UNIVERSITÄT BAYREUTH

# Toward Sustainable Smart Cities: Driving Sustainable Innovation in Districts and Mobility

**Dissertation**

zur Erlangung des Grades eines Doktors der Wirtschaftswissenschaft

der Rechts- und Wirtschaftswissenschaftlichen Fakultät

der Universität Bayreuth

*Vorgelegt*

*von*

*Felix Walter Röhrich*

*aus*

*Augsburg*

| | |
|---|---|
| *Dekan:* | *Prof. Dr. André Meyer* |
| *Erstberichterstatter:* | *Prof. Dr. Maximilian Röglinger* |
| *Zweitberichterstatter:* | *Prof. Dr. Robert Keller* |
| *Tag der mündlichen Prüfung:* | *22.06.2023* |

## Abstract

Urbanization and climate change represent significant challenges that require a rethinking of urban living in many areas. The development of sustainable smart cities addresses these challenges and makes cities both more sustainable and suitable for the increasing number of people residing in dense environments. Digitalization can contribute significantly to this development: On the one hand, through new technologies that make previous approaches more efficient and simpler and, on the other hand, through entirely new services that can be realized only through the new possibilities engendered through technological progress. Sustainable smart cities are complex constructs that require the involvement of a diverse range of stakeholders, including citizens, local governments, and private sector organizations. In this challenging transformation process for cities, it is important to avoid top-down approaches. Otherwise, solutions will emerge that do not meet the real needs of the citizens.

This cumulative doctoral thesis focuses on two specific sectors of sustainable smart cities: Districts, which represent the immediate living environment of citizens and mobility, which connects citizens to the rest of the city. Districts can serve as a bridge between the promised advantages of sustainable smart cities and their implementation close to the real needs of citizens. Beyond the district itself, urban mobility connects citizens to the rest of the city, as workplaces and leisure activities usually are spread all over the city or nearby areas. More research is needed to develop these sectors to be a beneficial part of sustainable smart cities. To avoid top-down approaches and achieve long-term effects, we need a citizen-centric understanding of these areas to design the components appropriately. The use of information systems research can assist in the understanding and design of innovative sustainable business models.

The overarching aim of this thesis is to support science and practice in driving sustainable innovation in the fields of districts and mobility to come closer to achieving the existing ideal of a sustainable smart city. The thesis contributes to the existing research on sustainable smart cities by providing insights into diverse aspects of urban design, citizen engagement, mobility, and information systems in the course of the development of sustainable smart cities.

# Table of Contents

# I. Introduction[1]

## 1 Motivation

Urbanization and climate change are two of the most pressing issues of our time, requiring a fundamental rethinking of urban development. Climate change has led to global warming, making weather events more extreme and engendering an increasing number of threats to human life (Jain et al., 2022). The results of the latest report of the Intergovernmental Panel on Climate Change show the urgency of this development, as we are expected to exceed the 1.5 °C limit for global warming above pre-industrial levels already within the next ten years (Intergovernmental Panel on Climate Change, 2023). The increase in greenhouse gas emissions is a key factor that contributes to climate change, and this increase has persisted across all sectors, including cities, which demand energy and mobility for their citizens (Intergovernmental Panel on Climate Change, 2023). Concurrently, urban areas play a crucial role in both direct and indirect global effects associated with energy usage, alterations in land usage, and the escalation of resource consumption (Burger et al., 2017; Burger et al., 2019; Galli et al., 2020).

However, despite the environmental impacts, cities continue to grow year by year. Urbanization is a massive trend that has accelerated in recent decades, with more than half of the world's population living in cities (United Nations, 2019). Urbanization is not a new phenomenon. It has been a major trend in human history but accelerated in recent decades as the world's population became increasingly concentrated in urban areas. While urbanization can bring many benefits, it also poses challenges and cities encounter a greater level of complexity in tackling the issues that they already confront, which include traffic congestion, ecological harm, insufficient and outdated infrastructure, unaffordability, non-expandable healthcare and education systems, social fragmentation, poverty, scarcity of resources such as water, energy, healthcare, and housing (Rosemann et al., 2020; Sun et al., 2020; Liu et al., 2022; Zhang et al., 2022).

Consequently, cities are often caught in a problematic dichotomy: They are, simultaneously, a partial cause of the problem and, in their development into smart cities, a significant part of the solution (Benevolo et al., 2016; Bibri, 2018). The emergence of smart cities is seen as a promising solution, aiming to create more sustainable and livable urban environments for an increasing number of people on limited land (Marrone and Hammerle, 2018). Smart cities, through the

[1] This section partly comprises content from this thesis' research articles. To improve the readability of the text, I omitted the standard labelling of these citations.

use of innovative technologies, optimize space and resources while reducing carbon footprints. Sustainable smart cities (SSC) aim to integrate sustainability goals into urban development and design, promoting economic, environmental, and social sustainability (Silva et al., 2018; Macke et al., 2019). Accordingly, smart cities have expedited sustainability transitions by implementing information and communication technologies along with smart mobility and energy technology (Fridgen et al., 2020; Kutty et al., 2020; Gimpel et al., 2021). The success of implementing these technologies has demonstrated that developing SSCs can be essential in attaining the United Nations' Sustainable Development Goals (Corbett and Mellouli, 2017). By merging the transformational potential of information systems (IS) with the sustainability-related strategies of cities, SSCs can be instrumentalized in handling the grand challenges of our times, such as climate change and urban resilience (Silva et al., 2018; Thomson et al., 2021).

SSCs are very complex constructs, thus, involving citizens in their development can be very difficult (Ji et al., 2021). Districts can serve as a bridge between the promised advantages of SSCs and their implementation close to the real needs of citizens (Hosseini et al., 2018; Graf-Drasch et al., 2022). In this context, a district denotes an area of connected buildings, including green areas, and it is pertinent to focus on this contained compass because the best practice, by consensus, is to connect and familiarize citizens with one another in their immediate environment before any services or further measures are introduced at a smart city level (Brauer and Kolbe, 2016; Ramaswami et al., 2016). In previous smart city initiatives, top-down approaches can often be recognized, which, in many cases, have led to a lack of acceptance among the population (Angelidou, 2017; Corbett and Mellouli, 2017). In districts, we are able to follow bottom-up approaches, which enables a design closer to residents. Furthermore, from a district perspective, it is often easier to detect synergistic effects between various areas such as mobility and energy than at the level of the entire city (Powell et al., 2022). Sustainable smart districts (SSD) focus on supporting their citizens in living a sustainable life, especially an ecologically sustainable life, as urbanization is driven by the built infrastructure, which has a significant impact on the environment and efforts to safeguard environmental sustainability (Hosseini et al., 2018; Martin et al., 2019). As recent studies have indicated, urban planners have yet to tap into the considerable potential of Green Information Systems (Green IS) for bringing ecologically sustainable services to citizens within their immediate environment and supporting sustainable behavior (Corbett and Mellouli, 2017; Bartelt et al., 2020; Velsberg et al., 2020). Green IS aim to foster environmental sustainability with the use of information technology (IT) (Harnischmacher et al. 2020). As most established Green IS designs in the smart city context are provider centric, they tend to disregard the real needs of citizens, such as transparent services, ease of access, and usability for people with impairments (Rosemann et al. 2020). Considering this potential of Green IS in SSDs, a major part of this work is dedicated to SSDs and the citizen-centric (bottom-up) designs of the Green IS within them.

Beyond the district itself, the subsequent building block of SSCs is mobility. Urban mobility connects citizens to the rest of the city, as workplaces and leisure activities are normally spread all over the city or located in the city's neighboring regions. Urban transport contributes a large part of emissions and requires considerable space. Thus, changes in mobility are an important part of the transformation to sustainable urban living, making mobility an essential factor in city and district planning (Le Boennec et al., 2019; Pribyl et al., 2020). As in districts, technology-driven, mobility concepts can drive the sustainable transformation of urban areas (Cledou et al., 2018). Thus, I want to analyze these mobility concepts more deeply within this thesis.

Most sustainable mobility concepts are a response to the fact that less individual mobility is needed in cities (Benevolo et al., 2016; Barr, 2018). Many residents do not need their own car, as it is usually used only for a fraction of the day and is, therefore, not cost effective for the owners (Shoup, 2019; Hjorteset and Böcker, 2020). Shared mobility approaches are, consequently, especially successful in cities. One of the most successful concepts of recent times is carsharing (CS) (Shaheen and Cohen, 2013; Cohen and Kietzmann, 2014). CS is an innovative opportunity to reduce the negative effects of individual motorized traffic and fosters sustainable transport in urban areas (Stillwater et al., 2009; Ferrero et al., 2018; Münzel et al., 2018; Shaheen and Cohen, 2020). Additionally, CS contributes to reducing individual car ownership and saves valuable space in cities and their districts (Martin et al., 2010; Shaheen and Cohen, 2013; Thigpen, 2018). Due to the reduced production of new cars, greater use of sustainable cars, and fewer kilometers driven, CS significantly decreases greenhouse gas emissions (Loose, 2010; Martin and Shaheen, 2011; Chen and Kockelman, 2016). However, this service is still used by a very small part of the population and the user numbers of CS in its current form show tendencies of saturation in European and North American markets (Shaheen, 2020). Therefore, the offered services need to evolve and be tailored to the needs of the users. To do this, we need to understand the usage behavior of active CS users and use these insights for the design of future mobility concepts. One way to do this is to first divide users into groups and understand them and their driving behavior (Ferrero et al., 2018). Key driving behavior metrics help understand the areas that operators need to target to improve their business models. Besides improving their services by analyzing customer behavior, the operator also faces various challenges to keep the service profitable. IS research can foster profitability in CS systems, akin to how it has engendered improvements in similar fields of research, e.g. in the development of charging approaches for electric cars (Baumgarte et al., 2021b; Baumgarte et al., 2022a). However, this is very challenging, especially for smaller operators, as they often lack digital capabilities within their organizations (Keller et al., 2022). Nevertheless, operators should be supported in using these tools to raise profitability and their service level (Cledou et al., 2018). One exemplary approach to broaden the use of CS among the population is to determine the most optimal locations for CS stations depending on the user groups. An alternative possibility involves achieving the best possible vehicle usage in the system across different stations (Ferrero et al., 2018). Another way is to integrate the service into more comprehensive mobility products. Mobility as a service (MaaS) concepts combine different forms of mobility to offer customers a wide transport choice and, therefore the possibility to choose freely and according to their needs (Jittrapirom et al., 2017; Polydoropoulou et al., 2020). For CS operators, these concepts offer opportunities to enlarge their customer base. Thus far, the inclusion of CS in such systems has not been examined extensively in research. As there is much potential for CS in MaaS concepts, we have a closer look how such an inclusion is structured and how customers react on the resulting mobility offers. Especially in SSC, MaaS concepts can use their full potential by using existing data on citizens' needs to improve their services.

In addition to the two perspectives of districts and mobility, there are several other important developments toward SSCs, including the sectors of energy, healthcare, education, water, and smart waste management (Rosemann et al., 2020). Despite and because of the substantial relevance of these sectors, I have to limit this thesis to the consideration of two sectors: districts and mobility. Additionally, in the selected areas, only specific aspects were emphasized. For instance, despite CS being a well-known option for sustainable urban mobility, it is not the only one. Other alternatives must also be considered and backed by scientific research. By framing the topic in this way in this thesis, it is possible to achieve the necessary depth at the individual points to create added value for the development of SSCs.

## 2 Research Aim

To meet the challenges of urbanization and climate change, society must initiate developments toward the SSC in many areas (Silva et al., 2018; Macke et al., 2019). The means of digitalization can make a significant contribution to this: Through new technologies that make previous approaches more efficient and simpler and through completely new services that can be realized only through the new possibilities (Kutty et al., 2020; Gimpel et al., 2021). SSCs use these new technologies to attain various goals. This thesis highlights research in two interrelated areas that are central to the cities of tomorrow. In the area of housing, SSDs should be investigated, as successful transformation can only be developed close to and with the actual residents (Harnischmacher et al., 2020). As districts are responsible for large parts of the $CO_2$ emissions of cities and, at the same time, often a relevant perspective in the search for the origin of social problems, they are of big relevance in the SSC development. Furthermore, due to increasing urban migration, space in urban areas is becoming increasingly scarce (Sun et al., 2020). In the area of mobility, the elementary connection of citizens to areas outside of their districts, exist similar problems related to emissions and scarcity of space (Le Boennec et al., 2019). Individual mobility, particularly, is an environmental problem for cities, as the production of mostly petrol-powered cars is extremely resource intensive (Pribyl et al., 2020).

The first research area, therefore, is supporting research and practice in designing SSDs to make them attractive to residents and effectively integrate them into an overall picture of a sustainable smart city. To achieve this, a clear definition of the SSD is needed for all stakeholders of a potential district. Furthermore, sufficient research has still not been conducted on how to create SSDs and under which circumstances they are successful (Hosseini et al., 2018; Reuver et al., 2018). It is important to know more about the factors that are relevant for cities and other stakeholders when planning such districts (Bastidas et al., 2018; Bastidas et al., 2021). In this thesis, I intend to first present preliminary insights into the design of such SSDs. This is followed by a description of how guidelines can be supportive in designing such districts. When such framework conditions for the design of a district have been created and tested, the next step is to support all stakeholders in achieving their sustainability-related goals (Kumar et al., 2020). Green IS, among other measures, can support this development. Green IS aims to foster environmental sustainability with the use of IT (Harnischmacher et al., 2020). Guidelines for Green IS applications in SSDs can be useful in building Green IS close to the needs of citizens and their immediate surroundings (Seidel et al., 2018; Mora et al., 2019). However, sufficient research has not been conducted on the use of Green IS in the context of SSDs. Thus, similar to the design of the SSDs itself, stakeholders need support and guidelines in the development of Green IS in SSDs. This thesis provides this support in form of design guidelines for Green IS in SSDs.

Beyond the district itself, the individual areas of everyday life must also be understood and further developed to reach sustainability on a city level. The second research area “mobility” has a major influence on the climate and the respective urban environment. Urban mobility is a significant contributor to emissions and space limitations, yet mobility remains a crucial aspect of achieving sustainable urban living (Pribyl et al., 2020). One concept that is crucial to achieving this goal is shared mobility (Sopjani et al., 2020). Shared mobility refers to the shared use of transportation modes, such as cars, bikes, or scooters, among individuals, which reduces the need for personal vehicle ownership. It promotes the efficient use of resources, reduces traffic congestion, and provides more accessible and affordable transportation options (Shaheen et al., 2016). Shared mobility services can include CS, bikesharing, ridesharing, and scooter-sharing (Mourad et al., 2019). These services are typically accessed through smartphone apps that allow users to locate, reserve, and pay for a vehicle or ride. Shared mobility has gained popularity in recent years as urban populations grow and transportation options become more varied. It is seen as a sustainable and convenient alternative to traditional transportation methods, reducing the environmental impact of transportation and improving mobility options for all (Shaheen et al., 2016).

One form of shared mobility that is particularly suitable in densely populated urban areas and ensures sustainability is CS (Shaheen and Cohen, 2013; Cohen and Kietzmann, 2014). CS is a service that allows individuals to rent a car on a short-term basis, typically by the hour or day, without the commitment and expenses associated with owning a car. The service is usually provided by a CS operator or a community-based organization that owns a fleet of vehicles that are shared among members (Münzel et al., 2018). CS provides an affordable and convenient alternative to owning a car, particularly in urban areas where parking and traffic congestion are significant issues. CS can have several benefits, including reducing the number of cars on the road, reducing emissions and air pollution, and promoting more sustainable mobility patterns (Boldrini et al., 2019; Migliore et al., 2020; Wong et al., 2020). It can also help alleviate parking and traffic congestion in urban areas and provide more equitable access to transportation for people who cannot afford to own a car or who do not use a car frequently. Due to the various positive benefits of CS, cities and mobility operators are striving to make CS more attractive to a wider range of citizens (Shaheen and Cohen, 2020). To understand how CS services have to be designed to be meaningfully integrated into SSDs and SSCs, the user as well as the operator's perspectives need to be understood better. From the user perspective, how users behave in CS systems is of great importance, as this provides substantial information regarding their mobility needs (Ferrero et al., 2018; Ramos et al., 2023). The operator perspective concentrates more on profitability and enlargement of the service, which can be achieved by finding the right locations for CS stations or more cost-effective distribution of the cars (Ferrero et al., 2018). Both perspectives are examined in this thesis. Another way to promote the use of carsharing is to integrate the service into overarching innovative mobility concepts. Therefore, I will closely investigate how CS can be used in combined tariffs with other sustainable forms of mobility.

The overarching aim of this thesis is to support science and practice in driving specific forms of sustainable innovation in the areas of districts and mobility to help realize the existing ideal of an SSC. Although other aspects of an SSC need to be explored to drive development in this direction, in this thesis, I aim to contribute beneficial knowledge on only some aspects of the specified research areas. This is far away from a comprehensive overview about these areas in the context of the SSC. However, I hope the presented findings support research in these areas and support the development of cities to SSCs.

## 3 Structure of the Thesis and Overview of Embedded Research Papers

In the following section, I describe the structure of this doctoral thesis and provide an overview of the embedded research articles. This cumulative doctoral thesis comprises seven research articles that investigate design and its associated factors in the context of shared mobility and smart districts. Therefore, this thesis incorporates findings gathered from various research articles. As outlined in *Figure 1*, the research articles in this thesis focus on various aspects of innovative development in urban areas. These research articles are strongly interconnected, and all of them contribute to the knowledge about urban development in the specified areas.

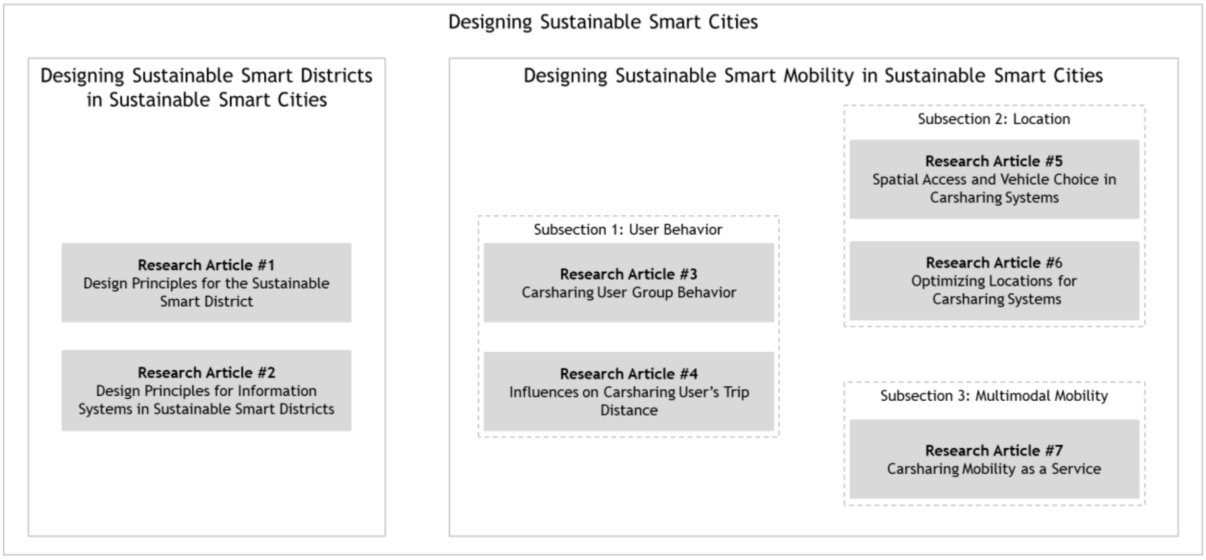


*Figure 1: Structure of the thesis*

| Research article | Research article title | Research question |
|---|---|---|
| Research article #1 | Sustainability's Coming Home: Preliminary Design Principles for the Sustainable Smart District | (I) What are preliminary design principles for a platform-based ecosystem of a sustainable smart district? |
| Research article #2 | The Design of Citizen-Centric Green IS in Sustainable Smart Districts | (I) What are design principles for citizen-centric Green IS within sustainable smart districts? |
| Research article #3 | You'll Never Share Alone: Analyzing Carsharing User Group Behavior | (I) What are different CS groups in the urban environment?<br>(II) How do the identified patterns manifest within the urban and suburban environment? |
| Research article #4 | Revealing influences on carsharing user's trip distance in small urban areas | (I) What factors affect the trip's distance of CS in small urban environments?<br>(II) How do these factors influence CS distance traveled? |
| Research article #5 | Exploring the Impact of Spatial Access on User Decision-Making in Urban Carsharing | (I) How does spatial access affect individual user decision-making in CS?<br>(II) How can explainable machine learning help to investigate the effect of spatial access on user decision making |
| Research article #6 | Back to Balance – Fostering Sustainable Urban Mobility with Optimized Carsharing Systems | (I) Which impacts has the optimization of car allocation in existing station-based round-trip CS systems? |
| Research article #7 | New Ways for Carsharing - Can Mobility as a Service Boost Carsharing? | (I) How a real-world example of a MaaS business model is structured<br>(II) What are differences in usage between standalone CS and CS in the context of a MaaS concept |

*Table 1: Overview of the research articles*

Each research article addresses specific research questions related to a particular aspect of the transformation of urban areas to SSCs (Table 1). *Figure 1* provides an overview of the general allocation of the research articles to thematic areas, the subsections, and the articles' connections to one another.

The thesis is organized as follows. Section II presents details of the research articles of Table 1 in the greater context of the two research areas, the SSD and shared mobility in the urban environment, and their part in the development of cities to SSCs. Research article #1 begins, with a description of the prescriptive guidelines for the design of SSDs. It is followed by research article #2, which discusses the design of IS within a prospective or existing SSD. By discussing this perspective, I aim to support the development of districts to SSDs by providing concrete guidelines for participating stakeholders. The second part of Section II discusses shared mobility, focusing on CS, as it is one of the most successful examples of innovation in this area. Research article #3 starts by describing different user groups of CS and analyzes their behavior in an urban environment. This sets the context for research article #4, which deepens this analysis on the basis of specific parameters. A user-orientated perspective helps in understanding the mobility behavior of citizens and how to design urban mobility services in urban areas close to their actual needs. This is followed by a change in perspective to the CS system provider. Research article #5 analyzes the distance users are willing to travel to reach a station. This analysis supports the operator in deciding where to place CS stations. This decision-making process is further clarified in research article #6, which proposes an optimization approach for the proper allocation of CS cars in the station network. The findings help operators make decisions regarding station placement and car allocation. As stations and cars are major contributors to the running costs of CS systems, these findings may lead to cost reduction and more profitability of the system. Subsection 2, containing the research articles #5 and #6 are also related to the research articles #1 and #2, since the location perspective of the stations is strongly interrelated to the districts of its users as I will explain in the following sections.

Following the discussion on districts, user behavior and the optimal placement of CS stations and allocation of cars, research article #7 discusses how CS services can be incorporated in bigger mobility offers to reach a broader part of the citizenship. This is important since the connection of CS to other forms of mobility is an essential factor in developing it to a broadly accepted alternative for individual mobility. The observations made in research article #7 are connected to the district perspective, discussed initially, as CS can be a part of the mobility concepts of SSDs and SSCs. I end the thesis in Section III by presenting a short summary and delineating the limitations and suitable topics for future research.

# II. Overview and Context of the Research Articles[2]

When dealing with humanity's grand challenges, such as climate change, cities are both a partial cause of the problem and a significant component of the solution, the latter because of the progression toward smart cities (Benevolo et al., 2016; Bibri, 2018). Smart cities use advanced technology and data-driven solutions to improve the quality of life for their citizens, enhance sustainability, and optimize urban services and infrastructure. They leverage various technologies, such as the Internet of Things, artificial intelligence, and big data analytics, to gather and analyze information from various sources, such as sensors, devices, and systems, to make informed decisions and optimize urban operations in real time (Bibri and Krogstie, 2017). Smart cities have accelerated the transition toward sustainability by adopting information and communication technologies as well as smart energy and mobility solutions. (Kutty et al., 2020; Gimpel et al., 2021). As sustainability is a significant aspect of future urban areas, the term *sustainable smart city* (SSC) is growing in importance, especially in the context of meeting the United Nations' Sustainable Development Goals (Corbett and Mellouli, 2017). By merging the transformational potential of IS with the sustainability-related strategies of cities, SSCs can be instrumentalized in addressing the grand challenges of our times, such as climate change and the lack of urban resilience (Ahvenniemi et al., 2017; Trindade et al., 2017; Silva et al., 2018; Thomson et al., 2021). One of the many examples of the transformational potential of IS are smart energy concepts, which advance the efficient use of energy from renewable and, if possible, local energy sources (Silva et al., 2018). Recent studies have suggested that there is significant untapped potential in promoting ecologically sustainable services and concepts to citizens in their immediate environment and encouraging more sustainable behaviors through the use of new technologies and business models in their daily lives (Corbett and Mellouli, 2017; Bartelt et al., 2020; Velsberg et al., 2020). The switch to a more citizen-centered perspective demands the discussion of two underlying areas related to SSCs, which are very close to the everyday life of citizens.

The first area is the concept of SSDs, a planning approach where the citizen-centric service perspective of housing is particularly well aligned with the core idea of sustainability in the direct surrounding of the citizens (Ahvenniemi et al., 2017; Koutra et al., 2018; Graf-Drasch et al., 2022). The second research area is shared mobility services, which are able to connect

[2] This section partly comprises content from this thesis' research articles. To improve the readability of the text, I omitted the standard labelling of these citations.

citizens to various parts of the city without many of the negative effects of individual mobility (Barr, 2018; Pribyl et al., 2020). In this chapter, I start by discussing the SSD perspective, as it normally serves as the center of life for most citizens. Subsequently, I discuss the mobility perspective. After a brief introduction to shared mobility, I focus on the concept of CS and its connection to citizens and the city itself.

## 1 Designing Sustainable Smart Districts in Urban Areas

SSCs are very complex constructs. Thus, involving citizens in their development can be very difficult. Districts can serve as a bridge between the promised advantages of SSCs and their implementation close to the real needs of citizens (Hosseini et al., 2018; Keller et al., 2019; Graf-Drasch et al., 2022). It is also possible to use the concepts of districts for smaller municipalities such as small towns, villages, or rural areas in general (Hosseini et al., 2018). Consumer trends often take place on a district level and contribute to the ecological, social, and economic development of the district. The implementation of sustainability in districts due to new mobility concepts, sharing concepts, and platform-based collaboration is already happening in many districts (Hamari et al., 2016; Zervas et al., 2017). However, to achieve these benefits, there is a need for an adequate information and communications technology infrastructure. This technological basis and the connectedness of all stakeholders lead to smart districts. The implementation of digital technologies in districts, combined with a sustainable mindset, may form the ecosystem of an SSD.

In line with this description, in this thesis, I describe SSDs as being integral, normative, and visionary subsystems of SSCs that bridge the gap between digital and sustainable goals, ultimately leading to a better quality of life (Martin et al., 2019). However, despite the relevance of SSDs to the transformation of our cities into SSCs, there is little research tackling the adequate implementation and theoretical background of the SSD. In times of global warming and social alienation, guidance on a sustainable design is essential for the future development of smart districts and, subsequently, SSDs. Research article #1, thus, presents the first step in this direction and builds a theoretical foundation for the implementation of SSDs by deriving nine preliminary design principles (DPs) from the literature, which would serve as a foundation for the design of SSDs. DPs in IS research refer to a set of guidelines or recommendations for designing tools or environments that are effective, efficient, and user friendly (Ramaswami et al., 2016; Seidel et al., 2018; Mora et al., 2019; Gregor et al., 2020). These DPs are typically based on established theories, best practices, and empirical research in the field of IS. They cover various aspects of design, such as usability, functionality, user experience, security, privacy, and scalability. The aim of these DPs is to guide the development of IS and related instantiations that meet the needs of users while addressing broader organizational and societal goals of the system (Möller et al., 2020). Research article #1 also shows the development of these principles, which was done in an iterative approach based on the literature, semi-structured interviews with experts, and interviews with a sample of the German population to ensure their acceptance. As research article #1 was one of the first research articles in this field and there was no broad basis of existing approaches the article described the resulting DPs as preliminary. The resulting nine preliminary DPs are presented in Table 2. These DPs will provide designers of SSDs with initial guidance on what is important when developing SSD concepts.

| No. | Preliminary design principles |
|---|---|
| 1 | Define adaptable spatial boundaries of the SSD to be able to identify the given characteristics and properties of the SSD. |
| 2 | Identify stakeholders taking part in the platform-based ecosystem of the SSD to assign roles. |
| 3 | Provide the SSD with an adaptable and scalable digital infrastructure to integrate heterogeneous, connected IT systems and features, to facilitate the platform-based ecosystem. |
| 4 | Establish a transparent, cooperative and participatory structure to enable collaboration and competition between stakeholders. |
| 5 | Design the services of the SSD in a simple and accessible way to integrate all users. |
| 6 | Determine tangible and intangible values to derive an incentive-structure and enable the development of value-adding services, to satisfy the stakeholders' needs. |
| 7 | Continuously monitor the SSD and evaluate feedback to achieve or iteratively adapt visionary objectives and goals. |
| 8 | Integrate public and IT security concepts to provide safety for people, public, and private property. |
| 9 | Comply with current law and regulations to aim for legal certainty. |

*Table 2: Preliminary DPs for SSDs (Source: Research article #1)*

After creating a basis for the design of SSD concepts, it is still unclear how sustainability comes to practice within these districts. Thus, switching to a more detailed, granular level is indispensable for deepening the understanding of innovation in SSDs. To bring ecologically sustainable services closer to citizens within their immediate environment, Green IS have shown significant potential in supporting environmental sustainability with the use of IT (Corbett and Mellouli, 2017; Bartelt et al., 2020; Harnischmacher et al., 2020; Velsberg et al., 2020). As most established Green IS designs in the context of smart cities are provider centric, they often overlook the actual needs of citizens, such as the need for transparent services, ease of access, and usability for people with disabilities (Rosemann et al., 2020). However, in addition to this multitude of top-down (city-centric perspective) designs of smart cities and districts (Angelidou, 2017), many bottom-up (citizen-centric perspective) methods of supporting citizens with Green IS applications are currently in the making (Harnischmacher et al., 2020).

Guidelines for the application of Green IS in SSDs can be useful in building Green IS close to the needs of citizens and their immediate surroundings. Their main advantage is that they would enable going beyond the provider centric and single infrastructure level. As already shown in research article #1, DPs are helpful in guiding service design efforts to tackle sustainability-related challenges in SSDs and Green IS in smart cities (Ramaswami et al., 2016; Seidel et al., 2018; Mora et al., 2019). Designers of Green IS in SSDs can be part of municipalities that aim to create a healthy environment for citizens or a private organization that creates attractive and profitable districts. The DPs offer guidance for designers designing for a comparable complex environment with, simultaneously, new possibilities and multiple stakeholders (Rosemann et al., 2020; Razmjoo et al., 2022). This inevitably leads to various trade-offs between citizens and the changes induced by the use of new technology within the design process on a technological and a social level. These guidelines foster the integration of citizen-centricity into Green IS design within the SSD context. This integration benefits both the designer and the citizens, as citizens profit from a district design that considers their needs and, consequently, accept and even welcome necessary changes in the newly designed district which is in best interest of the designer (Graf-Drasch et al., 2022).

Research article #2 outlines seven overarching DPs that unite the various established perspectives for citizen-centric Green IS in SSDs. In doing so, this paper aims to facilitate sustainable behavior among citizens with the help of citizen-centric Green IS. Working with the design science research paradigm (Hevner et al., 2004), research article #2 deduced three meta-requirements from the literature, which defined the scope and boundaries for the derivation of seven DPs (Gregor et al., 2007). Each DP consists of an *aim*, a *context*, a *mechanism*, a *rationale*, and *exemplary actions*. Table 3 shows the names and the specific aims of each DP.

| No. | *Name of the DP* | *Aim* |
|---|---|---|
| 1 | Involvement of Citizens | To foster a positive attitude to the Green IS among citizens, which should lead to a greater understanding and more extensive use. |
| 2 | Realization of District Objectives | To align technology and its use with the objectives of the respective district under careful consideration of any potential conflict of interest. |
| 3 | Response to the Feed-back of Citizens | To consider the feedback of citizens through an iterative process in order to im-prove the Green IS in response to their needs. |
| 4 | Adoption of a Holistic District Perspective | To facilitate constructive interaction among essential district components. |
| 5 | Facilitation of a Flexible IT Architecture | To run a scalable Green IS that supports continuous provision of services. |
| 6 | Exploitation of the Full Potential of District Data | To (re-)develop services with the help of data in order to tackle complex sustaina-bility-related goals. |
| 7 | Preservation of Privacy and Security | To protect the digital and physical integrity of each citizen under consideration of legal and ethical issues. |

*Table 3: DPs for Green IS in the SSD*
*(Source: Research article #2)*

We derived the DPs by two means: A systematic literature review and a consultation with experts in SSDs, infrastructure, and society. Predicating this study on the design science research paradigm helped us contribute to the theoretical work on design and action (Gregor, 2006). Testing our findings through an iterative process showed us that the findings could be considered prescriptive knowledge for designing a Green IS in SSDs. Research article #2 contains detailed descriptions of the DPs.

Research article #2 advances the research on Green IS, specifically on sustainable systems engineering (van der Aalst et al., 2023), by developing design knowledge in the form of operational guidelines for Green IS in an SSD environment. It also advances the practical development of Green IS within SSDs by showing how one should use these guidelines in SSDs. To reconcile the practical and theoretical insights into the DPs, in research article #2, we incrementally and iteratively develop a Green IS – specifically, a mobile app – within the project “Stadtquartier 2050”, for which we worked closely with relevant district stakeholders. This prototype helps understand the impact DPs have on the design of IS within districts. Figure 2 shows four screenshots of the created prototype.

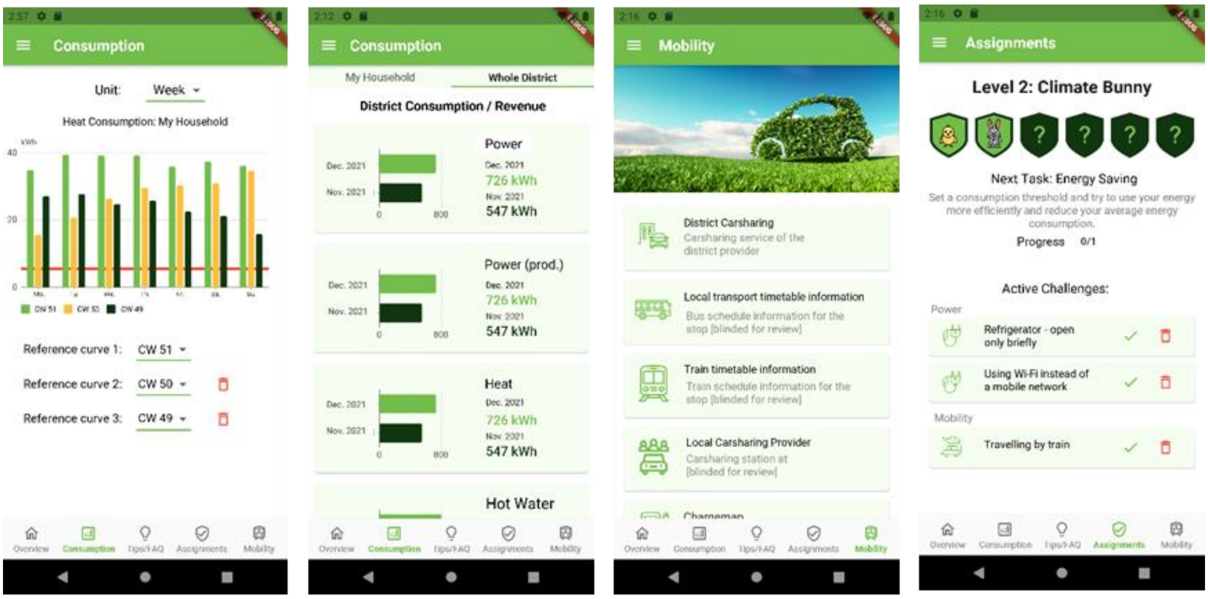


*Figure 2: Prototype of an IS in an SSD*
*(Source: Research article #2)*

With these results, research article #2 ultimately contributes to enabling better integration of future Green IS into SSCs and urban contexts in general, as Harnischmacher et al. (2020) demand. The resulting guidelines are probably transferable to an SSC level. However, on a city level the number of persons affected considerably increases and, thus, the number of persons who must be included. Nevertheless, these guidelines can support the transformation of cities to SSCs by steering the districts and the services they offer in a smart and sustainable direction. However, this is only possible if the citizens of the districts are part of their development, as otherwise, their needs won't be given the recognition they deserve.

## 2 Designing Shared Mobility Services in Urban Areas

Mobility is of great importance to citizens' immediate surroundings, their daily life, and the districts. It determines how citizens move from one place to another (Sandau et al., 2016). Almost every day, citizens leave their home districts to work, do grocery shopping, or enjoy various leisure activities. Thus, the sector of mobility is an important factor when discussing the future of urban life. New forms of mobility are an essential part of smart cities, as individual mobility causes some serious problems for which SSCs intend to find solutions (Cledou et al., 2018). Exemplary problems of traditional forms of mobility are traffic congestion, air pollution, high space requirements in cities, and, with a view toward sustainability, the enormous resource cost of car production. In particular, the problems of high resource and space requirements have their roots in an increasing trend toward individual mobility (Le Boennec et al., 2019). At the same time, private cars are unused most time of the day, which shows the need for alternative mobility concepts. Shared mobility can help counteract this trend and the problems coming with it, especially in cities, which have high population density and are open to new technological concepts (Sopjani et al., 2020).

Sustainable and smart forms of shared mobility such as CS can significantly reduce the number of private cars in already dense urban areas (Chen and Kockelman, 2016; Migliore et al., 2020; Riggs and Appleyard, 2020; Te and Lianghua, 2020). Furthermore, CS improves life in urban areas by reducing pollution, congestion, and parking scarcity, which has environmental and social benefits (Boldrini et al., 2019; Wong et al., 2020). It also offers cost savings and convenience, with CS users not being required to attend to maintenance or insurance issues (Shaheen, 2020). As CS is one of the most successful forms of shared mobility, I decided to analyze it and its impacts on SSCs in greater detail. CS is an umbrella term for many business models that combine different CS schemes suited to the area in question and the people who use the respective service. Most operators offer station-based (SB) one-way or two-way CS services or a more flexible free-floating alternative (Wagner et al., 2014). The following research articles focus mostly on SB CS unless stated otherwise. Currently, CS continues to evolve in different forms and in different places all over the world. The first signs of market saturation in Europe and America were compensated by a two-year growth in membership of 61% in Asia in 2018. In Asia, the CS market has grown more than twice as much as the CS market in Europe in the same period (Shaheen, 2020). However, with the growth of the market, market competition and complexity have increased, posing challenges to the profitability of CS business models (Shaheen and Cohen, 2007; Shaheen, 2018; Steinman et al., 2020). At the end of 2019, Share Now, one of the biggest CS operators, left the North American market and, with it, one-quarter of its customers (Migdal, 2019; Share Now, 2019a, 2019b). In contrast, small operators, especially, seem to grow in non-metropolitan regions, broadening their range of services and business models. While international operators with enormous resources struggle in certain markets, smaller operators are quite successful at the same time in those same markets. Regional operators in Germany highlight their proximity to their customers as a critical factor determining their success (Schreier et al., 2018). To succeed in an increasingly competitive urban mobility landscape, operators need to understand customer needs, behavior, and the surrounding urban area to develop suitable business models (Burkhardt, 2005). As the growth of the industry seems to have stagnated, at least in Europe, operators have to rethink their business models. To derive valuable insights about CS customers and their relationship to the urban environment, for this thesis, I collaborated with a regional CS operator operating in a city with 300,000 inhabitants and its surroundings. Based on a rich dataset of more than 12,000 users and 450,000 trips from 2019 to 2021, I was able to conduct an extensive analysis of behavioral and spatial characteristics of CS use at the intersection of traditional two-way SB systems, free-floating CS, and mobility-as-a-service approaches.

While several survey-based studies provide valuable starting points by investigating CS customers' behavior and motivation for using CS services (Kopp et al., 2015; Becker et al., 2017), a comprehensive review by Ferrero et al. (2018) finds a significant lack of research in CS customer segmentation. Research article #3 addresses this research gap by analyzing CS customers based on real-world user behavior, placing particular emphasis on understanding the relationship between CS and the surrounding urban environment. Thus, other developments in the SSC regarding mobility become easier to connect and more tangible. To reach this understanding, research article #3 identifies 20 user groups and examines their usage of different CS services in urban and suburban environments. These user groups, shown in Table 4, reveal insights about recurring behavioral and spatial patterns, which may help researchers and operators in improving customer-centric business models for CS. The knowledge about these groups and their characteristics fosters the integration of CS in multimodal transport environments of SSCs.

| | *Users* | *Share female* | *Age* | *Median trips* | *Median trip length [km]* | *Median trip duration [h]* | *Home-station-rating* | *Different stations [per 100 trips]* | *Share of top 25%* |
|---|---|---|---|---|---|---|---|---|---|
| *SB standard user (SU)* | 1900 | .42 | 37.2 | 9 | 33 | 3.4 | .60 | 33 | 1 |
| *SB top 25% (TU)* | 634 | .39 | 38.4 | 36 | 70 | 5.7 | .54 | 18 | 1 |
| *Frequent users* | 338 | .43 | 38.1 | 55 | 43 | 4.2 | .57 | 13 | .53 |
| *Long-Term users* | 146 | .32 | 38.1 | 18 | 103 | 9.1 | .48 | 29 | .23 |
| *Long-Distance users* | 150 | .37 | 39.4 | 15 | 139 | 7.9 | .54 | 28 | .24 |
| *Carsharing top users based on individual characteristics* | | | | | | | | | |
| *Women* | 249 | 1 | 39.8 | 41 | 65 | 5.7 | .59 | 15 | .39 |
| *Men* | 385 | 0 | 37.5 | 35 | 74 | 5.8 | .50 | 21 | .61 |
| *Public transport Annual subscribers* | 240 | .37 | 36.3 | 35 | 70 | 5.7 | .49 | 21 | .38 |
| *Public transport Non-Annual subscribers* | 394 | .41 | 39.7 | 38 | 69 | 5.8 | .57 | 17 | .62 |
| *Students* | 88 | .20 | 26.5 | 36 | 65 | 5.5 | .44 | 22 | .14 |
| *Carsharing top users based on usage patterns* | | | | | | | | | |
| *Workday users* | 256 | .50 | 39.0 | 42 | 57 | 5.1 | .58 | 16 | .40 |
| *Weekend users* | 378 | .32 | 38.0 | 33 | 77 | 6.3 | .50 | 20 | .60 |
| *Home-Station users* | 158 | .51 | 41.4 | 42 | 56 | 5.3 | .85 | 9 | .25 |
| *Non-Home-Station users* | 158 | .27 | 35.8 | 36 | 76 | 6.2 | .30 | 28 | .25 |
| *Suburb users* | 28 | .39 | 43.4 | 38 | 53 | 4.5 | .77 | 12 | .04 |
| *Holiday users* | 44 | .39 | 39.1 | 11 | 230 | 26.6 | .57 | 23 | .07 |
| *Organizations* | | | | | | | | | |
| *Top organizations* | 47 | - | - | 71 | 125 | 7.2 | .42 | 15 | - |

*Table 4: User groups of SB CS*

*(Source: Research article #3)*

Research article #3 focuses on the top users of the SB CS service, as they contribute a disproportionately high share to the overall revenues of the operator in question. Different forms of segmentation and explorative clustering algorithms were used to identify relevant user groups. Categorizing these user groups is an essential step for understanding customers and their relationship to their urban environment. The article investigates the behavior of the identified CS user groups within the urban environment by analyzing trip data along spatial characteristics. Furthermore, it identifies recurring patterns in trip characteristics and spatial as well as multimodal behavior of different user groups. This behavior analysis opens new possibilities for operators and researchers to assess CS users' behavior in the urban environment from a customer-centric perspective. For a better understanding, research article #3 also extends the spatial perspective on these user groups. Figure 3 illustrates the number of trips by the group "SB top 25% (TU)," starting from specific stations and districts. The "SB top 25% (TU)" group consists of the upper quarter of CS users with regard to driven distance during 2019.

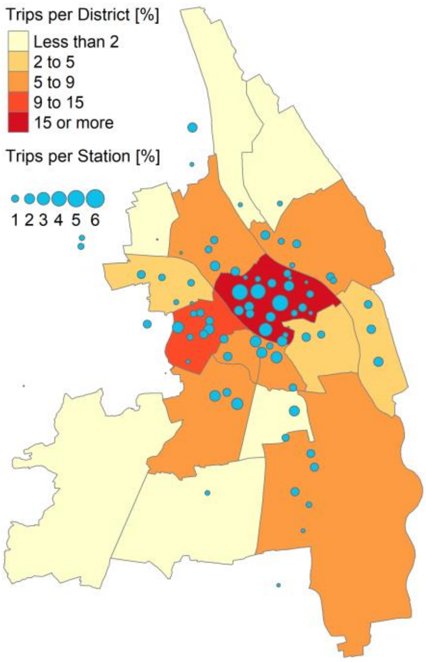


*Figure 3: Spatial view of a specific user group of SB CS*
*(Source: Research article #3)*

In summary, this perspective helps understand the spatial distribution of these different groups. In combination with the insights of research articles #1 and #2, this view can help urban planners make design decisions for SSDs, depending on where these districts are planned. In the example of the present use case, especially districts in the city center would benefit from a high station density (Figure 3). Many trips start from the stations in the city center (blue bubbles), which fits the high population density in this district.

After identifying relevant user groups in CS, a more in-depth analysis of the specific parts of their usage behavior helps to align the concept more closely to the needs of the users. The findings may help convince more citizens to use shared mobility and avoid individual mobility. At the same time, the operator can use this knowledge to increase its profitability and expand its area of operation. In contemporary research, the challenge of expanding the business and rising profitably in CS businesses often leads to the question of trip characteristics and the behavior of CS users (Jorge et al., 2015; Golalikhani et al., 2021b). One example of such research is customer-focused pricing schemes depending on their driving habits (Perboli et al., 2018; Feng et al., 2020). In combination with the usage time, the distance traveled during a CS trip has a significant influence on the resulting usage fee per CS trip (Golalikhani et al., 2021b) as well as the decision to choose a specific car type (Costain et al., 2012; Jian et al., 2017; Golalikhani et al., 2021a). Considering these findings, the potentially different behavior of CS users in terms of trip distance is a critical issue for research and practice (Costain et al., 2012; Jian et al., 2017). Accordingly, the distance traveled is one of the most important indicators of CS usage behavior, as it affects diverse aspects of the most common CS business models in urban areas. For this reason, research article #4 closely investigates the factors that affect the trips' distance of CS in urban environments. The results, obtained using the same data set as mentioned earlier and by using machine learning and explainable artificial intelligence, contain insights that provide a deeper understanding of travel behavior and distance traveled. Such findings are crucial for operators to tailor CS services, fleet size, and the ability to satisfy to the needs of citizens in urban areas. The analysis shows the importance of time-related features for the resulting trip distance, explains their impact on different user groups, and reveals other non-time-related important features.

Another important factor influencing CS usage in urban areas, already mentioned in research article #3, is the spatial distribution of stations around the city itself. In this regard, individual vehicle access (i.e., close spatial distance to the preferred vehicle), as one of the main motivational factors for CS usage, is suspected to be integral to user convenience (Schaefers, 2013; Juschten et al., 2019; Lempert et al., 2019). Research article #5 aims to provide novel findings on the role of spatial access in individual user decision-making in CS. Specifically, it aims to investigate how the distance users need to cover to access CS stations and vehicles affects the individual usage decision and how certain policy-relevant factors impact this relation. Furthermore, with the help of a model-agnostic approach based on explainable machine learning, research article #5 investigates the actual effect of explanatory variables such as individual spatial access on the performance of prediction models. The analysis resulted in three main findings. First, a positive correlation exists between travel distance and the distance between the station and the home of the user. Second, a short distance between the home and the station may have a significant positive effect on perceived service utility, usage intention, and usage frequency. Third, CS users with an active public transport subscription are found to access vehicles, on average, farther away from their homes than the rest of the users.

The first finding allows conclusions to be drawn about the purpose of the trip. A greater distance to the station is positively related to the longer usage of CS vehicles until a certain threshold is reached. This outcome is confirmed by the results of the model-agnostic approach as well as by the descriptive analysis that has found a similar relationship between “walking distance” and vehicle kilometers traveled. This contradicts previous findings suggesting that a greater access distance reduces trip duration (Costain et al., 2012). However, it supports the above assumption that the willingness to cover greater distances to access a vehicle is tied to the purpose of the trip (e.g., vacation trips).

The second finding enables more concrete options for operators and policy. The analysis shows that 64 % of CS trips start from a station not more than 1 km away from the home of the users. On average, users cover a distance corresponding to a walking time of 12.5 minutes to start a trip. The average active user lives within a 400-meter linear distance radius of the closest station. These results obtained from real-world transaction and user data provide evidence for previous findings from stated preferences studies reporting that close distance to stations may have a significant positive effect on perceived service utility (Zoepf and Keith, 2016), usage intention (Herrmann et al., 2014), and usage frequency (Lindloff et al., 2014). From a policy perspective, the insights present an incentive for operators to evaluate and optimize the spatial distribution of stations, similar to efforts in other mobility areas where, e.g., the expansion of charging infrastructure is incentivized by policymakers (Baumgarte et al., 2021c). Establishing a finer grid of stations fulfills the need for close spatial accessibility and satisfies short-term mobility needs comparable to privately owned cars, thereby fostering CS usage. In this connection, the above findings may serve as a foundation for sustainable planning as well as evidence-based negotiations between operators and the municipal administration regarding the infrastructural development of the CS program. (e.g., opening up new areas for stations). Municipal measures to support CS programs in reducing the walking distances to the next vehicle could be establishing exclusive CS parking spaces in dense areas, opening residential parking zones for CS users, or incentivizing the expansion of the service in suburban areas or low-income neighborhoods. The final measure also represents a way of making car-based mobility more diverse and socially just. From a district design perspective, municipalities can set incentives when planning new districts and buildings by reducing the number of mandatory parking spaces if CS parking spaces are available.

Another promising course of action to increase the availability of CS capacities for the citizens who need them is optimizing car allocation in existing CS systems (Ferrero et al., 2018). For following this approach, in research article #6, a stochastic optimization model for round-trip CS location specifications was created. With the help of a sample average approximation, research article #6 transforms the model into a mixed-integer program that optimizes the difference between supply and demand for each station. The model contributes to a better understanding of the relationship between fleet size, supply, demand, and the optimal distribution among stations in round-trip CS systems. It supports CS research by indicating opportunities for increasing availability and occupancy in CS systems and, with that, consumers' acceptance of CS. A simplified visualization of the underlying model is shown in Figure 4. Here, it is shown how cars in the CS system can be redistributed between stations to balance demand and capacity.

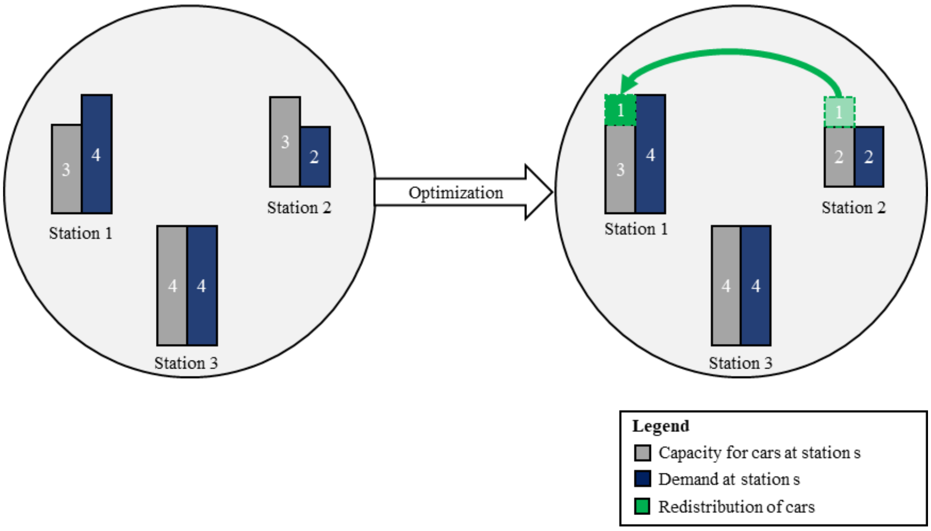


*Figure 4: Simplistic visualization of the underlying model*
*(Source: Research article #5)*

Operators and researchers can use this knowledge about the stations in active systems to adapt or create tariff designs and pricing mechanisms. The model is a step in this direction due to its use of an automated approach to identify stations with either a demand surplus or a demand deficit. This point is of special interest, as current CS research neglects the relationship between tariff design and operational issues (Ferrero et al., 2018; Perboli et al., 2018). Namely, the operator can now respond to demand with an automated allocation approach instead of distributing cars by eye. Even if actual redistribution is not possible due to limited station capacity, the operators are able to make objective decisions based on the model, e.g., concessions at less popular stations to relieve overbooked stations. This advantage becomes particularly interesting when the model user considers other factors, e.g., time or car-related attributes. Furthermore, the model supports tactical decision-making concerning fleet size. As the results of the sensitivity analysis show, the smaller the fleet size, the more critical appropriate IS become. Against the background of high financial investments for acquiring and maintaining a larger fleet, applying IS and optimizing car allocation to reduce the fleet size appear particularly fruitful. Thus, optimizing car allocation and redistribution in existing CS station networks is a crucial factor for a cost-effective and more sustainable CS system and business model. The full potential of this approach can be explored in the smart city context. Through the networking between the operator and the IS of the smart city, optimization can be provided with significantly more information. The higher capacity of optimization allows synchronization of car distribution with the capacity utilization of public transport or regional events.

The third finding of research article #5 is also tied to the combination of CS with other forms of sustainable mobility. Users with an active public transport subscription are found to access vehicles further away from their homes than the rest of the users, which emphasizes the potential of CS as an integral part of intermodal mobility. These findings should encourage policymakers to intensify the linkage of different urban mobility concepts and incentivize their combined usage (e.g., through price adjustments such as waiving off monthly fees). In this way, municipalities can reduce barriers to entry, exploit synergistic effects between different mobility concepts, and stimulate sustainable mobility. Operators should draw on insights to enhance cooperation with other mobility providers and diversify their own offers (e.g., optimize the availability of demanded vehicle types in densely populated areas).

For this purpose, it makes sense to integrate CS concepts into multimodal mobility approaches. One approach for integrative mobility, which fosters ecological sustainability in urban environments, is MaaS (Utriainen and Pöllänen, 2018). MaaS is a concept that refers to the combination of different modes of transportation, such as CS, bikesharing, public transport, ridesharing, and other forms of mobility within one platform. The goal of MaaS is to provide a seamless and efficient form of transportation, which allows one to use various forms of transport with a single app or platform, without the need for multiple accounts or payment systems (Kamargianni et al., 2016). MaaS often uses digital technologies, such as mobile apps, data analytics, and payment systems, to create user-friendly approaches for users. With this innovative approach, MaaS aims to reduce congestion and emissions. The integration of a variety of transportation modes into one service provides an alternative to classic ways of individual mobility without a significant loss of flexibility or convenience (Pangbourne et al., 2020; Reyes García et al., 2020; Shaheen and Cohen, 2021). In many cases, CS is already a crucial part of private and public sector MaaS concepts (Stopka et al., 2018; Utriainen and Pöllänen, 2018). MaaS is a very young concept that holds the chance to make existing forms of mobility such as CS more attractive, especially in cities, through smart ways of connecting them (Utriainen and Pöllänen, 2018). However, the youth of these concepts lends them their disadvantage, i.e., their immaturity. Additionally, in research, there is a lack of knowledge about the design of these systems. To extend the knowledge about this topic, especially in the context of CS, research article #7 analyzes an innovative real-world example of MaaS in a medium-sized German city. The concept of the "Mobil-Flat" in Augsburg bundles CS, bikesharing, and the use of public transportation into one service with a specific usage contingent based on time and distance as a subscription model. Thus, research article #7 addresses two problems in the context of urban areas: It seeks to understand the lack of structured scientific approaches to the concept and the lack of knowledge about user behavior within such concepts.

First, research article #7 shows how this particular real-world example of a MaaS business model is structured. Taking Osterwalder's (2004) approach, it applies the common standard for structuring business models as a basis for the analysis of the service design. The approach structures the business model along four pillars – product, customer interface, infrastructure management, and financial aspects. Afterward, these four fields are divided into a total of nine building blocks. This results in the synopsis of the business model. Here, the most essential components are listed with a visualization of the interconnections between one another indicated. This analysis also enriches the general knowledge about the business side of such innovative MaaS concepts (Jittrapirom et al., 2017).

Second, on this basis, research article #7 analyzes differences in usage between standalone CS and CS in the context of a MaaS concept. With CS usage data of customers of the new MaaS concept as well as data of the customers of the standalone CS business model in the same environment, research article #7 draws a comprehensive picture of the differences between various kinds of user groups of CS with and without MaaS concepts. Furthermore, three different tariff options open the possibility of comparing demand within the MaaS concept. This is done by adopting the methodical approach of research article #3. The key results are displayed in Table 5.

| | *Users* | *Share female* | *Age* | *Median trips* | *Median Trip length [km]* | *Median Trip duration [h]* | *Home-station-rating* |
|---|---|---|---|---|---|---|---|
| *SB top 25% (TU)* | 857 | .40 | 39.6 | 40 | 73 | 5.7 | .53 |
| *SB standard (SU)* | 3428 | .41 | 37.9 | 15 | 40 | 3.6 | .57 |
| *Female users* | 339 | 1 | 40.2 | 41 | 68 | 5.3 | .57 |
| *Male users* | 518 | 0 | 39.2 | 39 | 77 | 5.8 | .50 |
| | | | *Mobil-Flat* | | | | |
| *Mobil flat (MFU)* | 286 | .50 | 43.9 | 36 | 51 | 3.8 | .63 |
| *Mobil flat 15 (MF-15)* | 96 | .57 | 45.3 | 29 | 43 | 3.5 | .66 |
| *Mobil flat 30 (MF-30)* | 169 | .47 | 43.8 | 43 | 59 | 4 | .63 |
| *Mobil flat S (MF-S)* | 19 | .63 | 45.8 | 6 | 29 | 3.1 | .64 |
| *Mobil flat M (MF-M)* | 93 | .46 | 43.9 | 35 | 44 | 3.6 | .59 |
| *Mobil flat L (MF-L)* | 98 | .52 | 44.9 | 59 | 54 | 4.3 | .60 |

*Table 5: Usage behavior within the concept "Mobil Flat"*

*(Source: Research article #7)*

In summary, research article #7 contributes to recent urban mobility and CS research by giving insights into the subscription-based aspect of CS in a MaaS concept, based on a real-world data set. This enriches the current state of research on the demand side of CS in MaaS concepts by providing an examination of the usage behavior and users' reactions to cost structures. Furthermore, the results may help evaluate chances for CS business development resulting from its connection to other forms of sustainable mobility such as bikesharing and public transport. Thus, MaaS concepts can drive the adoption of integrated and tailored mobility solutions in SSCs to ensure a sustainable future.

Operators can use the findings of research articles #3 to #7 to improve their service, lower operating costs, increase revenue and usage per user, and attract new customers. Specific decision support and management tools can foster the business model of the operator by diverse measures such as detailed discount analyses, targeted marketing techniques, and fleet management optimization. For policymakers, an understanding of user groups and their preferences as well as the challenges of the operators can be insightful when discussing the design options for shaping the urban transportation environment in SSCs toward sustainable mobility.

# III. Summary and Future Research[3]

## 1 Summary and Discussion

Our direct environments – the places in which we live and work together – are changing massively to adapt to the global challenges of humanity. SSCs are a part of the solution to contemporary challenges. These very complex structures consist of many different components, which makes it easy to get lost in their complexity. In this cumulative doctoral thesis, I address two areas that have a direct impact on the daily lives of residents of urban areas: The districts of a city, the direct living space of the citizens, and their connection to the rest of the city through sustainable forms of mobility. These two areas are closely interconnected and should not be considered in complete isolation from each other. When designing these sectors in SSCs, the context needs to be carefully designed and adapted to the needs of the users so that it is effective in the long term. The seven research articles in this thesis each consider individual questions (Table 1) which in their totality contribute to a common goal: Understanding and supporting citizens live sustainably in the digital age in urban environments by implementing citizen-centric design to their environment and the accompanying services. With qualitative as well as quantitative methods, this thesis gains insights into the means of fostering such citizen-centric design of urban districts and mobility.

Section II begins by providing insights into the citizen-centric design of districts and their services. Research article #1 focuses on the design of the district itself and the formulation of, with help of citizens and smart city experts, nine preliminary DPs for SSDs. This is followed by a closer look at the design of Green IS within such SSDs in research article #2. The seven resulting DPs will help avoid top-down approaches and provide smart services in diverse areas of life. This thesis, thereby, provides a preliminary glimpse of citizen-centric SSDs and Green IS embedded in SSCs. When this is achieved, the Green IS contributes to the SSD's sustainability-related goals and ultimately improves the quality of life for the citizens (Bisello and Vettorato, 2018; Gimpel et al., 2021). Thereafter, Section II is dedicated to the design of sustainable and shared mobility for the inhabitants of urban areas and, in particular, CS. This is achieved by examining an extensive data set of a CS system in a medium-sized German city with the help of various data-driven analyses and methods. Research articles #3 and #4 start with detailed

[3] This section partly comprises content from this thesis' research articles. To improve the readability of the text, I omitted the standard labelling of these citations.

analyses of user segmentation and behavior in CS to clarify the interdependencies and needs of citizens in the context of CS. The results deepen existing knowledge about user behavior and segmentation, based on a comprehensive real-world data set and contribute to existing research streams (Ferrero et al., 2018). The spatial perspective covered by research articles #5 and #6 is heavily linked to the district perspective of the first section in II, as it has a substantial impact on the usage and operation of the system. The proximity to stations and the availability of vehicles has a strong influence on citizens' decision making and acceptance of CS systems in urban environments. Research article #6 shows that, to overcome distances between potential users and stations, other forms of sustainable mobility such as pubic transport are used. This leads to the recommendation to consider CS in a broader context in connection with other forms of mobility. Research article #7 addresses this recommendation and analyzes CS in the context of a MaaS approach, especially the demand perspective, as this topic is underrepresented in current research (Polydoropoulou et al., 2020). Overall, the understanding of sustainable living and mobility that is created in this way promotes the development of these areas in the cities of the future.

This thesis supports Green IS research and aims to promote sustainability in districts and mobility by fostering the gradual transformation of cities into SSCs. It includes analysis of real-world data, which provides practical benefits, e.g., optimization approaches for the proper allocation of CS cars in CS stations. In this way, the thesis offers insights into the effectiveness of data-driven approaches and presents recommendations for policymakers and practitioners on how to use data to reach their goals. By doing so, it indirectly contributes to fighting climate change and the negative impacts of urbanization.

## 2 Limitations and Future Research[4]

As with any kind of scientific research, this doctoral thesis comes with some limitations regarding its content and likewise outlines prospects for further research.

First, the development of SSCs, as well as the areas addressed in this thesis, are too complex to be covered in a single doctoral thesis. Therefore, I was obligated to limit the perspective of this work to specific research questions. With a focus on districts and mobility, I address two issues that are particularly close to the citizens. There are several other important developments toward

[4] Please refer to the individual research articles for details on limitations and future research.

SSCs, including the use of renewable energy and smart waste management. These developments must also be designed in a citizen-centered way so that they are successful in the long term. Additionally, only certain aspects were highlighted within the selected areas. For example, CS is only one of many possibilities for sustainable mobility in urban areas. Other possible areas are for example micro mobility or electric vehicles. Also, other overarching areas of the SSC such as the sectors of energy, healthcare, education, water, and smart waste management must stay a relevant topic in research. These other areas also need to be understood and supported with scientific analysis. Future research should analyze these other areas to draw a more comprehensive picture of the areas of action in the transformation of urban environments into SSCs. Only then is it possible to exploit synergistic effects and fully achieve the goals that the creators of SSCs have set themselves.

Second, the outcomes of this thesis are heavily reliant on the quality of the data used. The various articles used interviews and comprehensive datasets based on real-world information, each with its own strengths and limitations. More precisely, five of the presented research articles rely on a dataset of the same German CS operator. This shows a significant dependence on this operator and the data the operator provides. Even though the data was tested for consistency and credibility, it was not independently collected as part of the underlying research. This leaves room, although unlikely, for manipulation or withholding of certain parts of the data. For this reason, future research should apply similar approaches to other datasets in comparable cities to see if the results remain reproducible.

Third, all the research articles in this thesis were written from a central European perspective, which, in some cases, makes them difficult to transfer to other geographical regions. One exemplary difference is the size of the respective city. In many parts of the world, cities are much more densely populated than in Europe and therefore have very different requirements for districts and mobility. Future research should review the results for transferability and conduct similar studies in other countries around the world. It should also be investigated which levers can be used to exploit region-specific characteristics in order to promote sustainable forms of mobility and districts.

Fourth, technological developments and the opportunities they create for cities and their citizens are extremely fast-moving. Approaches for SSCs exist all over the world. This has many advantages, but also carries the risk that research such as the presented in this thesis can quickly become of limited use. New comprehensive mobility concepts can overtake previous MaaS approaches as described in research article #7 and the results associated with it. It is possible that, in contrast to the bottom-up approaches mentioned in research article #2, top-down approaches may turn out to be the better solution for citizens and the environment if they are properly executed. Therefore, future research in this area must always question previous results, pay attention to their applicability in the current time, and, most importantly, not lose sight of the citizens who will live in the cities of tomorrow.

In this spirit, I hope that the results of this thesis help facilitate further research in the adoption of innovation for SSCs and, thus, support citizens in living a sustainable life in the urban areas of the future.

## Publication Bibliography


Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., Airaksinen, M., 2017. What are the differences between sustainable and smart cities? Cities 60, 234–245.

Albrecht, T., Keller, R., Röglinger, M., Röhrich, F., 2023. Exploring the Impact of Spatial Access on User Decision-Making in Urban Carsharing. Working Paper.

Angelidou, M., 2017. Smart city planning and development shortcomings. TeMA - Journal of Land Use, Mobility and Environment.

Barr, S., 2018. Personal mobility and climate change. WIREs Clim Change 9.

Bartelt, V.L., Urbaczewski, A., Mueller, A.G., Sarker, S., 2020. Enabling collaboration and innovation in Denver's smart city through a living lab: a social capital perspective. European Journal of Information Systems 29, 369–387.

Bastidas, V., Helfert, M., Bezbradica, M., 2018. A Requirements Framework for the Design of Smart City Reference Architectures, in: Proceedings of the 51st Hawaii International Conference on System Sciences. Hawaii International Conference on System Sciences.

Bastidas, V., Reychav, I., Ofir, A., Bezbradica, M., Helfert, M., 2021. Concepts for Modeling Smart Cities: An ArchiMate Extension. Business & Information Systems Engineering.

Baumgarte, F., Brandt, T., Keller, R., Röhrich, F., Schmidt, L., 2021a. You'll never share alone: Analyzing carsharing user group behavior. Transportation Research Part D: Transport and Environment 93, 102754.

Baumgarte, F., Dombetzki, L., Kecht, C., Wolf, L., Keller, R., 2021b. AI-based Decision Support for Sustainable Operation of Electric Vehicle Charging Parks, in: Proceedings of the 54th Hawaii International Conference on System Sciences. Hawaii International Conference on System Sciences. Hawaii International Conference on System Sciences.

Baumgarte, F., Eiser, N., Kaiser, M., Langer, K., Keller, R., 2022a. Smart Electric Vehicle Charging considering Discounts for Customer Flexibility. AMCIS 2022 Proceedings.

Baumgarte, F., Kaiser, M., Keller, R., 2021c. Policy support measures for widespread expansion of fast charging infrastructure for electric vehicles. Energy Policy 156, 112372.

Baumgarte, F., Keller, R., Röhrich, F., Valett, L., Zinsbacher, D., 2022b. Revealing influences on carsharing users' trip distance in small urban areas. Transportation Research Part D: Transport and Environment 105, 103252.

Becker, H., Ciari, F., Axhausen, K.W., 2017. Comparing car-sharing schemes in Switzerland: User groups and usage patterns. Transportation Research Part A: Policy and Practice 97, 17–29.

Benevolo, C., Dameri, R.P., D'Auria, B., 2016. Smart Mobility in Smart City. In: Torre, T., Braccini, A.M., Spinelli, R. (Eds.) Empowering Organizations, vol. 11. Springer International Publishing, Cham, pp. 13–28.

Bibri, S.E., 2018. A foundational framework for smart sustainable city development: Theoretical, disciplinary, and discursive dimensions and their synergies. Sustainable Cities and Society 38, 758–794.

Bibri, S.E., Krogstie, J., 2017. ICT of the new wave of computing for sustainable urban forms: Their big data and context-aware augmented typologies and design concepts. Sustainable Cities and Society 32, 449–474.

Bisello, A., Vettorato, D., 2018. Multiple Benefits of Smart Urban Energy Transition. In: Urban Energy Transition. Elsevier, pp. 467–490.

Boldrini, C., Bruno, R., Laarabi, M.H., 2019. Weak signals in the mobility landscape: car sharing in ten European cities. EPJ Data Sci. 8, 1–24.

Brauer, B., Kolbe, L., 2016. Towards IS enabled Sustainable Communities A Conceptual Framework and Research Agenda, in: Proceedings of the 22nd Americas Conference on Information Systems (AMCIS 2016). Association for Information Systems.
Burger, J.R., Brown, J.H., Day, J.W., Flanagan, T.P., Roy, E.D., 2019. The Central Role of Energy in the Urban Transition: Global Challenges for Sustainability. Biophys Econ Resour Qual 4.
Burger, J.R., Weinberger, V.P., Marquet, P.A., 2017. Extra-metabolic energy use and the rise in human hyper-density. Scientific reports 7, 43869.
Burkhardt, J.E., 2005. Car-sharing: where and how it succeeds. Transportation Research Board, Washington, D.C, 1 Band.
Chen, T.D., Kockelman, K.M., 2016. Carsharing's life-cycle impacts on energy use and greenhouse gas emissions. Transportation Research Part D: Transport and Environment 47, 276–284.
Cledou, G., Estevez, E., Soares Barbosa, L., 2018. A taxonomy for planning and designing smart mobility services. Government Information Quarterly 35, 61–76.
Cohen, B., Kietzmann, J., 2014. Ride On! Mobility Business Models for the Sharing Economy. Organization & Environment 27, 279–296.
Corbett, J., Mellouli, S., 2017. Winning the SDG battle in cities: how an integrated information ecosystem can contribute to the achievement of the 2030 sustainable development goals. Information Systems Journal 27, 427–461.
Costain, C., Ardron, C., Habib, K.N., 2012. Synopsis of users' behaviour of a carsharing program: A case study in Toronto. Transportation Research Part A: Policy and Practice 46, 421–434.
Feng, X., Sun, H., Wu, J., Liu, Z., Lv, Y., 2020. Trip chain based usage patterns analysis of the round-trip carsharing system: A case study in Beijing. Transportation Research Part A: Policy and Practice 140, 190–203.
Ferrero, F., Perboli, G., Rosano, M., Vesco, A., 2018. Car-sharing services: An annotated review. Sustainable Cities and Society 37, 501–518.
Fridgen, G., Keller, R., Körner, M.-F., Schöpf, M., 2020. A holistic view on sector coupling. Energy Policy 147, 111913.
Galli, A., Iha, K., Moreno Pires, S., Mancini, M.S., Alves, A., Zokai, G., Lin, D., Murthy, A., Wackernagel, M., 2020. Assessing the Ecological Footprint and biocapacity of Portuguese cities: Critical results for environmental awareness and local management. Cities 96, 102442.
Gimpel, H., Graf-Drasch, V., Hawlitschek, F., Neumeier, K., 2021. Designing smart and sustainable irrigation: A case study. Journal of Cleaner Production 315, 128048.
Golalikhani, M., Oliveira, B.B., Carravilla, M.A., Oliveira, J.F., Antunes, A.P., 2021a. Carsharing: A review of academic literature and business practices toward an integrated decision-support framework. Transportation Research Part E: Logistics and Transportation Review 149, 102280.
Golalikhani, M., Oliveira, B.B., Carravilla, M.A., Oliveira, J.F., Pisinger, D., 2021b. Understanding carsharing: A review of managerial practices towards relevant research insights. Research in Transportation Business & Management, 100653.
Graf-Drasch, V., Keller, R., Meindl, O., Röhrich, F., 2023. The Design of Citizen-Centric Green IS in Sustainable Smart Districts. Business & Information Systems Engineering.
Graf-Drasch, V., Meindl, O., Voucko-Glockner, H., 2022. Life is a Journey in Smart and Sustainable Districts, in: Proceedings of the 17th International Conference on Wirtschaftsinformatik (WI 2022).
Gregor, 2006. The Nature of Theory in Information Systems. MIS Quarterly 30, 611.

Gregor, S., Jones, D., others, 2007. The anatomy of a design theory. Journal of the Association for Information Systems.
Gregor, S., Kruse, L., Seidel, S., 2020. Research Perspectives: The Anatomy of a Design Principle. Journal of the Association for Information Systems 21, 1622–1652.
Hamari, J., Sjöklint, M., Ukkonen, A., 2016. The sharing economy: Why people participate in collaborative consumption. J Assn Inf Sci Tec 67, 2047–2059.
Harnischmacher, C., Herrenkind, B., Weilbier, L., 2020. Yesterday, Today, and Tomorrow-Perspectives on Green Information Systems Research Streams, in: Proceedings of the 28th European Conference on Information Systems (ECIS 2020). 28th European Conference on Information Systems (ECIS 2020).
Herrmann, S., Schulte, F., Voß, S., 2014. Increasing Acceptance of Free-Floating Car Sharing Systems Using Smart Relocation Strategies: A Survey Based Study of car2go Hamburg. In: González-Ramírez, R.G., Schulte, F., Voß, S., Ceroni Díaz, J.A. (Eds.) Computational Logistics, vol. 8760. Springer International Publishing, Cham, pp. 151–162.
Hevner, March, Park, Ram, 2004. Design Science in Information Systems Research. MIS Quarterly 28, 75.
Hjorteset, M.A., Böcker, L., 2020. Car sharing in Norwegian urban areas. Transportation Research Part D: Transport and Environment 84, 102322.
Hosseini, S., Frank, L., Fridgen, G., Heger, S., 2018. Do Not Forget About Smart Towns. Business & Information Systems Engineering 60, 243–257.
Intergovernmental Panel on Climate Change, 2023. Synthesis Report of the IPCC Sixth Assessment Report Summary for Policymakers.
Jain, P., Castellanos-Acuna, D., Coogan, S.C.P., Abatzoglou, J.T., Flannigan, M.D., 2022. Observed increases in extreme fire weather driven by atmospheric humidity and temperature. Nat. Clim. Chang. 12, 63–70.
Ji, T., Chen, J.-H., Wei, H.-H., Su, Y.-C., 2021. Towards people-centric smart city development: Investigating the citizens' preferences and perceptions about smart-city services in Taiwan. Sustainable Cities and Society 67, 102691.
Jian, S., Rashidi, T.H., Dixit, V., 2017. An analysis of carsharing vehicle choice and utilization patterns using multiple discrete-continuous extreme value (MDCEV) models. Transportation Research Part A: Policy and Practice 103, 362–376.
Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., González, M.J.A., Narayan, J., 2017. Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. UP 2, 13.
Jorge, D., Molnar, G., Almeida Correia, G.H. de, 2015. Trip pricing of one-way station-based carsharing networks with zone and time of day price variations. Transportation Research Part B: Methodological 81, 461–482.
Juschten, M., Ohnmacht, T., Thao, V.T., Gerike, R., Hössinger, R., 2019. Carsharing in Switzerland: identifying new markets by predicting membership based on data on supply and demand. Transportation 46, 1171–1194.
Kamargianni, M., Li, W., Matyas, M., Schäfer, A., 2016. A Critical Review of New Mobility Services for Urban Transport. Transportation Research Procedia 14, 3294–3303.
Keller, R., Ollig, P., Rövekamp, P., 2022. Pathways to Developing Digital Capabilities within Entrepreneurial Initiatives in Pre-Digital Organizations. Business & Information Systems Engineering 64, 33–46.
Keller, R., Röhrich, F., Schmidt, L., Fridgen, G., 2019. Sustainability's Coming Home: Preliminary Design Principles for the Sustainable Smart District, in: Proceedings of the 14th International Conference on Wirtschaftsinformatik (WI 2019). 14th International Conference on Wirtschaftsinformatik (WI 2019).

Keller, R., Röhrich, F., Wiedemann, S., Wiethe, C., 2023. Back to Balance – Fostering Sustainable Urban Mobility with Optimized Carsharing System. Working Paper.
Kopp, J., Gerike, R., Axhausen, K.W., 2015. Do sharing people behave differently? An empirical evaluation of the distinctive mobility patterns of free-floating car-sharing members. Transportation 42, 449–469.
Koutra, S., Becue, V., Ioakimidis, C.S., 2018. A Multiscalar Approach for 'Smart City' Planning, in: 2018 IEEE International Smart Cities Conference (ISC2). 2018 IEEE International Smart Cities Conference. 2018, pp. 1–7.
Kumar, H., Singh, M.K., Gupta, M.P., Madaan, J., 2020. Moving towards smart cities: Solutions that lead to the Smart City Transformation Framework. Technological Forecasting and Social Change 153, 119281.
Kutty, A.A., Abdella, G.M., Kucukvar, M., Onat, N.C., Bulu, M., 2020. A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. Sustainable Development 28, 1347–1365.
Le Boennec, R., Nicolaï, I., Da Costa, P., 2019. Assessing 50 innovative mobility offers in low-density areas: A French application using a two-step decision-aid method. Transport Policy 83, 13–25.
Lempert, R., Zhao, J., Dowlatabadi, H., 2019. Convenience, savings, or lifestyle? Distinct motivations and travel patterns of one-way and two-way carsharing members in Vancouver, Canada. Transportation Research Part D: Transport and Environment 71, 141–152.
Lindloff, K., Pieper, N., Bandelow, N.C., Woisetschläger, D.M., 2014. Drivers of carsharing diffusion in Germany: an actor-centred approach. Int. J. Automotive Technology and Management 14, 217–245.
Liu, H., Cui, W., Zhang, M., 2022. Exploring the causal relationship between urbanization and air pollution: Evidence from China. Sustainable Cities and Society 80, 103783.
Loose, W., 2010. The state of European car-sharing.
Macke, J., Rubim Sarate, J.A., Atayde Moschen, S. de, 2019. Smart sustainable cities evaluation and sense of community. Journal of Cleaner Production 239, 118103.
Marrone, M., Hammerle, M., 2018. Smart Cities: A Review and Analysis of Stakeholders' Literature. Business & Information Systems Engineering 60, 197–213.
Martin, C., Evans, J., Karvonen, A., Paskaleva, K., Yang, D., Linjordet, T., 2019. Smart-sustainability: A new urban fix? Sustainable Cities and Society 45, 640–648.
Martin, E., Shaheen, S.A., Lidicker, J., 2010. Impact of Carsharing on Household Vehicle Holdings. Transportation Research Record 2143, 150–158.
Martin, E.W., Shaheen, S.A., 2011. Greenhouse Gas Emission Impacts of Carsharing in North America. IEEE Trans. Intell. Transport. Syst. 12, 1074–1086.
Migdal, A., 2019. Hundreds of thousands of Car2Go members to lose service as company pulls out of North America. https://www.cbc.ca/news/canada/british-columbia/car2go-share-now-shutting-down-1.5401113. Accessed 4 May 2022.
Migliore, M., D'Orso, G., Caminiti, D., 2020. The environmental benefits of carsharing: the case study of Palermo. Transportation Research Procedia 48, 2127–2139.
Möller, F., Guggenberger, T.M., Otto, B., 2020. Towards a Method for Design Principle Development in Information Systems. In: Hofmann, S., Müller, O., Rossi, M. (Eds.) Designing for Digital Transformation. Co-Creating Services with Citizens and Industry, vol. 12388, pp. 208–220.
Mora, L., Deakin, M., Reid, A., 2019. Strategic principles for smart city development: A multiple case study analysis of European best practices. Technological Forecasting and Social Change 142, 70–97.
Mourad, A., Puchinger, J., Chu, C., 2019. A survey of models and algorithms for optimizing shared mobility. Transportation Research Part B: Methodological 123, 323–346.

Münzel, K., Boon, W., Frenken, K., Vaskelainen, T., 2018. Carsharing business models in Germany: characteristics, success and future prospects. Inf Syst E-Bus Manage 16, 271–291.
Pangbourne, K., Mladenović, M.N., Stead, D., Milakis, D., 2020. Questioning mobility as a service: Unanticipated implications for society and governance. Transportation Research Part A: Policy and Practice 131, 35–49.
Perboli, G., Ferrero, F., Musso, S., Vesco, A., 2018. Business models and tariff simulation in car-sharing services. Transportation Research Part A: Policy and Practice 115, 32–48.
Polydoropoulou, A., Pagoni, I., Tsirimpa, A., Roumboutsos, A., Kamargianni, M., Tsouros, I., 2020. Prototype business models for Mobility-as-a-Service. Transportation Research Part A: Policy and Practice 131, 149–162.
Powell, S., Cezar, G.V., Min, L., Azevedo, I.M.L., Rajagopal, R., 2022. Charging infrastructure access and operation to reduce the grid impacts of deep electric vehicle adoption. Nat Energy 7, 932–945.
Pribyl, O., Blokpoel, R., Matowicki, M., 2020. Addressing EU climate targets: Reducing CO2 emissions using cooperative and automated vehicles. Transportation Research Part D: Transport and Environment 86, 102437.
Ramaswami, A., Russell, A.G., Culligan, P.J., Sharma, K.R., Kumar, E., 2016. Meta-principles for developing smart, sustainable, and healthy cities. Science 352, 940–943.
Ramos, É.M.S., Mattos, D.I., Bergstad, C.J., 2023. Roundtrip, free-floating and peer-to-peer carsharing: A Bayesian behavioral analysis. Transportation Research Part D: Transport and Environment 115, 103577.
Razmjoo, A., Mirjalili, S., Aliehyaei, M., Østergaard, P.A., Ahmadi, A., Majidi Nezhad, M., 2022. Development of smart energy systems for communities: technologies, policies and applications. Energy 248, 123540.
Reuver, M. de, Sørensen, C., Basole, R.C., 2018. The Digital Platform: A Research Agenda. Journal of Information Technology 33, 124–135.
Reyes García, J.R., Lenz, G., Haveman, S.P., Bonnema, G.M., 2020. State of the Art of Mobility as a Service (MaaS) Ecosystems and Architectures—An Overview of, and a Definition, Ecosystem and System Architecture for Electric Mobility as a Service (eMaaS). WEVJ 11, 7.
Riggs, W., Appleyard, B., 2020. Exploring the Implications Travel Behavior During COVID-19 for Transit: Potential for Ridesharing and Carsharing. SSRN Journal.
Röhrich, F., Prank, M., Keller, R., 2023. New Ways for Carsharing in Urban Areas - Can Mobility as a Service boost Carsharing? Working Paper.
Rosemann, M., Becker, J., Chasin, F., 2020. City 5.0. Business & Information Systems Engineering.
Sandau, A., Marx Gómez, J., Stamer, D., Wagner vom Berg, B., Halberstadt, J., 2016. Model of mobility demands for future short distance public transport systems. CONF-IRM 2016 Proceedings.
Schaefers, T., 2013. Exploring carsharing usage motives: A hierarchical means-end chain analysis. Transportation Research Part A: Policy and Practice 47, 69–77.
Schreier, H., Grimm, C., Kurz, U., Schwieger, B., Keßler, S., Möser, G., 2018. Analyse der Auswirkungen des Car-Sharing in Bremen.
Seidel, S., Chandra Kruse, L., Székely, N., Gau, M., Stieger, D., 2018. Design principles for sensemaking support systems in environmental sustainability transformations. European Journal of Information Systems 27, 221–247.
Shaheen, S., 2018. Innovative Mobility: Carsharing Outlook.
Shaheen, S., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends - Spring 2020.

Shaheen, S., Cohen, A., 2021. Shared Mobility: An Overview of Definitions, Current Practices, and Its Relationship to Mobility on Demand and Mobility as a Service. In: Vickerman, R. (Ed.) International Encyclopedia of Transportation. Elsevier, San Diego, pp. 155–159.
Shaheen, S., Cohen, A., Zohdy, I., 2016. Shared Mobility: Current Practices and Guiding Principles.
Shaheen, S.A., Cohen, A., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends - Spring 2020.
Shaheen, S.A., Cohen, A.P., 2007. Growth in Worldwide Carsharing. Transportation Research Record 1992, 81–89.
Shaheen, S.A., Cohen, A.P., 2013. Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. International Journal of Sustainable Transportation 7, 5–34.
Share Now, 2019a. Facts and Figures. https://brandhub.share-now.com/web/6570a0eb69e15b2f/factsheets/?mediaId=2ED6BD0D-4FA7-4C9C-A6118D6B45C3C3DA. Accessed 4 May 2022.
Share Now, 2019b. Important Update: Service Ending February 29th. https://www.share-now.com/us/en/important-update/. Accessed 31.06.2022.
Shoup, D.C., 2019. The high cost of free parking. Routledge, London, 765 pp.
Silva, B.N., Khan, M., Han, K., 2018. Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities. Sustainable Cities and Society 38, 697–713.
Sopjani, L., Stier, J.J., Hesselgren, M., Ritzén, S., 2020. Shared mobility services versus private car: Implications of changes in everyday life. Journal of Cleaner Production 259, 120845.
Steinman, W., Rodewyk, V., Peine, A., Stolle, W., 2020. The Demystification of Car Sharing. https://www.kearney.com/automotive/article/-/insights/the-demystification-of-car-sharing. Accessed 19 April 2023.
Stillwater, T., Mokhtarian, P.L., Shaheen, S.A., 2009. Carsharing and the Built Environment. Transportation Research Record 2110, 27–34.
Stopka, U., Pessier, R., Günther, C., 2018. Mobility as a Service (MaaS) Based on Intermodal Electronic Platforms in Public Transport. In: Kurosu, M. (Ed.) Interaction in context, vol. 10902. Springer, Cham, pp. 419–439.
Sun, L., Chen, J., Li, Q., Huang, D., 2020. Dramatic uneven urbanization of large cities throughout the world in recent decades. Nature communications 11, 5366.
Te, Q., Lianghua, C., 2020. Carsharing: mitigation strategy for transport-related carbon footprint. Mitig Adapt Strateg Glob Change 25, 791–818.
Thigpen, C.G., 2018. Giving parking the time of day: A case study of a novel parking occupancy measure and an evaluation of infill development and carsharing as solutions to parking oversupply. Research in Transportation Business & Management 29, 108–115.
Thomson, C.S., Karrbom Gustavsson, T., Karvonen, A., 2021. Grand challenges facing our cities: where construction management research meets the urban field. Construction Management and Economics 39, 874–878.
Trindade, E.P., Hinnig, M.P.F., Da Costa, E.M., Marques, J.S., Bastos, R.C., Yigitcanlar, T., 2017. Sustainable development of smart cities: a systematic review of the literature. J. open innov. 3.
United Nations, 2019. World urbanization prospects: The 2018 revision. United Nations, New York, 103 pp.
Utriainen, R., Pöllänen, M., 2018. Review on mobility as a service in scientific publications. Research in Transportation Business & Management 27, 15–23.

van der Aalst, W.M.P., Hinz, O., Weinhardt, C., 2023. Sustainable Systems Engineering. Business & Information Systems Engineering 65, 1–6.
Velsberg, O., Westergren, U.H., Jonsson, K., 2020. Exploring smartness in public sector innovation - creating smart public services with the Internet of Things. European Journal of Information Systems 29, 350–368.
Wagner, S., Brandt, T., Kleinknecht, M., Neumann, D., 2014. In Free-Float: How Decision Analytics Paves the Way for the Carsharing Revolution.
Wong, S.D., Broader, J.C., Shaheen, S.A., 2020. Can Sharing Economy Platforms Increase Social Equity for Vulnerable Populations in Disaster Response and Relief? A Case Study of the 2017 and 2018 California Wildfires. Transportation research interdisciplinary perspectives 5, 100131.
Zervas, G., Proserpio, D., Byers, J.W., 2017. The Rise of the Sharing Economy: Estimating the Impact of Airbnb on the Hotel Industry. Journal of Marketing Research 54, 687–705.
Zhang, X., Han, L., Wei, H., Tan, X., Zhou, W., Li, W., Qian, Y., 2022. Linking urbanization and air quality together: A review and a perspective on the future sustainable urban development. Journal of Cleaner Production 346, 130988.
Zoepf, S.M., Keith, D.R., 2016. User decision-making and technology choices in the U.S. carsharing market. Transport Policy 51, 150–157.

# IV. Appendix

## 1 Index of Research Articles'

**Research Article #1: Sustainability's Coming Home: Preliminary Design Principles for the Sustainable Smart District**

Keller, R., Röhrich, F., Schmidt, L., & Fridgen, G. (2019). Sustainability's Coming Home: Preliminary Design Principles for the Sustainable Smart District. In *14. International Conference on Wirtschaftsinformatik.*
(VHB-JOURQUAL 3: Category C)

**Research Article #2: The Design of Citizen-Centric Green IS in Sustainable Smart Districts**

Graf-Drasch, V.**,** Keller, R., Meindl, O. & Röhrich, F. (2023). The Design of Citizen-Centric Green IS in Sustainable Smart Districts**.** *Business & Information Systems Engineering.* (VHB-JOURQUAL 3: Category B)

**Research Article #3: You'll Never Share Alone: Analyzing Carsharing User Group Behavior**

Baumgarte, F., Brandt, T., Keller, R., Röhrich, F., & Schmidt, L. (2021). You'll never share alone: Analyzing carsharing user group behavior. *Transportation Research Part D: Transport and Environment, 93*.
(VHB-JOURQUAL 3: Category B)

**Research Article #4: Revealing influences on carsharing user's trip distance in small urban areas**

Baumgarte, F., Keller, R., Röhrich, F., Valett, L., & Zinsbacher, D. (2022). Revealing influences on carsharing users' trip distance in small urban areas. *Transportation Research Part D: Transport and Environment, 105*
(VHB-JOURQUAL 3: Category B)

**Research Article #5: Exploring the Impact of Spatial Access on User Decision-Making in Urban Carsharing**
Albrecht, T., Keller, R. & Röhrich, F. (2023). Exploring the Impact of Spatial Access on User Decision-Making in Urban Carsharing. Working Paper.

**Research Article #6: Back to Balance – Fostering Sustainable Urban Mobility with Optimized Carsharing System**

Keller, R., Röhrich, F., Wiedemann, S. & Wiethe, C. (2023). Back to Balance – Fostering Sustainable Urban Mobility with Optimized Carsharing Systems. Working Paper.

**Research Article #7: New Ways for Carsharing in Urban Areas - Can Mobility as a Service boost Carsharing?**

Röhrich, F., Prank, M. & Keller, R. (2023). New Ways for Carsharing in Urban Areas - Can Mobility as a Service boost Carsharing? Working Paper.

## 2 Individual Contribution to the Research Articles

This doctoral thesis is cumulative and consists of seven research articles that comprise the main body of work. All research articles were developed in teams with multiple co-authors. This section provides details on the respective research settings and highlights my contributions to each article.

**Research Article #1** (Keller et al., 2019) was developed together with three co-authors. I was primarily responsible for the underlying literature work and for structuring and implementing the implications for research and practice. I substantially contributed to the evaluation and analysis of the results. I also took a key role in revising the article for re-submission. In sum, I was involved in each part of the project.

**Research Article #2** (Graf-Drasch et al., 2023) was developed together with three co-authors. The article was submitted to the academic journal *Business & Information Systems Engineering* and is currently under its second major revision. All co-authors contributed to the evaluation and analysis of the results and the derivation of managerial and policy implications. Particularly, I substantially drove the definition of the research question, the elaboration of the results and the details on the implications of the design principles. I also took a key role in revising the article for re-submission. In sum, I was involved in each part of the project.

**Research Article #3** (Baumgarte et al., 2021a) was developed together with four co-authors. I took a key role in initiating the project and the idea. I was responsible for acquiring the used data sets from an external company. Particularly, I substantially drove the definition of the research question, designed the research method and was responsible for writing major parts of the article. I also took a key role in the evaluation of our results. Throughout, I had a key role in all parts of the research project.

**Research Article #4** (Baumgarte et al., 2022b) was developed together with four co-authors. All co-authors were to differing parts responsible for writing the text of the originally submitted version and the revised versions of the article. In particular, I engaged in the further development of the research idea, the synthesis and presentation of the research results as well as textual elaboration. In addition, I contributed to the paper by providing mobility know-how, research guidance and literature. Moreover, I participated in research discussions and provided feedback on the article’s content and structure.

**Research Article #5** (Albrecht et al., 2023) was developed together with three co-authors. The article was submitted to the academic journal *Transportation Research Part D* and is currently under review. All co-authors were jointly responsible for writing the text of the originally submitted version and the revised versions of the article. All co-authors contributed equally to the evaluation and analysis of the results and the derivation of managerial and policy implications I was responsible for acquiring the used data sets from an external company. I was also primarily responsible for the underlying literature work and for structuring and implementing the descriptive part of the analysis.

**Research Article #6** (Keller et al., 2023) was developed together with three co-authors. The article was submitted to the *18. International Conference on Wirtschaftsinformatik* and is currently under review. I took a key role in initiating the project and the idea. I was also responsible for acquiring the used data sets from an external company. Further, all co-authors contributed equally to the analysis of the results and the textual elaboration. I was also primarily responsible for the underlying literature work. Moreover, I participated in research discussions and provided feedback on the article's content and structure.

**Research Article #7** (Röhrich et al., 2023) was developed together with two co-authors with me being the lead author. The article was submitted to the academic journal *Transportation Research Part D* and is currently under review. As the leading author of this article, I developed the basic idea, structured the research process, and created its content to a large extent. Particularly, I substantially drove the definition of the research question, designed the research method as well as the results, and their concluding implications for research and practice. I was also responsible for acquiring the used data sets from an external company.

## 3 Research Article #1: Sustainability's Coming Home: Preliminary Design Principles for the Sustainable Smart District

Authors: Robert Keller, Felix Röhrich, Lukas Schmidt, Gilbert Fridgen

Published in: Proceedings of the 14th International Conference on Wirtschaftsinformatik (2019), Siegen, Germany

Abstract: Consumer trends like local consumption, sharing of property, and environmental awareness change our habits and thereby our surroundings. These trends have their origin in our direct environment, in the districts of our city or community, where we live and socialize. Cities and districts are changing to “smart cities” and “smart districts” as a part of the ongoing digitalization. These changes offer the possibility to entrench the idea of sustainability and build a platform-based ecosystem for a sustainable smart district. This research aims to identify guidelines in form of preliminary design principles for sustainable smart districts. To achieve this, we conduct a structured literature review. On this basis, we derive and develop preliminary design principles with the help of semi-structured interviews and a non-representative sample of the German population. The resulting nine preliminary design principles describe a first insight into the design of sustainable smart districts.

Keywords: Sustainability, Smart District, Platform-based Ecosystem, Smart City, Design Principles

# 4 Research Article #2: The Design of Citizen-Centric Green IS in Sustainable Smart Districts

Authors: Valerie Graf-Drasch, Oliver Meindl, Robert Keller, Felix Röhrich

Published in: Business & Information Systems Engineering (2023)

Abstract: Green information systems are praised for their potential to foster sustainability in citizens' daily lives and meet their needs. With this focus on citizens, districts that use smart technologies provide a litmus test of sorts, the results of which will indicate how to design smart green information systems that get closer to citizens' needs and desires. To date, however, guidelines on how to design green information systems in urban areas or actively involve citizens in designing such systems are few and far between. Working with the design science research paradigm, we develop seven design principles for citizen-centric green information systems that can be used in sustainable smart districts. We evaluate these principles in 15 semi-structured interviews and prototypically instantiate a mobile district app of a citizen-centric green information system. By taking this citizen-centric perspective, we foster the active involvement of humans in the design of sustainable urban environments.

Keywords: Sustainable Smart Districts, Smart cities, Green Information Systems, Sustainability, Citizen-centricity, Design Principles

# 5 Research Article #3: You'll Never Share Alone: Analyzing Carsharing User Group Behavior

Authors: Felix Baumgarte, Tobias Brandt, Robert Keller, Felix Röhrich, Lukas Schmidt

Published in: Transportation Research Part D: Transport and Environment (2021)

Abstract: The rapidly developing concept of carsharing is an essential and scalable part of sustainable, multimodal mobility in urban environments. There is a clear need for carsharing operators to understand their users and how they use different transportation modes to intensify the development of carsharing and its positive impacts on the environment and urban cohabitation. We foster this understanding by analyzing usage data of carsharing in a medium-sized German city. We compare user groups based on individual characteristics and their carsharing usage behavior. We focus on a station-based two-way carsharing scheme and its relation to free-floating carsharing. Based on different clustering and segmentation approaches, we defined 20 particularly interesting user groups among the carsharing users and analyzed noticeable usage patterns. Additionally, we examined these partially overlapping user groups in the spatial dimension. With these results, we support research and operators in understanding carsharing customers and assessing users' individual behavior.

Keywords: Carsharing, Station-based, Free-floating, Urban Environment, Shared

# 6 Research Article #4: Revealing influences on carsharing user’s trip distance in small urban areas

Authors: Felix Baumgarte, Robert Keller, Felix Röhrich, Lynne Valett, Daniela Zinsbacher

Published in: Transportation Research Part D: Transport and Environment (2022)

Abstract: Carsharing is an essential part of the transformation towards sustainable mobility in smaller urban areas. To expand their services and the positive social and environmental benefits, carsharing operators must understand their user's travel behavior. To accelerate this understanding, we analyze usage data of a station-based carsharing service from a small city in Germany with machine learning and explainable artificial intelligence to reveal influencing factors on the trip distance. The resulting four overarching groups are personal characteristics, time-related, car-related, and environmental features. We further analyze the driving distance of several subgroups split by personal and time-related features. Our findings highlight the importance of time-related features for the trip distance of carsharing users in all subgroups. We also discuss the influence of non-time-related features on the user groups. With these results, we derive valuable insights for research and carsharing operators by understanding patterns in individual user behavior in smaller urban areas.

Keywords: Carsharing, User Behavior, Trip Distance, Machine Learning, Explainable Artificial Intelligence, Feature Importance

# 7 Research Article #5: Exploring the Impact of Spatial Access on User Decision-Making in Urban Carsharing

Authors: Tobias Albrecht, Robert Keller, Felix Röhrich

Status: Working Paper

Extended Abstract: Carsharing is a valuable mobility concept to counteract urban mobility challenges such as space shortage, noise pollution, and carbon dioxide emissions (Chen and Kockelman, 2016; Jian et al., 2017; Nijland and van Meerkerk, 2017; Thigpen, 2018). For carsharing operators as service providers, utility and high perceived service quality by the users are key prerequisites to succeed in this competitive market (Molnar and Correia, 2019). Consequently, operators seek to better understand usage factors and user decision-making to refine supply attributes according to demand characteristics (Lindloff et al., 2014). In this regard, individual vehicle access (i.e., close spatial distance to the preferred vehicle) is suspected to be an integral part contributing to user convenience as one of the main motivational factors for carsharing usage (Schaefers, 2013; Juschten et al., 2019; Lempert et al., 2019). Data based insights on this aspect of situational user decision-making can serve as a basis for strategic operator decisions like station (location) optimization (Abbasi et al., 2021) or fleet management (Xu and Meng, 2019) as well as for policy decisions like offering adoption incentives (e.g., student benefits), linking carsharing with other urban mobility concepts (e.g., public transport), or adapting regulatory barriers (e.g., parking restrictions) (Hu and Liu, 2016; Perboli et al., 2018; Mounce and Nelson, 2019). However, extant research considering the role of the distance users need to cover to access carsharing stations and vehicles – mostly based on stated preference methods – only scratches the surface of this topic. Thus, in-depth insights based on real-world transaction data are needed to advance descriptive knowledge of the decision-making behavior of carsharing users (Zoepf and Keith, 2016).

To fill this gap, the research goal of this study is twofold. First, it aims to provide novel insights on the role of spatial access in individual user decision-making in carsharing. Specifically, it means to investigate how the distance, users need to cover to access carsharing stations and vehicles affects the individual usage decision and how selected policy-relevant factors impact this relation. Second, this work presents a model-agnostic approach based on explainable machine learning to investigate the actual effect of explanatory variables on the performance of prediction models. In doing so, it means to deliver tailored insights for prescriptive models to support operational as well as policy decisions and, at the same time, to make a step toward the use of interpretable machine learning models in carsharing research. The paper draws on a two-phase research approach. First, it analyzes the real-world transaction and user data by means of descriptive statistics and graphical visualization before being triangulated with relevant results from previous studies. The main objective of this research phase is to better understand the role of spatial access in individual user decision-making when it comes to the actual usage of carsharing for individual trips. Second, the present study draws on three different machine learning algorithms (i.e., random forests, gradient boosting machines, and deep neural networks) and one benchmark model (i.e., generalized linear model) complemented by explainable machine learning in the form of model-agnostic permutation feature importance (Fisher et al., 2019) and accumulated local effects plots (Apley and Zhu, 2020) to investigate the actual effect of explanatory variables like individual spatial access on the performance of prediction models.

Keywords: Carsharing, Decision Support, Explainable Machine Learning, Green Travel, Spatial Access, User Behavior

Publication Bibliography:

Abbasi, S., Ko, J., Kim, J., 2021. Carsharing station location and demand: Identification of associated factors through Heckman selection models. Journal of Cleaner Production 279, 123846.

Apley, D.W., Zhu, J., 2020. Visualizing the effects of predictor variables in black box supervised learning models. J. R. Stat. Soc. B 82, 1059–1086.

Baumgarte, F., Brandt, T., Keller, R., Röhrich, F., Schmidt, L., 2021. You'll never share alone: Analyzing carsharing user group behavior. Transportation Research Part D: Transport and Environment 93, 102754.
Baumgarte, F., Keller, R., Röhrich, F., Valett, L., Zinsbacher, D., 2022. Revealing influences on carsharing users' trip distance in small urban areas. Transportation Research Part D: Transport and Environment 105, 103252.
Chen, T.D., Kockelman, K.M., 2016. Carsharing's life-cycle impacts on energy use and greenhouse gas emissions. Transportation Research Part D: Transport and Environment 47, 276–284.
Cheng, J., Chen, X., Ye, J., Shan, X., 2021. Flow-based unit is better: exploring factors affecting mid-term OD demand of station-based one-way electric carsharing. Transportation Research Part D: Transport and Environment 98, 102954.
Fisher, A., Rudin, C., Dominici, F., 2019. All Models are Wrong, but Many are Useful: Learning a Variable's Importance by Studying an Entire Class of Prediction Models Simultaneously. Journal of Machine Learning Research 20, 1–81.
Golalikhani, M., Oliveira, B.B., Carravilla, M.A., Oliveira, J.F., Antunes, A.P., 2021. Carsharing: A review of academic literature and business practices toward an integrated decision-support framework. Transportation Research Part E: Logistics and Transportation Review 149, 102280.
Hu, L., Liu, Y., 2016. Joint design of parking capacities and fleet size for one-way station-based carsharing systems with road congestion constraints. Transportation Research Part B: Methodological 93, 268–299.
Jian, S., Rashidi, T.H., Dixit, V., 2017. An analysis of carsharing vehicle choice and utilization patterns using multiple discrete-continuous extreme value (MDCEV) models. Transportation Research Part A: Policy and Practice 103, 362–376.
Juschten, M., Ohnmacht, T., Thao, V.T., Gerike, R., Hössinger, R., 2019. Carsharing in Switzerland: identifying new markets by predicting membership based on data on supply and demand. Transportation 46, 1171–1194.
Lei, Z., Qian, X., Ukkusuri, S.V., 2020. Efficient proactive vehicle relocation for on-demand mobility service with recurrent neural networks. Transportation Research Part C: Emerging Technologies 117, 102678.
Lempert, R., Zhao, J., Dowlatabadi, H., 2019. Convenience, savings, or lifestyle? Distinct motivations and travel patterns of one-way and two-way carsharing members in Vancouver, Canada. Transportation Research Part D: Transport and Environment 71, 141–152.
Lindloff, K., Pieper, N., Bandelow, N.C., Woisetschläger, D.M., 2014. Drivers of carsharing diffusion in Germany: an actor-centred approach. Int. J. Automotive Technology and Management 14, 217–245.
Luca, S. de, Di Pace, R., 2015. Modelling users' behaviour in inter-urban carsharing program: A stated preference approach. Transportation Research Part A: Policy and Practice 71, 59–76.
Molnar, G., Correia, G.H.d.A., 2019. Long-term vehicle reservations in one-way free-floating carsharing systems: A variable quality of service model. Transportation Research Part C: Emerging Technologies 98, 298–322.
Mounce, R., Nelson, J.D., 2019. On the potential for one-way electric vehicle car-sharing in future mobility systems. Transportation Research Part A: Policy and Practice 120, 17–30.
Nijland, H., van Meerkerk, J., 2017. Mobility and environmental impacts of car sharing in the Netherlands. Environmental Innovation and Societal Transitions 23, 84–91.
Perboli, G., Ferrero, F., Musso, S., Vesco, A., 2018. Business models and tariff simulation in car-sharing services. Transportation Research Part A: Policy and Practice 115, 32–48.

Schaefers, T., 2013. Exploring carsharing usage motives: A hierarchical means-end chain analysis. Transportation Research Part A: Policy and Practice 47, 69–77.
Schmöller, S., Bogenberger, K., 2020. Carsharing: An overview on what we know. In: Demand for Emerging Transportation Systems. Elsevier, pp. 211–226.
Shaheen, S., Cohen, A., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends - Spring 2020, 7 pp.
Thigpen, C.G., 2018. Giving parking the time of day: A case study of a novel parking occupancy measure and an evaluation of infill development and carsharing as solutions to parking oversupply. Research in Transportation Business & Management 29, 108–115.
Wang, T., Hu, S., Jiang, Y., 2021. Predicting shared-car use and examining nonlinear effects using gradient boosting regression trees. International Journal of Sustainable Transportation 15, 893–907.
Willing, C., Klemmer, K., Brandt, T., Neumann, D., 2017. Moving in time and space – Location intelligence for carsharing decision support. Decision Support Systems 99, 75–85.
Xu, M., Meng, Q., 2019. Fleet sizing for one-way electric carsharing services considering dynamic vehicle relocation and nonlinear charging profile. Transportation Research Part B: Methodological 128, 23–49.
Zoepf, S.M., Keith, D.R., 2016. User decision-making and technology choices in the U.S. carsharing market. Transport Policy 51, 150–157.

# 8 Research Article #6: Back to Balance – Fostering Sustainable Urban Mobility with Optimized Carsharing Systems


Authors: Robert Keller, Felix Röhrich, Stefanie Wiedemann, Christian Wiethe



Status: Working Paper



Extended Abstract: Carsharing is a known way to reduce the negative effects of individual motorized traffic and fosters sustainable transport in urban areas (Stillwater et al., 2009; Ferrero et al., 2018; Münzel et al., 2018; Shaheen and Cohen, 2020). Additionally, carsharing contributes to reduced individual car ownership and thus saves valuable space in cities and their districts (Martin et al., 2010; Shaheen and Cohen, 2013; Thigpen, 2018). Despite these positive effects, carsharing still struggles to reach cost-effectiveness in its business models.

A high occupancy rate of the fleet is a key parameter in reaching cost-effectiveness, which can be achieved by a careful allocation of the cars and is actively supported by information systems (Nourinejad and Roorda, 2015; Ferrero et al., 2018). One of the main issues in station-based round-trip systems is to match the supply and demand of cars in an already existing station network (Stillwater et al., 2009; Ferrero et al., 2018). This perspective is relevant since each car in the fleet causes operational costs, which substantially impact the tariff design, a so far underrepresented aspect of carsharing research (Ferrero et al., 2018). Information systems can help to fill this gap by supporting system operators in making better decision in their car allocation. To minimize the difference between demand and supply by optimizing the number of cars at specific stations in existing carsharing round-trip networks and thus improve cost-effectiveness, our work aims to increase the occupancy rate as well as availability in existing carsharing systems using an automated allocation approach which serves as a tool for decision support in form of an information system artifact. In this way, the study contributes to the scientific body of knowledge by introducing an optimization approach in the field of round-trip carsharing

station optimization and providing compelling empiric evidence in favor of applying information systems in car allocation. Thereby, we support round-trip carsharing operators in establishing a sustainable form of mobility and fostering the reduction of individual car ownership. To do so, we develop a stochastic optimization model for round-trip carsharing location specifications to adapt supply to demand. With the help of a Sample Average Approximation, we transform the model into a Mixed-Integer Program that optimizes the difference between supply and demand for each station.

We evaluate this approach with a rich data set of a German carsharing operator that contains detailed information on stations and the members' usage behavior. We use a real-world data set to derive probability distributions for estimating the number of requests and their starting time and duration. Based on these, we create various demand scenarios that we finally use in the optimization model. Thus, we determine the optimal redistribution of the cars and create a better understanding of the supply and demand balance.

Keywords: Carsharing, Optimization, Round-trip, Mixed-integer Problem

Publication Bibliography:

Ferrero, F., Perboli, G., Rosano, M., Vesco, A., 2018. Car-sharing services: An annotated review. Sustainable Cities and Society 37, 501–518.

Martin, E., Shaheen, S.A., Lidicker, J., 2010. Impact of Carsharing on Household Vehicle Holdings. Transportation Research Record 2143, 150–158.

Münzel, K., Boon, W., Frenken, K., Vaskelainen, T., 2018. Carsharing business models in Germany: characteristics, success and future prospects. Inf Syst E-Bus Manage 16, 271–291.

Nourinejad, M., Roorda, M.J., 2015. Carsharing operations policies: a comparison between one-way and two-way systems. Transportation 42, 497–518.

Shaheen, S.A., Cohen, A., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends - Spring 2020.

Shaheen, S.A., Cohen, A.P., 2013. Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. International Journal of Sustainable Transportation 7, 5–34.

Stillwater, T., Mokhtarian, P.L., Shaheen, S.A., 2009. Carsharing and the Built Environment. Transportation Research Record 2110, 27–34.

Thigpen, C.G., 2018. Giving parking the time of day: A case study of a novel parking occupancy measure and an evaluation of infill development and carsharing as solutions to parking oversupply. Research in Transportation Business & Management 29, 108–115.

# 9 Research Article #7: New Ways for Carsharing - Can Mobility as a Service Boost Carsharing?

Authors: Felix Röhrich, Marius Prank, Robert Keller

Status: Working Paper

Extended Abstract: Mobility as a Service (MaaS) is an upcoming development in mobility research and practice. It holds the potential to foster diverse forms of sustainable mobility in a multimodal way (Stopka et al., 2018). These MaaS concepts are an opportunity for existing forms of sustainable mobility to reach a broader user base and extend their service offerings. Especially in urban areas, people shift away from private means of transportation towards integrated and tailored mobility (Stopka et al., 2018; Ceder, 2021). To achieve this, mobility operators must align their business models to meet customers' changing needs. MaaS offerings are an approach for integrative mobility, which contributes to ecological sustainability in urban environments (Utriainen and Pöllänen, 2018). It combines a variety of transportation modes into one service and therefore provides an alternative to traditional ways of individual mobility without a significant loss of flexibility or convenience (Pangbourne et al., 2020; Reyes García et al., 2020; Shaheen and Cohen, 2021). In many cases, carsharing is a key part of private and public sector MaaS concepts (Stopka et al., 2018; Utriainen and Pöllänen, 2018). Carsharing has already shown the ability to reduce car ownership, greenhouse gas emissions, and parking scarcity in high-density urban areas (Martin and Shaheen, 2011a; Martin and Shaheen, 2011b; Chen and Kockelman, 2016; Thigpen, 2018). While the user numbers of carsharing show tendencies of saturation in European and North American markets in its current form (Shaheen, 2020), MaaS, as a very young concept, is holding the chance to make existing forms of mobility like carsharing more attractive by smart ways of connecting these diverse forms of mobility (Utriainen and Pöllänen, 2018).

In the spirit of these opportunities for carsharing, we find diverse theoretical research about MaaS concepts, but rarely based on real-world applications (Kamargianni et al., 2016; Karlsson et al., 2016; Smith et al., 2018; Utriainen and Pöllänen, 2018). Especially the demand side in form of user behavior and the users' reaction to cost structures of MaaS concepts in general is heavily underrepresented so far (Polydoropoulou et al., 2020). To deepen and extend the knowledge about this topic, especially in the context of carsharing, we analyze an innovative real-world example of MaaS in a medium-sized German city. To understand the results in the proper context, we structure our research in two steps. (i) We show how this particular real-world example of a MaaS business model is structured. (ii) On this basis, we analyze differences in usage between standalone carsharing and carsharing in the context of a MaaS concept.

Our contribution to the field of urban mobility and carsharing research involves providing valuable insights into the subscription-based aspect of carsharing within the context of a MaaS concept based on a real-world data set consisting of more than 100,000 carsharing trips in the year 2021. This enriches current research on the demand side of carsharing in MaaS concepts in form of usage behavior and the users' reactions to cost structures. Furthermore, the results may help to evaluate chances for carsharing business development due to its connection to other types of sustainable mobility, such as public transport and bikesharing. Like this, MaaS concepts can assist the change toward integrated and tailored mobility solutions in urban areas as part of a sustainable future.

Keywords: Mobility as a Service, Business Model, Shared Mobility, Carsharing, Urban Mobility, Multimodal Mobility

Publication Bibliography:

Ceder, A., 2021. Urban mobility and public transport: future perspectives and review. International Journal of Urban Sciences 25, 455–479.

Chen, T.D., Kockelman, K.M., 2016. Carsharing's life-cycle impacts on energy use and greenhouse gas emissions. Transportation Research Part D: Transport and Environment 47, 276–284.

Kamargianni, M., Li, W., Matyas, M., Schäfer, A., 2016. A Critical Review of New Mobility Services for Urban Transport. Transportation Research Procedia 14, 3294–3303.

Karlsson, I.C.M., Sochor, J., Strömberg, H., 2016. Developing the 'Service' in Mobility as a Service: Experiences from a Field Trial of an Innovative Travel Brokerage. Transportation Research Procedia 14, 3265–3273.

Martin, E., Shaheen, S., 2011a. The Impact of Carsharing on Public Transit and Non-Motorized Travel: An Exploration of North American Carsharing Survey Data. Energies 4, 2094–2114.

Martin, E.W., Shaheen, S.A., 2011b. Greenhouse Gas Emission Impacts of Carsharing in North America. IEEE Trans. Intell. Transport. Syst. 12, 1074–1086.

Pangbourne, K., Mladenović, M.N., Stead, D., Milakis, D., 2020. Questioning mobility as a service: Unanticipated implications for society and governance. Transportation Research Part A: Policy and Practice 131, 35–49.

Polydoropoulou, A., Pagoni, I., Tsirimpa, A., Roumboutsos, A., Kamargianni, M., Tsouros, I., 2020. Prototype business models for Mobility-as-a-Service. Transportation Research Part A: Policy and Practice 131, 149–162.

Reyes García, J.R., Lenz, G., Haveman, S.P., Bonnema, G.M., 2020. State of the Art of Mobility as a Service (MaaS) Ecosystems and Architectures—An Overview of, and a Definition, Ecosystem and System Architecture for Electric Mobility as a Service (eMaaS). WEVJ 11, 7.

Shaheen, S., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends - Spring 2020.

Shaheen, S., Cohen, A., 2021. Shared Mobility: An Overview of Definitions, Current Practices, and Its Relationship to Mobility on Demand and Mobility as a Service. In: Vickerman, R. (Ed.) International Encyclopedia of Transportation. Elsevier, San Diego, pp. 155–159.

Smith, G., Sochor, J., Karlsson, I.M., 2018. Mobility as a Service: Development scenarios and implications for public transport. Research in Transportation Economics 69, 592–599.

Stopka, U., Pessier, R., Günther, C., 2018. Mobility as a Service (MaaS) Based on Intermodal Electronic Platforms in Public Transport. In: Kurosu, M. (Ed.) Interaction in context, vol. 10902. Springer, Cham, pp. 419–439.

Thigpen, C.G., 2018. Giving parking the time of day: A case study of a novel parking occupancy measure and an evaluation of infill development and carsharing as solutions to parking oversupply. Research in Transportation Business & Management 29, 108–115.

Utriainen, R., Pöllänen, M., 2018. Review on mobility as a service in scientific publications. Research in Transportation Business & Management 27, 15–23.