mileage(
              km)] - Previous([Mileage(km)])))) as
              Distance, // example, not tested
347         if(FLAG_STOP_END = 1 and Previous(
              FLAG_STOP_BEGIN) = 1, round(([SOC(\%)]
              - Previous([SOC(\%)])))) as Delta_SOC,
              // example not tested // >>> ERGAENZT !
              <<<<
348         if(FLAG_STOP_END = 1 and Previous(
              FLAG_STOP_BEGIN) = 1, [SOC(\%)] as
              SOC_BEGIN, // example not tested //
349         if(FLAG_STOP_END = 1 and Previous(
              FLAG_STOP_BEGIN) = 1, Previous([SOC(\%)]))
              as SOC_END // example not tested //
350 Resident PARK_03
351 Order by VIN, [Acquisition Time];
352
353 DROP Table PARK_03;
354
355 %%%%%%%%%%%%%%
356
357 // ----- Reverse -----
358
359 // Reverse Start
360 REVERSE:
361 LOAD VIN,
362         [Acquisition Time],
363         [Gears Position],
364         [Mileage(km)],
365         [SOC(\%)], // >>> ERGAENZT ! <<<<
366         \%Key,

```

```

367         if( (VIN = Previous(VIN) and [Gears
            Position] = 'R' and Previous([Gears
            Position]) <> 'R') or VIN <> Previous(
            VIN), 1, 0) as FLAG_STOP_BEGIN
368 Resident Data_delta;
369
370 // Reverse End
371 REVERSE_02:
372 NoConcatenate LOAD VIN,
373     [Acquisition Time],
374     [Gears Position],
375     [Mileage(km)],
376     [SOC(\%)], // >>> ERGAENZT ! <<<
377     \%Key,
378     FLAG_STOP_BEGIN,
379     if((VIN = Previous(VIN) and [Gears
            Position] = 'R' and Previous([Gears
            Position]) <> 'R') or VIN <> Previous(
            VIN), 1, 0) as FLAG_STOP_END
380 Resident REVERSE
381 Order by VIN, [Acquisition Time] desc;
382
383 DROP Table REVERSE;
384
385 // Reverse Start & End
386 REVERSE_03:
387 NoConcatenate LOAD * Resident REVERSE_02 Where
            FLAG_STOP_BEGIN <> FLAG_STOP_END;
388
389 DROP Table REVERSE_02;
390
391 // Reverse Duration
392 Duration:
393 LOAD \%Key,
394     if(FLAG_STOP_END = 1 and Previous(
            FLAG_STOP_BEGIN) = 1, round((
            Acquisition Time] - Previous([
            Acquisition Time])) * 3600 * 24)) as
            Duration,
395     if(FLAG_STOP_END = 1 and Previous(
            FLAG_STOP_BEGIN) = 1, round((
            [Mileage(km)] - Previous([Mileage(km)]))) as
            Distance, // example, not tested
396     if(FLAG_STOP_END = 1 and Previous(
            FLAG_STOP_BEGIN) = 1, round((
            [SOC(\%)] - Previous([SOC(\%)])
            )) as Delta_SOC,
            // example not tested // >>> ERGAENZT !
            <<<
397     if(FLAG_STOP_END = 1 and Previous(
            FLAG_STOP_BEGIN) = 1, [SOC(\%)]) as
            SOC_BEGIN, // example not tested // >>>

```

```

                                ERGAENZT ! <<<
398      if(FLAG_STOP_END = 1 and Previous(
                                FLAG_STOP_BEGIN) = 1, Previous([SOC(\%)])
                                as SOC_END // example not tested // >>>
                                ERGAENZT ! <<<
399  Resident REVERSE_03
400  Order by VIN, [Acquisition Time];
401
402  DROP Table REVERSE_03;
403
404  %%%%%%%%%%%
405
406  // ----- Neutral -----
407
408  // Neutral Start
409  NEUTRAL:
410  LOAD VIN,
411          [Acquisition Time],
412          [Gears Position],
413          [Mileage(km)],
414          [SOC(\%)], // >>> ERGAENZT ! <<<
415          \%Key,
416          if( (VIN = Previous(VIN) and [Gears
                                Position] = 'N' and Previous([Gears
                                Position]) <> 'N') or VIN <> Previous(
                                VIN), 1, 0) as FLAG_STOP_BEGIN
417  Resident Data_delta;
418
419  // Neutral End
420  NEUTRAL_02:
421  NoConcatenate LOAD VIN,
422          [Acquisition Time],
423          [Gears Position],
424          [Mileage(km)],
425          [SOC(\%)], // >>> ERGAENZT ! <<<
426          \%Key,
427          FLAG_STOP_BEGIN,
428          if((VIN = Previous(VIN) and [Gears
                                Position] = 'N' and Previous([Gears
                                Position]) <> 'N') or VIN <> Previous(
                                VIN), 1, 0) as FLAG_STOP_END
429  Resident NEUTRAL
430  Order by VIN, [Acquisition Time] desc;
431
432  DROP Table NEUTRAL;
433
434  // Neutral Start & End
435  NEUTRAL_03:
436  NoConcatenate LOAD * Resident NEUTRAL_02 Where
                                FLAG_STOP_BEGIN <> FLAG_STOP_END;
437

```

```

438 DROP Table NEUTRAL_02;
439
440 // Neutral Duration
441 Duration:
442 LOAD \;%Key,
443     if(FLAG_STOP_END = 1 and Previous(
444         FLAG_STOP_BEGIN) = 1, round(([
445             Acquisition Time] - Previous([
446                 Acquisition Time])) * 3600 * 24)) as
447         Duration,
448     if(FLAG_STOP_END = 1 and Previous(
449         FLAG_STOP_BEGIN) = 1, round(([Mileage(
450             km)] - Previous([Mileage(km)])))) as
451         Distance, // example, not tested
452     if(FLAG_STOP_END = 1 and Previous(
453         FLAG_STOP_BEGIN) = 1, round(([SOC(\%)]
454             - Previous([SOC(\%)])))) as Delta_SOC,
455         // example not tested // >>> ERGAENZT !
456         <<<
457     if(FLAG_STOP_END = 1 and Previous(
458         FLAG_STOP_BEGIN) = 1, [SOC(\%)] as
459         SOC_BEGIN, // example not tested // >>>
460         ERGAENZT ! <<<
461     if(FLAG_STOP_END = 1 and Previous(
462         FLAG_STOP_BEGIN) = 1, Previous([SOC(\%)]))
463         as SOC_END // example not tested // >>>
464         ERGAENZT ! <<<
465 Resident NEUTRAL_03
466 Order by VIN, [Acquisition Time];
467
468 DROP Table NEUTRAL_03;
469
470 // delete Duations < Zero
471 Duration2:
472 NoConcatenate LOAD * Resident Duration Where
473     Duration > 0;
474
475 DROP Table Duration;
476 RENAME Table Duration2 to Duration;
477
478 %%%
479 // min. 'D' per vehicle !!
480 // Comments: min. 'D' per VIN per Day
481 MIN_D:
482 LOAD VIN,
483     //DATE,
484     MinString([Acquisition Time]) as [
485         Acquisition Time],
486     '1' as MIN_D_FLAG

```

```
470 Resident Data_delta
471 Where [Gears Position] = 'D'
472 group by VIN//, DATE
473 ;
474
475 MAX_D:
476 LOAD VIN,
477         MaxString([Acquisition Time]) as [
478             Acquisition Time],
479         '1' as MAX_D_FLAG
480 Resident Data_delta
481 Where [Gears Position] = 'D'
482 group by VIN;
483
484 Join (Data_delta)
485 LOAD * Resident MIN_D;
486
487 Join (Data_delta)
488 LOAD * Resident MAX_D;
489
490 DROP Table MIN_D, MAX_D;
491
492 EXIT Script;
```

Appendix D

List of POIs in ArcMap 10.2.2

分类代码 Code	中文分类名称 CN	En
汽车服务相关 Automobile Service		
010100	加油站	Gas Station
010101	中国石化	Sinopec
010102	中石油	PetroChina
010103	壳牌	Shell
010104	美孚	Mobil
010105	加德士	CATDEX
010107	东方	Oreant
010108	中石油销售	PetroChina BP
010109	中石化销售	Sinopec BP
010110	通达尔	TOT
010111	埃索	Exxo
010200	其它加油站	Others
010300	加气站	Air Station
010400	汽车养护	Mobil Services
010500	洗车场	Car Wash
010600	汽车俱乐部	Car Club
010700	汽车救援	Vehicle Rescue Service.
010800	汽车配件销售	Parts
010900	汽车租赁	Rental
010901	汽车租赁5车	Rental and Return
011000	二手车交易	Used Car Trade
汽车销售 Dealers		
020000	上海大众销售	Shanghai Volkswagen
020101	一汽大众销售	FAW-Volkswagen
020102	斯柯达销售	Skoda sales
020103	VICO销售	VICO sales
020104	宾利销售	Bentley
020105	兰博基尼销售	Lamborghini
020201	广汽本田销售	Guangqi Honda
020202	东风本田销售	Dongfeng Honda
020203	本田讴歌销售	Acura
020301	一汽大众奥迪销售	Faw-vw audi
020401	凯迪拉克销售	Cadillac
020402	别克销售	Buick
020403	雪佛兰销售	Chevy
020404	欧宝销售	Opel
020405	萨博销售	SAAB
020600	宝马销售	BMW
020601	宝马MINI车销售	BMW Mini
020602	劳斯莱斯销售	Rolls-Royce
020701	东风日产销售	Dongfeng Nissan
020702	郑州日产销售	Zhengzhou Nissan
020703	英菲尼迪销售	Infiniti
020800	雷诺销售	Renault
020900	梅赛德斯-奔驰销售	Mercedes-Benz
020905	精英销售	Esprit
021000	丰田销售	Toyota
021001	一汽丰田销售	FAW Toyota
021002	广汽丰田销售	Guangqi Toyota
021003	雷克萨斯销售	Lexus
021100	斯巴鲁销售	Subaru
021201	东风雷诺龙销售	Dongfeng Citroen
021202	标致销售	Peugeot

021203	其他雷诺龙销售	Other Citroen
021300	三菱销售	Mitsubishi
021400	菲亚特销售	Fiat
021401	阿尔法-罗密欧销售	Alfa Romeo
021500	法拉利销售	Ferrari
021501	玛莎拉蒂销售	Maserati
021502	现代销售	HYUNDAI
021700	起亚销售	Kia
021800	福特销售	Ford
021802	马自达销售	Mazda
021803	林肯销售	Lincoln
021900	美洲豹销售	Jaguar
022000	路虎销售	Land-Rover
022100	保时捷销售	Porsche
022200	东风销售	DFM
022300	吉利销售	GEELY
022301	沃尔沃销售	Volvo
022400	奇瑞销售	CHERY
022500	克莱斯勒销售	Chrysler
022501	吉普销售	Jeep
022502	道奇销售	Dodge
汽车维修 Vehicle Maintenance		
030000	汽车综合维修	Comprehensive maintenance
030100	上海大众维修	Shanghai Volkswagen
030201	一汽大众维修	FAW-Volkswagen
030202	斯柯达维修	Skoda sales
030203	VICO维修	VICO sales
030204	宾利维修	Bentley
030205	兰博基尼维修	Lamborghini
030206	广汽本田维修	Guangqi Honda
030301	广汽本田维修	Guangqi Honda
030302	东风本田维修	Dongfeng Honda
030303	本田讴歌维修	Acura
030401	一汽大众奥迪维修	Faw-vw audi
030501	凯迪拉克维修	Cadillac
030502	别克维修	Buick
030503	雪佛兰维修	Chevy
030504	欧宝维修	Opel
030505	萨博维修	SAAB
030700	宝马维修	BMW
030701	宝马MINI维修	BMW Mini
030702	劳斯莱斯维修	Rolls-Royce
030801	东风日产维修	Dongfeng Nissan
030802	郑州日产维修	Zhengzhou Nissan
030803	英菲尼迪维修	Infiniti
030900	雷诺维修	Renault
031000	梅赛德斯-奔驰维修	Mercedes-Benz
031100	丰田维修	Toyota
031101	一汽丰田维修	FAW Toyota
031102	广汽丰田维修	Guangqi Toyota
031103	雷克萨斯维修	Lexus
031200	斯巴鲁维修	Subaru
031301	标致维修	Peugeot
031302	东风雷诺龙维修	Dongfeng Citroen
031303	其他雷诺龙维修	Other Citroen

031400	三菱维修	Mitsubishi
031500	菲亚特维修	Fiat
031600	法拉利维修	Ferrari
031601	法拉利维修	Ferrari
031700	现代维修	Hyundai
031800	起亚维修	Kia
031900	福特维修	Ford
031902	马自达维修	Mazda
031903	林肯维修	Lincoln
032000	路虎维修	Land Rover
032100	保时捷维修	Porsche
032200	东风维修	DFM
032400	吉利维修	Geely
032401	沃尔沃维修	Volvo
032500	奇瑞维修	Chery
032600	克莱斯勒维修	Chrysler
032601	吉普维修	Jeep
032602	道奇维修	Dodge
040000	摩托至服务相关	Motorcycle Service
050000	餐饮相关	Food and Beverage
060000	购物相关场所	Shopping
060100	商场	Mall
060101	购物中心	Shopping Center
060102	批发市场	General Store
060103	免税品店	Duty free
060200	便民商店/便利店	convenience store
060201	7-Eleven便利店	Seven-eleven
060202	OK便利店	OK store
060300	家电电子产品	Home appliance electronic stores
060301	综合家电商场	Comprehensive electrical shop
060302	国美	Gome
060303	大中	dazhong Electronics
060304	苏宁	Su-Ning electronics
060305	手机销售	Mobile Sales
060306	数码电子	Digital Electronics
060307	丰泽	Fortress
060308	苏宁数码	Suning Chitall
060400	超市	Supermarket
060401	家乐福	Carrefour
060402	沃尔玛	Wal-Mart
060403	华润	China Resources
060404	北国华联	Beijing Huailian
060405	上海华联	Shanghai huailian
060406	聚德龙	Meituo
060407	乐天玛特	Lotus Mart
060409	卜蜂莲花	Lotus
060411	屈臣氏	Watsons
060412	乐购	TESCO
060413	惠康超市	Wellcome
060414	百姓超市	Parkson
060415	万宁超市	Manning's Plus
060500	花鸟鱼虫市场	fishes and birds
060501	花卉市场	Flower Market
060502	宠物市场	pet market

060600	家居建材市场	Home building materials
060601	家居建材综合市场	furniture building materials
060602	家具城	Furniture Mall
060603	建材五金市场	Hardware building materials
060604	厨卫市场	kitchen materials
060605	布艺市场	Cloth art market
060606	灯具灯饰市场	lamps and lanterns
060700	综合市场	General Mall
060701	小商品市场	commodity fair
060702	旧货市场	flea market
060703	农产品市场	agricultural products market
060704	果品市场	fruit market
060705	蔬菜市场	vegetable market
060706	水产海鲜市场	seafood market
060800	文化用品店	stationary shop
060900	体育用品店	Sports Shop
060901	李宁专卖店	Li Ning
060902	耐克专卖店	Nike
060903	阿迪达斯专卖店	Adidas
060904	锐步专卖店	Reebok
060905	彪马专卖店	Puma
060906	高尔夫用品店	Golf
060907	户外用品	Outdoor use
061000	特色商业街	Featured Commercial Street
061001	步行街	vehicle-free promenade
061100	服装鞋帽专卖店	Clothing shoes and hats
061101	品牌服装店	Featured brands
061102	品牌鞋店	Brand shoe store
061103	品牌皮具店	Brand leather shop
061200	专营店	Specialty stores
061201	古玩字画店	Antique Store
061202	珠宝首饰工艺品店	Jewelry Store
061203	钟表店	Clock Shop
061204	眼镜店	Glasses Store
061205	书店	Book Store
061206	音像店	Video store
061207	儿童用品店	Children's Store
061208	自行车专卖店	bike store
061209	礼品饰品店	Gift shop
061210	烟酒专卖店	tobacco and liquor store
061211	宠物用品店	pet supply store
061212	摄影器材店	Photo Equipment & Supplies
061213	宝马经销商	BMW Lifestyle
061300	特殊交易场所	Special trade
061301	拍卖行	auction house
061302	典当行	Pawn shops
061400	其它个人用品店	general personal store
061401	莎莎	Sasha jewelry
070000	生活服务场所	Daily Service
070100	旅行社	travel agency
070200	信息咨询中心	Information Consulting Center
070300	售票处	Tickets office
070301	飞机票代售点	Air ticket office
070302	火车票代售点	Train ticket office
070303	长途汽车票代售点	Coach ticket office

070304	船票代售点	Boat ticket office
070305	公交车/月票代售点	bus pass office
070306	公园票务售票处	Park/recreation ticket office
070400	邮局	Post office
070401	邮政速递	Counter Post
070500	物流速递	Express Logistics
070600	电讯营业厅	telecommunications business hall
070601	中国电信业务厅	China Telecom Business Hall
070603	中国移动营业厅	China Mobile Office
070604	中国联通营业厅	China unicom business hall
070605	中国网通营业厅	China telecom business hall
070606	中国卫通营业厅	China satcom business hall
070607	和记电讯	Hutchison Telecom
070608	数码通讯	SMA RTONE TELE
070609	电讯盈科	Pacific Century CyberWorks Ltd
070610	中国移动香港	China Mobile HK
070700	事务所	law firm
070701	律师事务所	accounting firm
070702	会计师事务所	Evaluation firm
070703	评估事务所	audit firm
070704	审计事务所	Certified firm
070705	认证事务所	patent agency
070706	专利事务所	table market
070800	人才市场	tap water business hall
070900	自来水管业厅	Electric power business hall
071000	电力营业厅	Beauty parlor
071100	美容美发店	Site maintenance
071200	维修站点	Film developing
071300	摄影冲印	Bath massage Place
071400	洗浴桑拿场所	Laundry
071500	洗衣店	intermediary agency
071600	中介机构	moving company
071700	搬家公司	Lottery ticket office
071800	彩票影射售票点	Jockey Club betting centre
071801	马会投注站	Funeral facilities
071900	殡葬设施	cemetery
071901	公墓	memorial park
071902	公墓	funeral home
071903	殡仪馆	Sport court
080000	体育休闲服务场所	Sports Leisure Service
080100	运动场所	Sport court
080101	综合体育馆	general stadium
080102	保龄球馆	bowling alley
080103	网球场	tennis court
080104	篮球场	basketball fields
080105	足球场	football field
080106	滑雪场	ski resort
080107	溜冰场	ice rink
080108	户外健身场所	Outdoor fitness
080109	海滨浴场	bathing beach
080110	游泳池	swimming pool
080111	健身中心	fitness center
080112	乒乓球馆	Table Tennis
080113	台球厅	pool room
080114	壁球场	squash court

080115	马术俱乐部	Saddle Club
080116	赛马场	race course
080117	橄榄球场	football field
080118	羽毛球场	badminton court
080119	跆拳道馆	Taekwondo venue
080200	高尔夫相关	Golf
080201	高尔夫球场	Golf court
080202	高尔夫练习场	Golf practice court
080300	娱乐场所	entertainment venues
080301	夜总会	night club
080302	KTV	KTV
080303	迪厅	Disco
080304	酒吧	Bar
080305	游戏厅	Game room
080306	棋楼	Chess Room
080307	博彩中心	Digg center
080308	网吧	Internet cafe
080400	度假疗养场所	Resort spa
080401	度假村	holiday village
080402	疗养院	sanatorium
080500	休闲场所	leisure facility
080501	游乐场	playground
080502	垂钓园	Fishing park
080503	采摘园	pickling garden
080504	露营地	camping ground
080505	水上活动中心	Water Sports Centre
080600	影剧院相关	Cinema related
080601	电影院	Movie theater
080602	音乐厅	Music hall
080603	剧场	Open hall
080600	医疗保健服务场所	Health care services
080700	综合医院	
080701	三级甲等医院	
080702	卫生院	
080703	专科医院	
080704	整形美容	
080705	口腔医院	
080706	眼科医院	
080707	耳鼻喉医院	
080708	牙科医院	
080709	肿瘤医院	
080710	精神科医院	
080711	传染病医院	
080712	急救中心	
080713	急救中心	
080714	急救中心	
080715	急救中心	
080716	急救中心	
080717	急救中心	
080718	急救中心	
080719	急救中心	
080720	急救中心	
080721	急救中心	
080722	急救中心	
080723	急救中心	
080724	急救中心	
080725	急救中心	
080726	急救中心	
080727	急救中心	
080728	急救中心	
080729	急救中心	
080730	急救中心	
080731	急救中心	
080732	急救中心	
080733	急救中心	
080734	急救中心	
080735	急救中心	
080736	急救中心	
080737	急救中心	
080738	急救中心	
080739	急救中心	
080740	急救中心	
080741	急救中心	
080742	急救中心	
080743	急救中心	
080744	急救中心	
080745	急救中心	
080746	急救中心	
080747	急救中心	
080748	急救中心	
080749	急救中心	
080750	急救中心	
080751	急救中心	
080752	急救中心	
080753	急救中心	
080754	急救中心	
080755	急救中心	
080756	急救中心	
080757	急救中心	
080758	急救中心	
080759	急救中心	
080760	急救中心	
080761	急救中心	
080762	急救中心	
080763	急救中心	
080764	急救中心	
080765	急救中心	
080766	急救中心	
080767	急救中心	
080768	急救中心	
080769	急救中心	
080770	急救中心	
080771	急救中心	
080772	急救中心	
080773	急救中心	
080774	急救中心	
080775	急救中心	
080776	急救中心	
080777	急救中心	
080778	急救中心	
080779	急救中心	
080780	急救中心	
080781	急救中心	
080782	急救中心	
080783	急救中心	
080784	急救中心	
080785	急救中心	
080786	急救中心	
080787	急救中心	
080788	急救中心	
080789	急救中心	
080790	急救中心	
080791	急救中心	
080792	急救中心	
080793	急救中心	
080794	急救中心	
080795	急救中心	
080796	急救中心	
080797	急救中心	
080798	急救中心	
080799	急救中心	
080800	急救中心	
080801	急救中心	
080802	急救中心	
080803	急救中心	
080804	急救中心	
080805	急救中心	
080806	急救中心	
080807	急救中心	
080808	急救中心	
080809	急救中心	
080810	急救中心	
080811	急救中心	
080812	急救中心	
080813	急救中心	
080814	急救中心	
080815	急救中心	
080816	急救中心	
080817	急救中心	
080818	急救中心	
080819	急救中心	
080820	急救中心	
080821	急救中心	
080822	急救中心	
080823	急救中心	
080824	急救中心	
080825	急救中心	
080826	急救中心	
080827	急救中心	
080828	急救中心	
080829	急救中心	
080830	急救中心	
080831	急救中心	
080832	急救中心	
080833	急救中心	
080834	急救中心	
080835	急救中心	
080836	急救中心	
080837	急救中心	
080838	急救中心	
080839	急救中心	
080840	急救中心	
080841	急救中心	
080842	急救中心	
080843	急救中心	
080844	急救中心	
080845	急救中心	
080846	急救中心	
080847	急救中心	
080848	急救中心	
080849	急救中心	
080850	急救中心	
080851	急救中心	
080852	急救中心	
080853	急救中心	
080854	急救中心	
080855	急救中心	
080856	急救中心	
080857	急救中心	
080858	急救中心	
080859	急救中心	
080860	急救中心	
080861	急救中心	
080862	急救中心	
080863	急救中心	
080864	急救中心	
080865	急救中心	
080866	急救中心	
080867	急救中心	
080868	急救中心	
080869	急救中心	
080870	急救中心	
080871	急救中心	
080872	急救中心	
080873	急救中心	
080874	急救中心	
080875	急救中心	
080876	急救中心	
080877	急救中心	
080878	急救中心	
080879	急救中心	
080880	急救中心	
080881	急救中心	
080882	急救中心	
080883	急救中心	
080884	急救中心	
080885	急救中心	
080886	急救中心	
080887	急救中心	
080888	急救中心	
080889	急救中心	
080890	急救中心	
080891	急救中心	
080892	急救中心	
080893	急救中心	
080894	急救中心	
080895	急救中心	
080896	急救中心	
080897	急救中心	
080898	急救中心	
080899	急救中心	
080900	急救中心	
080901	急救中心	
080902	急救中心	
080903	急救中心	
080904	急救中心	
080905	急救中心	
080906	急救中心	
080907	急救中心	
080908	急救中心	
080909	急救中心	
080910	急救中心	
080911	急救中心	
080912	急救中心	
080913	急救中心	
080914	急救中心	
080915	急救中心	
080916	急救中心	
080917	急救中心	
080918	急救中心	
080919	急救中心	
080920	急救中心	
080921	急救中心	
080922	急救中心	
080923	急救中心	
080924	急救中心	
080925	急救中心	
080926	急救中心	
080927	急救中心	
080928	急救中心	
080929	急救中心	
080930	急救中心	
080931	急救中心	
080932	急救中心	
080933	急救中心	
080934	急救中心	
080935	急救中心	
080936	急救中心	
080937	急救中心	
080938	急救中心	
080939	急救中心	
080940	急救中心	
080941	急救中心	
080942	急救中心	
080943	急救中心	
080944	急救中心	
080945	急救中心	
080946	急救中心	
080947	急救中心	
080948	急救中心	
080949	急救中心	
080950	急救中心	
080951	急救中心	
080952	急救中心	
080953	急救中心	
080954	急救中心	
080955	急救中心	
080956	急救中心	
080957	急救中心	
080958	急救中心	
080959	急救中心	
080960	急救中心	
080961	急救中心	
080962	急救中心	
080963	急救中心	
080964	急救中心	
080965	急救中心	
080966	急救中心	
080967	急救中心	
080968	急救中心	
080969	急救中心	
080970	急救中心	
080971	急救中心	
080972	急救中心	
080973	急救中心	
080974	急救中心	
080975	急救中心	
080976	急救中心	
080977	急救中心	
080978	急救中心	
080979	急救中心	
080980	急救中心	
080981	急救中心	
080982	急救中心	
080983	急救中心	
080984	急救中心	
080985	急救中心	
080986	急救中心	
080987	急救中心	
080988	急救中心	
080989	急救中心	
080990	急救中心	
080991	急救中心	
080992	急救中心	
080993	急救中心	
080994	急救中心	
080995	急救中心	
080996	急救中心	
080997	急救中心	
080998	急救中心	
080999	急救中心	
081000	急救中心	
081001	急救中心	
081002	急救中心	
081003	急救中心	
081004	急救中心	
081005	急救中心	
081006	急救中心	
081007	急救中心	
081008	急救中心	
081009	急救中心	
081010	急救中心	
081011	急救中心	
081012	急救中心	
081013	急救中心	
081014	急救中心	
081015	急救中心	
081016	急救中心	
081017	急救中心	
081018	急救中心	
081019	急救中心	
081020	急救中心	
081021	急救中心	
081022	急救中心	
081023	急救中心	
081024	急救中心	
081025	急救中心	
081026	急救中心	
081027	急救中心	
081028	急救中心	
081029	急救中心	
081030	急救中心	
081031	急救中心	
081032	急救中心	
081033	急救中心	
081034	急救中心	
081035	急救中心	
081036	急救中心	
081037	急救中心	
081038	急救中心	
081039	急救中心	
081040	急救中心	
081041	急救中心	
081042	急救中心	
081043	急救中心	
081044	急救中心	
081045	急救中心	
081046	急救中心	
081047	急救中心	
081048	急救中心	
081049	急救中心	
081050	急救中心	
081051	急救中心	
081052	急救中心	
081053	急救中心	
081054	急救中心	
081055	急救中心	
081056	急救中心	
081057	急救中心	
081058	急救中心	
081059	急救中心	
081060	急救中心	
081061	急救中心	
081062	急救中心	
081063	急救中心	
081064	急救中心	
081065	急救中心	
081066	急救中心	
081067	急救中心	
081068	急救中心	
081069	急救中心	
081070	急救中心	
081071	急救中心	
081072	急救中心	
081073	急救中心	
081074	急救中心	
081075	急救中心	
081076	急救中心	
081077	急救中心	
081078	急救中心	
081079	急救中心	
081080	急救中心	
081081	急救中心	
081082	急救中心	
081083	急救中心	
081084	急救中心	
081085	急救中心	
081086	急救中心	
081087	急救中心	
081088	急救中心	
081089	急救中心	
081090	急救中心	
081091	急救中心	
081092	急救中心	
081093	急救中心	
081094	急救中心	
081095	急救中心	
081096	急救中心	
081097	急救中心	
081098	急救中心	
081099	急救中心	
081100	急救中心	
081101	急救中心	
081102	急救中心	
081103	急救中心	
081104	急救中心	
081105	急救中心	
081106	急救中心	
081107	急救中心	
081108	急救中心	
081109	急救中心	
081110	急救中心	
081111	急救中心	
081112	急救中心	
081113	急救中心	
081114	急救中心	
081115	急救中心	
081116	急救中心	
081117	急救中心	
081118	急救中心	
081119	急救中心	
081120	急救中心	
081121	急救中心	
081122	急救中心	
081123	急救中心	
081124	急救中心	
081125	急救中心	
081126	急救中心	
081127	急救中心	
081128	急救中心	
081129	急救中心	
081130	急救中心	
081131	急救中心	
081132	急救中心	
081133	急救中心	
081134	急救中心	
081135	急救中心	
081136	急救中心	
081137	急救中心	
081138	急救中心	
081139	急救中心	
081140	急救中心	
081141		

100100	宾馆酒店	Hotel	130408	慈善机构	charitable organization
100102	五星级宾馆	five - star hotel	130409	教会	Church
100103	四星级宾馆	four - star hotel	130500	公检法机关	public security organs
100104	三星级宾馆	three - star hotel	130501	公安警察	Public Security Police
100105	经济型连锁酒店	economical chain hotels	130502	检察院	procuratorate
100200	旅馆招待所	guest house	130503	法院	court
100201	青年旅舍	hostel	130504	消防机关	Fire forces
旅游景区			130505	公证处公证机构	Notary authentication institutions
110100	公园广场	Park plaza	130506	社会治安机构	Social security agencies
110101	公园	Park	130600	交通管理部门相关	Traffic management office
110102	动物园	Zoo	130601	交通管理部门	Transport Ticketing
110103	植物园	botanical garden	130602	车辆管理机构	Vehicle management
110104	水族馆	aquarium	130603	赛车场	Vehicle Checking
110105	城市广场	city square	130604	交通执法站	Traffic law enforcement station
110200	风景名胜	scenic attraction	130700	工商税务机构	Industrial and commercial tax authorities
110201	世界遗产	world class heritage	130701	工青部门	Business administration
110202	国家级景点	State class scenic spots	130702	国防机关	National tax authorities
110203	省级景点	Province class scenic spots	130703	地税机关	Tax office
110204	纪念馆	memorial hall	140000 科教文化场所		
110205	纪念馆	Temples	140100	博物馆	Science and Cultural
110206	教堂	Church	140101	奥迪博物馆	musium
110207	清真寺	mosque	140102	奔驰博物馆	Auto museum
110208	海滩	beach	140200	展览馆	mercedes-benz museum
120000 商务住宿相关			140300	会展中心	exhibition hall
120100	产业园区	industrial parks	140400	美术馆	convention center
120200	楼宇相关	Building related	140500	图书馆	Gallery
120201	商务写字楼	Commercial Building	140501	科技馆	library
120202	工业大厦建筑物	Industrial building	140600	天文馆	science & technology museum
120203	商住两用楼宇	Residential complex building	140700	文化馆	planetarium
120300	住宅区	residential area	140800	档案馆	cultural palace
120301	别墅	villa	140900	文艺团体	archives
120302	住宅小区	residence community	141000	传媒机构	literature and art organization
120303	宿舍	dorms	141100	电视台	Media Agency
120304	社区中心	community center	141101	电台	TV station
130000 政府及社会团体相关			141102	报社	broadcasting station
130100	政府机关相关	Government and social Groups	141103	杂志社	newspaper office
130101	国家级机关及事业单位	National authorities and institutions	141104	杂志社	periodical office
130102	省级城市级政府及事业单位	Provincial municipal levels of government and business units	141105	出版社	press company
130103	地市级政府及事业单位	municipal government and institutions	141200	学校	school
130104	区县级政府及事业单位	district government and institutions	141201	高等院校	colleges and universities
130105	乡镇级政府及事业单位	Township-level government and institutions	141202	小学	middle school
130106	乡镇以下级政府及事业单位	Township government at a lower level and business units	141203	幼儿园	primary school
130107	外地政府办	Foreign government	141204	成人教育	kindergarten
130200	外事机构相关	Foreign institutions	141205	职业技术学校	adult education
130201	外国使领馆	embassy	141206	科研机构	vocational-technical school
130202	国际组织办事处	International office	141300	培训机构	scientific research institution
130300	民主党派	democratic parties	141400	驾校	training institution
130400	社会团体相关	social groups	141500	150000 交通服务相关	
130401	共青团	communist youth league	150100	飞机场	Airport
130402	妇联	chinese young pioneers	150200	火车站	Train station
130403	妇联	the Women's Federation	150300	港口码头	Port
130404	残联	China CPPF	150301	客运站	passenger port
130405	红十字会	Red Cross	150302	车渡口	Car ferry
130406	消费者协会	consumers' association	150303	入渡口	passenger ferry
130407	行业协会	trade association	150400	长途汽车站	coach station

150500	地铁站	subway station
150600	轻轨站	light rail station
150800	班车站	shuttle bus stop
150900	停车场相关	Parking
150903	换乘停车场	Park-and-go
150904	公共停车场	public parking lot
150905	专用停车场	reserved parking
150906	路边停车场	curb parking
151000	过境口岸	Transit port
160000	金融保险机构	Financial Insurance Institutions
160100	银行	Bank
160101	中国人民银行	People's Bank of China
160102	国家开发银行	china development bank
160103	中国进出口银行	china ex-simport bank
160104	中国银行	bank of china
160105	中国工商银行	industrial and commercial bank of china
160106	中国建设银行	china construction bank
160107	中国农业银行	Agricultural Bank of China
160108	交通银行	Bank of Communications
160109	招商银行	china merchants bank
160110	华夏银行	huaxia bank
160111	中信银行	china citic bank
160112	中国民生银行	china minsheng bank
160113	中国光大银行	China Everbright Bank
160114	上海银行	Bank of Shanghai
160115	上海浦东发展银行	Shanghai Pudong Development Bank
160117	平安银行	Ping An Bank
160118	兴业银行	industrial bank
160119	北京银行	beijing bank
160120	广发银行	Guangdong Development Bank
160121	农村商业银行	rural commercial bank
160122	香港通生银行	HANG SENG bank
160123	东亚银行	Bank of East Asia
160124	花旗银行	Citibank
160125	渣打银行	Standard Chartered Bank
160126	汇丰银行	Hong Kong and Shanghai Banking Corporation
160127	荷兰银行	Algemene Bank Nederland
160130	美商银行	Bank of America
160131	蒙特利尔银行	Bank of Montreal
160133	苏格兰皇家银行	royal bank of scotland
160134	法国兴业银行	Societe Generale
160135	德意志银行	Deutsche Bank
160136	日本三井物产银行	barclays bank
160137	巴克莱银行	JPMorgan Chase
160138	摩根大通银行	Postal Savings Bank of China
160139	中国邮政储蓄银行	Hong Seng Bank
160140	香港渣打银行	Nanyang Commercial Bank
160141	南洋商业银行	Shanghai Commercial Bank
160142	上海商业银行	Wing Hang Bank
160143	永亨银行	Wing Lung Bank
160144	香港永隆银行	dah sing bank
160145	创兴银行	dah sing bank
160146	大新银行	CTIC Bank International
160147	中信银行国际	Public bank (Hong Kong)
160148	大众银行(香港)	

160200	银行相关	Bank related
160300	自动提款机	ATM
160301	中国银行ATM	bank of china ATM
160302	中国工商银行ATM	industrial and commercial bank of china ATM
160303	中国建设银行ATM	china construction bank ATM
160304	中国农业银行ATM	Agricultural Bank of China ATM
160305	交通银行ATM	Bank of Communications ATM
160306	招商银行ATM	china merchants bank ATM
160307	华夏银行ATM	huaxia bank ATM
160308	中信银行ATM	china citic bank ATM
160309	中国民生银行ATM	china minsheng bank ATM
160310	中国光大银行ATM	China Everbright Bank ATM
160311	上海银行ATM	Bank of Shanghai ATM
160312	上海浦东发展银行ATM	Shanghai Pudong Development Bank ATM
160314	平安银行ATM	Ping An Bank ATM
160315	兴业银行ATM	industrial bank ATM
160316	北京银行ATM	beijing bank ATM
160317	广发银行ATM	Guangdong Development Bank ATM
160318	农村商业银行ATM	rural commercial bank ATM
160319	香港通生银行ATM	HANG SENG bank ATM
160320	东亚银行ATM	Bank of East Asia ATM
160321	花旗银行ATM	Citibank ATM
160322	渣打银行ATM	Standard Chartered Bank ATM
160323	汇丰银行ATM	Hong Kong and Shanghai Banking Corporation ATM
160331	法商兴业银行ATM	Societe Generale ATM
160332	德意志银行ATM	Deutsche Bank ATM
160336	中国工商银行ATM	Postal Savings Bank of China ATM
160337	香港通生银行ATM	Hong Seng Bank ATM
160338	南洋商业银行ATM	Nanyang Commercial Bank ATM
160339	上海商业银行ATM	Shanghai Commercial Bank ATM
160340	永亨银行ATM	Wing Hang Bank ATM
160341	香港永隆银行ATM	Wing Lung Bank ATM
160342	创兴银行ATM	ehong hing bank ATM
160343	大新银行ATM	dah sing bank ATM
160344	中信银行国际ATM	CTIC Bank International ATM
160345	大众银行(香港)ATM	Public bank (Hong Kong) ATM
160400	保险公司	Insurance Company
160401	中国人民保险公司	people's insurance company of china
160402	中国人寿保险公司	China Life Insurance Company
160403	中国平安保险公司	Ping An Insurance Company of China
160404	中国再保险公司	China P&C Re
160405	中国平安保险	China Pacific Insurance
160406	新华人寿保险公司	New China life insurance company
160407	华安财产保险股份有限公司	Huatai property insurance
160408	泰康人寿保险公司	Taikang Life Insurance
160500	证券公司	security company
160501	证券营业厅	The brokerage
160600	财务公司	Finance company
170000	公司企业	Corporate/Business
170100	知名企业	well-known enterprise
170200	广告装饰	company
170201	装饰公司	Advertising/Decoration
170202	装修公司	construction company
170203	医药公司	medical corporation
170204	机械电子	mechano-electronic

170205	冶金化工	Engineering Chemistry & Metallurgy
170206	网络科技	Internet technology
170207	商业贸易	commercial trade
170208	电信运营	telecom
170209	矿产公司	mineral company
170300	工厂	factory
170400	其它农林渔基地	Agriculture, forestry and fishing base
道路附属设施		Road Affiliated Facilities
180000	收费站	toll station ;
180200	高速公路服务区	highway service zone
180301	高速公路加油站服务区	highway gas station service zone
180302	高速公路服务区	highway parking zone
道路相关信息		Road related information
190000	路口名	cross name
190302	环岛名	island name
190303	高速公路出口	highway exit
190304	高速公路入口	highway entry
190305	高速公路出口	city highway exit
190308	城市快速路出口	city highway exit
190309	城市快速路入口	city highway entry
190310	隧道	tunnel
公共设施		Public Facility
200000	接待亭	newsstand
200100	公用电话	public telephone
200200	公共厕所	public restroom
200300	紧急避难场所	emergency refuge space
200400		