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Article

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Mobility transition or just another business? Temporal and spatial analysis of the diffusion of station-based carsharing services in five German municipalities

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Abstract

Station-based carsharing systems are regularly seen as key building blocks for a successful sustainability transition of municipal mobility systems. While numerous studies deal with the optimal distribution of carsharing stations from a business perspective, none explores which spatial and temporal patterns shape the development of carsharing station networks, even though sustainability transitions and their patterns are perceived as strictly place-specific. This study uses a comparative cross-case analysis of five southwest German cities to reveal similarities in spatial and temporal patterns. The analysis differentiates between 'efficient causes', described by structural and social demographic characteristics of cities, and 'final causes', described by the causal pathway development of municipal carsharing policy. Results reveal that despite the different city characteristics and causal pathways, the spatial evolution of station-based carsharing systems

follow similar growth paths, tending towards consolidation of carsharing patterns regardless of municipal support. The study adds to our understanding of mobility transitions and casts doubt on the ability of current station-based carsharing systems to shift municipal mobility systems towards ecological sustainability.

Keywords: Carsharing ■ mobility systems ■ mobility transition ■ causal pathways

Mobilitätswende oder nur ein weiteres Geschäftsfeld? Zeitliche und räumliche Analyse der Verbreitung stationsbasierter Carsharing-Angebote in fünf deutschen Kommunen


Zusammenfassung

Stationsbasierte Carsharing-Systeme werden regelmäßig als wichtiger Baustein für eine erfolgreiche Nachhaltigkeitswende des kommunalen Mobilitätssystems angesehen. Während sich viele Studien mit der optimalen Verteilung von Carsharing-Stationen aus betriebswirtschaftlicher Sicht befassen, untersucht bislang keine, welche räumlichen und zeitlichen Muster die Entwicklung von Carsharing-Stationsnetzen prägen – und das, obwohl gerade Nachhaltigkeitstransitionen und deren Muster als streng ortsspezifisch geprägt gelten. Diese Studie verwendet eine vergleichende fallübergreifende Analyse von fünf südwestdeutschen Städten, um Ähnlichkeiten und Unterschiede in räumlichen und zeitlichen Mustern aufzudecken. Die Analyse unterscheidet zwischen ‚effizienten Ursachen‘, die durch strukturelle und soziodemographische Merkmale der Städte beschrieben werden, und ‚finalen Ursachen‘, die durch die kausale Pfadentwicklung der kommunalen Carsharing-Politiken charakterisiert werden. Die Ergebnisse zeigen, dass die räumliche Entwicklung stationsbasierter Carsharing-Sys-

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teme trotz unterschiedlicher Stadtcharakteristika und Kausalpfaden jeweils ähnlichen Wachstumspfaden folgt und auch unabhängig von Unterschieden in der kommunalen Unterstützung zu einer Konsolidierung von Carsharing-Mustern tendiert. Die Studie trägt zum räumlichen Verständnis von Mobilitätstransitionen bei und lässt Zweifel am Beitrag der derzeitigen stationsbasierten Carsharing-Systeme zur Veränderung kommunaler Mobilitätssysteme in Richtung ökologischer Nachhaltigkeit aufkommen.

Schlüsselwörter: Carsharing ■ Mobilitätssysteme ■ Mobilitätswende ■ kausale Pfade

1 Introduction

Carsharing business models are regularly described as emergent and disruptive innovations that could transform the urban mobility sector towards sustainability (Sarasini/Linder 2018; Meelen/Frenken/Hobrink 2019). From a normative sustainability perspective, carsharing is connected with better resource utilization, leading towards lower rates of car ownership, which frees up city space and supports less frequent car usage (Nijland/van Meerkerk 2017; Lempert/Zhao/Dowlatabadi 2019; Liao/Molin/Timmermans et al. 2020). Furthermore, carsharing is linked to reduced vehicle kilometres travelled per consumer and reduced greenhouse gas emissions per household (Shaheen/Cohen/Farrar 2019). Building on these promises, municipal interest associations, such as the German Association of Towns and Municipalities, proclaim that carsharing should be fostered as it is one of the building blocks for a sustainability transition of the municipal mobility system (Handschuh/Nehrke 2018).

Other research results criticize this positive view on carsharing. Station-based carsharing services in Germany are used mostly on weekends (Schmöller/Bogenberger 2020: 217), with an average booking time of 837 minutes and an average driving distance of 115.4 km (Bogenberger/Weickl/Schmöller et al. 2016: 162). Such usage patterns beg the question of whether customers replace necessary trips or just add recreational trips to their car consumption. Carsharing services suffer from rebound effects with hyper-consumption spoiling the potential ecological gains (Verboven/Vanherck 2016), and could even lead to adverse effects if policies and managerial decisions do not systemically support sustainability efforts (Esfandabadi/Ravina/Diana et al. 2020). Furthermore, Kolleck (2021) raises doubts about the impact of carsharing on car ownership in that he could not find a significant relationship between registered and shared cars in the car markets of 35 German cities. The question remains open regarding the importance of carsharing in terms of the politically desired sustainable mobility transition.

Nowadays, “all major cities in Germany offer station-based carsharing with the free-floating service being an extension mainly in metropolises” (Göddecke/Krauss/Gnann 2022: 870). The spatial and processual patterns underlying this evolution could be indicative of the potential for municipal mobility system transformation. From a transition research perspective, a mobility transition is understood as a structural systemic change in the current dominant car-based mobility regime over the course of multiple decades (Loorbach/Schwanen/Doody et al. 2021). Thereby, “the constellations of lock-in mechanisms, vested interests, and policy mixes” (Kotilainen/Aalto/Valta et al. 2019: 595) are strictly place-specific. The evolution of carsharing services is expected to follow an asynchronous temporal and spatial evolutionary path (Hansen/Coenen 2015; Meelen/Frenken/Hobrink 2019), which should result in processual and spatial patterns, different for each city. In contrast, from a business perspective, the diffusion of carsharing services is mainly determined by demand and supply factors, such as population density (Hu/Chen/Lin et al. 2018; Hjortset/Böcker 2020) or public transportation availability (Ménoire/Wielinski/Morency et al. 2020; Abbasi/Ko/Kim 2021). Thus, we should be able to observe spatial patterns that reflect particularities in terms of economies of scale and scope relative to the structural characteristics of the cities, but with similar tendencies everywhere.

While many studies deal with the optimal station distribution from a business perspective (e.g. Deveci/Canitez/Gökaşar 2018; Cheng/Chen/Ding et al. 2019), none explore which spatial and processual patterns shape the development of carsharing station networks. By performing a causal pathway analysis of the processual and spatial patterns of carsharing station placement in five southwest German cities, we generate insights on the current systemic transition potential of station-based carsharing services for municipal mobility systems. Our research questions are: (1) Did similar spatial patterns occur in the five cities despite differences in structural characteristics? (2) Did similar processual patterns occur in the five cities despite differences in municipal policy setting? To answer these questions, plausible hypothetical causal mechanisms (Beach/Pedersen 2013: 16–18) are compared to the historical distribution patterns of carsharing stations and cars and the rate of car ownership.

The paper is structured as followed. We begin with introducing the concept of causal pathways and the difference between structural characteristics and processual patterns. The theoretical background is followed by a short literature overview about structural characteristics that could explain spatial patterns of carsharing stations and cars. The identified characteristics guide the selection of cases and give us the opportunity to evaluate the suitability of each city to

host station-based carsharing businesses in comparison to the actual available carsharing cars per 1000 inhabitants. In the next section, we present spatial patterns on the historical development of carsharing in the five municipalities. This is followed by collecting data on events that structure processual patterns. We used grounded theorization, visual mapping and temporal bracketing (Langley 1999) to structure and explore the process data. Thematically similar events were abstracted into five causes and their key events visualized for each city, forming the processual pattern. In the final section we compare structural characteristics and processual patterns and discuss the research questions. The conclusion sums up our findings, includes a reflection on the methods and presents an outlook to future research.

2 Causal pathways of innovation

Causal pathways refer to arrangements of entities, relationships and causal capacities that convey an initial impulse towards an outcome of cases (Seawright 2016). In contrast to trajectory approaches that describe changes as chronological knowledge accumulation processes, enforced by path dependence (Geels/Schot 2007; Capello/Lenzi 2018), a causal pathway approach perceives time neither as discrete nor measurable (Lowe/Rod 2018). Instead, the kairotic moments can pick up and slow in pace (Araujo/Easton 2012). Causation involves a long sequence of decisions, actions and institutional patterns that connect to the outcome, generating a collection of real-world records and traces, which researchers can gather (Seawright 2016: 57–58). Processual patterns are based on longitudinal sequences of events (Abbott 2001: 16) that can be repacked into causal mechanisms whenever they follow specific trigger events, occur in specific contexts, lead to specific outcomes (Friedrichs 2016) and can be found regularly in cross-case analyses (Khan/van Wynsberghe 2008).

Longitudinal comparative studies on innovation market diffusion explain outcome through variance explanation that focuses on the relationship between variables or process explanation that focuses on the arrangement of events (McMullen/Dimov 2013). Although variance theorizing has an underlying chronological understanding of time, the sequence in which variables occur makes no difference for the explanation of the outcome (Langley/Smallman/Tsoukas et al. 2013). For example, variance in the spatial patterns of carsharing services can be explained by the variance in rates of car ownership (Meelen/Frenken/Hobrink 2019), independent of what occurred first, entrepreneurs adapting to neighbourhoods with car-reduced lifestyles or neighbourhoods adapting to carsharing availability. In comparison, processual patterns result from sequences of events

that comprise the history of each entrepreneurial effort in a holistic unit. While each event is necessary to explain the outcome, it is not sufficient in its own right. A final cause represents an end point, whose existence is only possible because of certain prior events (McMullen/Dimov 2013). Events result from activities that are performed by entities. Entities can be individual persons, groups, states, classes or structural phenomena, whereas activities should include verbs that define the transmitters of causal forces (Beach/Pedersen 2013: 49–50). The causal pathway approach combines the empirical analysis of spatial patterns, based on cities' structural characteristics that are derived from the literature, and of processual patterns, based on event chains derived from analysing case-related documents.

3 Structural characteristics of carsharing diffusion

Carsharing business models are differentiated in free-floating, station-based and peer-to-peer carsharing (Kuhn/Marquardt/Selinka 2021). However, the spatially dominant business model is currently station-based carsharing (Kuhn/Marquardt/Selinka 2021), as free-floating is limited to metropolises (Stolle/Steinmann/Rodewyk et al. 2019: 15), whereas the success of peer-to-peer carsharing is difficult to evaluate as most enlisted cars are seldom rented (Münzel/Boon/Frenken et al. 2020). Thus, we decided to focus on station-based carsharing.

In the carsharing literature focusing on cities' characteristics that support station-based carsharing systems, variances are explained by structural variables (Meelen/Frenken/Hobrink 2019), which we collected through a broad literature search (see Tab. 1). Carsharing diffusion is successful in areas with a high population density (Habib/Morency/Islam et al. 2012; Hjortset/Böcker/Røe et al. 2021), closer to the city centre (Braun/Koch/Hochschild 2016) or around education facilities (Hu/Chen/Lin et al. 2018; Münzel/Boon/Frenken et al. 2020). Whereas Juschten, Ohnmacht, Thao et al. (2019) show that parking space availability has a negative impact on carsharing demand, other studies using the age of the neighbourhood as an indicator for parking scarcity had positive and negative results (Celsor/Millard-Ball 2007; Abbasi/Ko/Kim 2021). Hjortset, Böcker, Røe et al. (2021) discuss semidetached and detached housing as limiting carsharing demand, as parking a private car is easier in such areas than in districts dominated by multi-family housing. Readily available public transportation close to living areas is seen as beneficial for carsharing diffusion (Stillwater/Mokhtarian/Shahen 2009; Braun/Koch/Hochschild 2016). Other studies focus on public transport usage, finding significant positive relationships between

Table 1 Correlation of structural characteristics to carsharing diffusion

Structural Characteristics	Direction of significance	Sources
Public transport availability	+	Abbasi/Ko/Kim (2021), Becker/Loder/Schmid et al. (2017), Braun/Koch/Hochschild (2016), Ciari/Weis/Balac (2016), Coll/Vandersmissen/Thériault (2014), Hjortset/Böcker/Røe et al. (2021), Hu/Chen/Lin et al. (2018), Juschten/Ohnmacht/Thao et al. (2019), Ménoire/Wielinski/Morency et al. (2020), Stillwater/Mokhtarian/Shahen (2009)
Population density	+	Braun/Koch/Hochschild (2016), Celsor/Millard-Ball (2007), Habib/Morency/Islam et al. (2012), Hjortset/Böcker (2020), Hjortset/Böcker/Røe et al. (2021), Hu/Chen/Lin et al. (2018)
Pedestrian and bike friendliness	+	Celsor/Millard-Ball (2007), Coll/Vandersmissen/Thériault (2014), Hu/Chen/Lin et al. (2018), Juschten/Ohnmacht/Thao et al. (2019)
Parking space availability	-	Abbasi/Ko/Kim (2021), Celsor/Millard-Ball (2007), Hjortset/Böcker/Røe et al. (2021), Juschten/Ohnmacht/Thao et al. (2019)
Car availability in household	-	Celsor/Millard-Ball (2007), Ciari/Weis/Balac (2016), Habib/Morency/Islam et al. (2012), Hjortset/Böcker (2020), Juschten/Ohnmacht/Thao et al. (2019), Kang/Hwang/Park (2016), Kim (2015), Meelen/Frenken/Hobrink (2019), Münzel/Boon/Frenken et al. (2020), Stillwater/Mokhtarian/Shahen (2009)
Age	+ younger	Abbasi/Ko/Kim (2021), Kang/Hwang/Park (2016)
	+ mid-aged	Braun/Koch/Hochschild (2016), Coll/Vandersmissen/Thériault (2014), Juschten/Ohnmacht/Thao et al. (2019), Ménoire/Wielinski/Morency et al. (2020)
	- older	Coll/Vandersmissen/Thériault (2014), Habib/Morency/Islam et al. (2012), Hu/Chen/Lin et al. (2018)
Income (higher)	+	Göddecke/Krauss/Gnann (2022), Hu/Chen/Lin et al. (2018), Hjortset/Böcker/Røe et al. (2021), Juschten/Ohnmacht/Thao et al. (2019), Meelen/Frenken/Hobrink (2019)
	-	Coll/Vandersmissen/Thériault (2014), de Lorimier/El-Geneidy (2013), Celsor/Millard-Ball (2007)
Education	+	Becker/Loder/Schmid et al. (2017), Celsor/Millard-Ball (2007), Ciari/Weis/Balac (2016), Coll/Vandersmissen/Thériault (2014), Hjortset/Böcker (2020), Hjortset/Böcker/Røe et al. (2021), Juschten/Ohnmacht/Thao et al. (2019)
Household size (larger)	+	Braun/Koch/Hochschild (2016), Coll/Vandersmissen/Thériault (2014)
	-	Abbasi/Ko/Kim (2021), Celsor/Millard-Ball (2007), Habib/Morency/Islam et al. (2012)
Gender	+ male	Ciari/Weis/Balac (2016), Hjortset/Böcker (2020), Hu/Chen/Lin et al. (2018), Juschten/Ohnmacht/Thao et al. (2019)
Employment	+	Abbasi/Ko/Kim (2021), Hjortset/Böcker (2020), Hjortset/Böcker/Røe et al. (2021), Ménoire/Wielinski/Morency et al. (2020)
Environmental awareness	+	Becker/Loder/Schmid et al. (2017), Braun/Koch/Hochschild (2016), Meelen/Frenken/Hobrink (2019), Münzel/Boon/Frenken et al. (2020)

annual ticket holders (Ciari/Weis/Balac 2016; Juschten/Ohnmacht/Thao et al. 2019), public transport commuters (Celsor/Millard-Ball 2007; Coll/Vandersmissen/Thériault 2014) and carsharing customers. Furthermore, it is argued that bike- and pedestrian-friendly cities have supportive structures for carsharing as they allow lifestyles that seldom need access to a car (Stillwater/Mokhtarian/Shahen 2009). Studies have operationalized pedestrian- and bike-friendliness through (smaller) street width (Stillwater/Mokhtarian/Shahen 2009), (shorter) road lengths (Hu/Chen/Lin et al. 2018) or a lack of barrier effects like highways (Coll/Vandersmissen/Thériault 2014). Others focused on consumers by measuring the amount of commuters that walk or bike to work (Celsor/Millard-Ball 2007). Likewise, car commuters are negatively correlated to carsharing vehicle usage (Celsor/Millard-Ball 2007; Kim 2015).

Focusing on socio-demographic features, the mid-aged group is positively correlated to carsharing demand (Braun/

Koch/Hochschild 2016; Ménoire/Wielinski/Morency et al. 2020). Younger age groups are positively correlated to carsharing demand as well (Kang/Hwang/Park 2016; Abbasi/Ko/Kim 2021). However, neighbourhoods with more mid-aged population seem to have higher carsharing demand than those with more young age groups (Coll/Vandersmissen/Thériault 2014). A negative correlation is found between older age groups and carsharing demand (Coll/Vandersmissen/Thériault 2014; Hu/Chen/Lin et al. 2018). Some studies find a positive correlation between carsharing demand and higher income (Juschten/Ohnmacht/Thao et al. 2019; Göddecke/Krauss/Gnann 2022), whereas other studies show a negative correlation (de Lorimier/El-Geneidy 2013; Coll/Vandersmissen/Thériault 2014). Hjortset, Böcker, Røe et al. (2021) find that the 2nd and 3rd income quartiles correlate positively with carsharing demand, whereas the 1st and 4th quartiles correlate negatively. Similarly, full-time employment is positively correlated to car-

sharing demand (Hjortset/Böcker 2020; Abbasi/Ko/Kim 2021). Hjortset, Böcker, Røe et al. (2021) find that people working in industries that represent cultural, artistic or scientific activities are positively correlated to carsharing demand. Furthermore, carsharing adoption is positively correlated to university degrees (Becker/Loder/Schmid et al. 2017). Ciari, Weis and Balac (2016) and Hjortset, Böcker, Røe et al. (2021) find an increasing positive correlation between education level and carsharing membership, but no correlation between students and carsharing demand. Most studies find that more carsharing cars are available in areas with smaller households (Celsor/Millard-Ball 2007; Abbasi/Ko/Kim 2021). However, Coll, Vandersmissen and Thériault (2014) find that families are more likely to be carsharing members. The majority of studies report that carsharing members are more often male than female (Ciari/Weis/Balac 2016; Juschten/Ohnmacht/Thao et al. 2019). Environmental awareness is additionally found to correlate positively with carsharing users, measured through Green party support in elections (Braun/Koch/Hochschild 2016) or membership of environmental organizations (Meelen/Frenken/Hobrink 2019).

4 Structural characteristics of carsharing diffusion: Case study in southwest Germany

Germany has the largest carsharing market in Europe (Schiller/Scheidl/Pottebaum 2017: 5), offering an excellent empirical basis for a comparative case study. As local governments are seen as using policy means to enable the development of sharing-economy business models (Bocken/Jonca/Södergren et al. 2020), carsharing governance is in principle local (Dowling/Kent 2015). Following Peltomaa and Tuominen (2022), the most crucial entities on the local level are carsharing companies, governmental entities and users.

The case study design focuses on comparing the station-location strategies of carsharing companies over a twenty-year period. As the influence of national and regional policies cannot be ruled out, the comparison focuses on five cities within Baden-Württemberg, which was chosen as it hosts the most successful station-based carsharing companies.¹ The selection of municipalities follows a diverse cross-case study design (Seawright/Gerring 2008), building on favourable and unfavourable structural cha-

racteristics for carsharing diffusion in comparison to carsharing cars per 1,000 inhabitants, resulting in a sample of five municipalities (Tab. 2).

Freiburg and Heidelberg are university-dominated cities with less than 250,000 inhabitants and similar population densities. Both cities have similar public transport availability, population age, voting patterns, are bike-friendly and are dominated by public service and service sectors with a high academic employment rate. Compared to the other cities, Freiburg and Heidelberg have populations that are slightly younger, vote green more often, own fewer cars and are employed more often in academic jobs. While these factors all correlate positively with carsharing use, other factors are negatively correlated: compared to the other three cities, they have lower population densities and a higher share of women. Furthermore, Freiburg is less wealthy than the other cities (except Mannheim), in that households have lower income per capita than the national average of €21,952 in 2016 (Seils/Baumann 2019). Freiburg had a mayor from the Green Party between 2002 and 2018. Overall, in Freiburg and Heidelberg most spatial and socio-demographic variables support a high level of carsharing diffusion. However, the cities differ substantially in the amount of carsharing cars per 1,000 inhabitants.

Karlsruhe has 300,000 inhabitants and is dominated by its university and the information and communication technology sector. The city structure has less apartment buildings than the other cases, which should lead to an abundance of parking possibilities in most residential areas. While higher than in Freiburg and Heidelberg, population density is much lower than in Mannheim and Stuttgart. Although the city is evaluated as bike-friendly and the modal split is comparable to Freiburg and Heidelberg, inhabitants own a lot more cars. In terms of household income per capita, Karlsruhe is slightly above average, with an older population than Freiburg and Heidelberg. The lower proportion of women in its population could support the diffusion of carsharing services. Overall, Karlsruhe is a mixed bag of supporting and hindering factors, but is the most successful city in terms of station-based carsharing cars per 1,000 inhabitants.

Mannheim has a similar population size to Karlsruhe, but with higher population density. Mannheim is dominated by the industrial sector, has considerably less academics in the labour force and is less wealthy than the other cities. The proportion of car ownership is highest and the modal split shows a higher car usage. The Green party has a lower share of the votes in elections compared to the other cities. Most of Mannheim's variables – except population density – are hindering factors for carsharing diffusion. Mannheim is also comparatively unsuccessful in carsharing cars per 1,000 inhabitants.

¹ <https://www.carsharing.de/alles-ueber-carsharing/carsharing-zahlen/carsharing-baden-wuerttemberg-stark-im-laendlichen-raum> (02.05.2023).

Table 2 City characteristics in 2019

Topic	Freiburg	Heidelberg	Karlsruhe	Mannheim	Stuttgart	Sources
Population	231,195	161,485	312,060	310,658	635,911	Statistisches Landesamt Baden-Württemberg
Population density (per km ²)	1,511	1,484	1,799	2,143	3,067	Statistisches Landesamt Baden-Württemberg
Age (average)	40.6	40.4	42.0	42.2	42.0	Statistisches Landesamt Baden-Württemberg
Young (15 - under 25)	14.1 %	15.4 %	13.3 %	12.4 %	10.8 %	Statistisches Landesamt Baden-Württemberg
Mid-aged (25 - under 65)	54.8 %	55.8 %	56.1 %	56.1 %	58.3 %	
Senior (65+)	16.7 %	16.5 %	18.5 %	18.3 %	17.9 %	
Women per 1,000 inhabitants	523	520	489	502	501	Statistisches Landesamt Baden-Württemberg
Household size (average)	2.0	2.0	2.0	1.9	2.0	Statistisches Landesamt Baden-Württemberg
Household income (per capita)	€ 21,256	€ 23,189	€ 22,045	€ 20,592	25,012 €	Seils/Baumann (2019)
Employees with academic qualifications	37.9 %	48.8 %	35.1 %	27.3 %	39.5 %	Statistisches Landesamt Baden-Württemberg
Students	31,966	34,135	39,882	28,654	61,368	Statistisches Landesamt Baden-Württemberg
Unemployment rate	4.9 %	4.0 %	3.9 %	5.3 %	4.1 %	Statistisches Landesamt Baden-Württemberg
Election results Green party	National 2017 23.3 %, Regional 2016 43.2 %, Green Mayor 2002-2018	National 2017 21.9 %, Regional 2016 41.0 %	National 2017 18.3 %, Regional 2016 35.7 %	National 2017 13.2 %, Regional 2016 27.2 %	National 2017 17.6 %, Regional 2016 36.4 %, Green Mayor 2013-2021	Statistisches Landesamt Baden-Württemberg
Dominating industry sectors	Public service and service sector	Service sector	Information and communication technology sector	Industry sector	Industry and service sector, car industry	https://zutun.de (Top 10 Unternehmen)
Residential housing types	Detached houses 41.4 % Semi-detached houses 15.1 % Apartments 42.9 %	Detached houses 42.8 % Semi-detached houses 16 % Apartments 40.5 %	Detached houses 48.2 % Semi-detached houses 14.3 % Apartments 37.3 %	Detached houses 46.6 % Semi-detached houses 14.3 % Apartments 38.8 %	Detached houses 35.4 % Semi-detached houses 14.6 % Apartments 49.5 %	Statistisches Landesamt Baden-Württemberg
Modal Split	Pedestrian 27 % Bike 23 % Public Transport 17 % Car 33 %	Pedestrian 26 % Bike 26 % Public Transport 13 % Car 35 %	Pedestrian 24 % Bike 23 % Public Transport 15 % Car 38 %	Pedestrian 24 % Bike 17 % Public Transport 15 % Car 44 %	Pedestrian 29 % Bike 8 % Public Transport 23 % Car 40 %	Ministerium für Verkehr Baden-Württemberg (2017)

Table 2 (Continued)

Topic	Freiburg	Heidelberg	Karlsruhe	Mannheim	Stuttgart	Sources
Cars (per 1,000 inhabitants)	401	377	449	488	475	Statistisches Landesamt Baden-Württemberg
Bike friendliness (scale 1-6; 1 friendly)	3.35	3.53	3.07	3.90	4.16	ADFC (2021)
Carsharing cars per 1,000 inhabitants	1.40	0.94	2.84	0.59	0.67	own calculation

Stuttgart is the biggest city in the sample with a population above 600,000. It has comparatively a high population density and a high share of apartment buildings. While the average age is older than in Heidelberg and in Freiburg, the proportion of mid-aged inhabitants is similar. In the modal split, public transport usage is above average, whereas bike usage is below average. It scores lower for bike friendliness. The city is dominated by the car industry and the service sector. There is a high amount of employed academics and the city is the richest in the sample. The city voted Green in the last two elections and had a Green mayor between 2013 and 2021. Hindering factors for carsharing services are the high rate of car ownership and the high car usage in the modal split. Overall, Stuttgart leans towards supportive factors for carsharing diffusion, but is comparatively unsuccessful in carsharing cars per 1,000 inhabitants.

1999 was selected as the starting year as it marks the founding of the biggest operator: the stadtmobil company network.² The study covers a period of around 20 years in all cities. Snapshots of the station and car development were taken every five years (2004, 2009, 2014 and 2019).

5 Spatial patterns of carsharing services from a comparative perspective

Spatial pattern dynamics were generated from numbers of carsharing vehicles and stations, with figures taken from company websites. A carsharing station is understood as a place where at least one carsharing car is regularly parked. The historical development of carsharing stations was reconstructed through data collection using the internet archive³ and by contacting carsharing operators. With the exception

of Freiburg, all necessary data was collected. We differentiated between the inner and outer city using the cities' own definitions.

In the carsharing literature, the distance a customer is willing to cover to the next carsharing stations varies severely (Rickenberg/Gebhardt/Breitner 2013). However, Jian, Hossein Rashidi, Wijayaratna et al. (2016: 139) observe that customers are affected by vehicle distances above 200 metres. Thus, we decided for a conservative station reach of 250 metres to calculate the business area. The OpenRouteService Tool was employed in QGIS, calculating station reach along two input variables: travel mode (foot-walking) and dimension (250 metres). The business area was then set in relation to the city's residential and traffic area.⁴ Furthermore, we compared rates of car ownership in the city quarters to the number of carsharing stations and vehicles by using annual data from the municipal statistical bureaus.

In all five cases we observed a rapid growth from 2009 to 2014 in the number of carsharing stations, vehicles and business areas covered. From 2014 to 2019, however, the increase in carsharing stations slows down severely in Heidelberg, Mannheim and Stuttgart. In Stuttgart, the growth of vehicles increases rapidly between 2014 and 2019. In Karlsruhe, the growth of stations between 2014 and 2019 increases, whereas the growth of cars slows down. In Freiburg, the growth of stations and cars between 2014 and 2019 increases (Tab. 3).⁵

Putting these statistics into spatial patterns of carsharing development, we observed in Stuttgart, Karlsruhe and Mannheim that carsharing companies tend to focus first on city centres or areas near city centres, before moving outwards to the city fringes (Fig.s 1 and 2). In Freiburg and Heidelberg, the administrations define the city centres

² <https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-fakten-zum-carsharing-deutschland> (02.05.2023).

³ <https://archive.org/web/>.

⁴ <https://www.statistik-bw.de/BevoelkGebiet/GebietFlaeche/01515310.tab?R=GS111000> (02.05.2023).

⁵ Due to changes in the statistical procedure on regional level, car ownership statistics before 2008 are not comparable.

Table 3 Carsharing and car ownership development in cities

	1999/2000	2004	2009	2014	2019
<i>Karlsruhe</i>					
Business area (km ²)	3.47	5.28	8.00	12.46	18.33
Stations inner city	24	27	48	70	98
Stations outer city	9	18	27	53	94
Stations total	33	45	75	123	192
Carsharing cars	69	85	120	531	887
Carsharing cars/1,000 inhabitants	0.25	0.30	0.41	1.77	2.84
Coverage (%)	4.5	6.9	10.0	15.4	22.6
Weighted mean car/1,000 inhabitants (inner city)	–	–	414	358	380
Weighted mean car/1,000 inhabitants (outer city)	–	–	495	509	525
<i>Heidelberg</i>					
Business area (km ²)	1.62	2.50	3.64	6.87	7.47
Stations inner city	3	4	4	7	7
Stations outer city	11	19	28	64	70
Stations total	14	23	32	71	77
Carsharing cars	18	36	54	114	151
Carsharing cars/1,000 inhabitants	0.13	0.25	0.37	0.74	0.94
Coverage (%)	5.1	7.8	11.1	20.9	22.5
Weighted mean car/1,000 inhabitants (inner city)	–	–	324	310	312
Weighted mean car/1,000 inhabitants (outer city)	–	–	417	414	417
<i>Stuttgart</i>					
Business area (km ²)	3.58	4.62	9.93	14.76	15.14
Stations inner city	6	6	10	11	12
Stations outer city	27	37	84	147	148
Stations total	33	43	94	158	160
Carsharing cars	33	69	200	258	425
Carsharing cars/1,000 inhabitants	0.04	0.12	0.33	0.42	0.67
Coverage (%)	3.5	4.4	9.3	13.8	14.1
Weighted mean car/1,000 inhabitants (inner city)	–	–	421	454	437
Weighted mean car/1,000 inhabitants (outer city)	–	–	509	512	522
<i>Mannheim</i>					
Business area (km ²)	0.94	2.20	2.88	6.01	6.50
Stations inner city	7	18	23	48	47
Stations outer city	3	5	6	16	20
Stations total	10	23	29	64	67
Carsharing cars	8	31	52	153	184
Carsharing cars/1,000 inhabitants	0.03	0.10	0.17	0.51	0.59
Coverage (%)	1.1	2.7	3.4	7.1	7.7
Weighted mean car/1,000 inhabitants (inner city)	–	–	415	376	388
Weighted mean car/1,000 inhabitants (outer city)	–	–	493	518	536
<i>Freiburg</i>					
Business area (km ²)	–	3.55	–	7.11	12.45
Stations inner city	–	3	–	4	15
Stations outer city	–	32	–	85	141
Stations total	–	35	–	89	156

Table 3 (Continued)

	1999/2000	2004	2009	2014	2019
Carsharing cars	–	–	–	138	323
Carsharing cars/1,000 inhabitants	–	–	–	0.62	1.40
Coverage (%)	–	7.4	–	14.5	25.2
Weighted mean car/1,000 inhabitants (inner city)	–	–	418	420	426
Weighted mean car/1000 inhabitants (outer city)	–	–	380	377	383

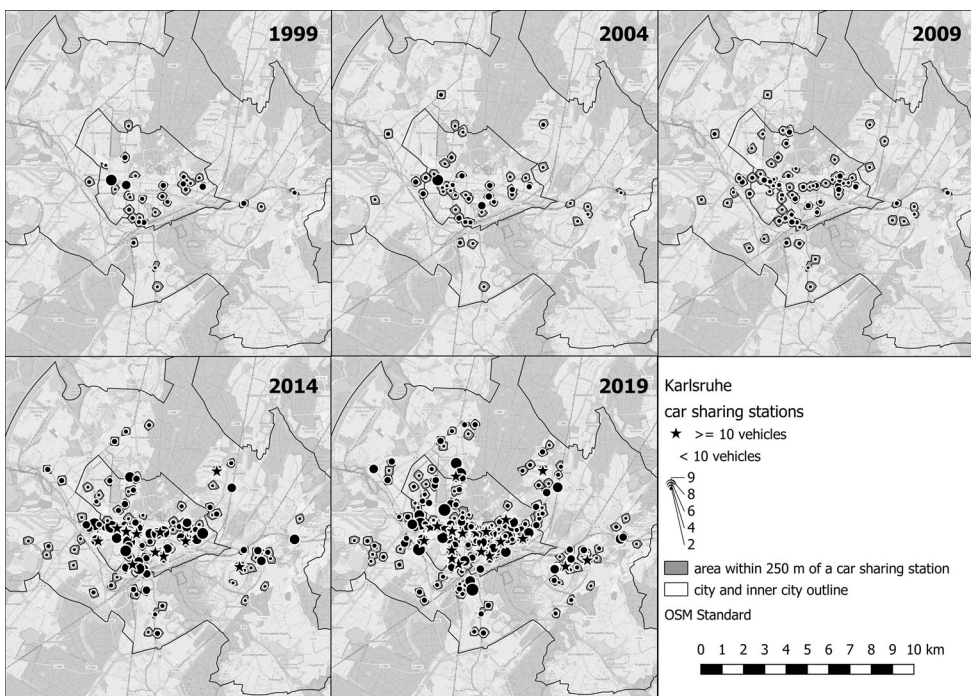
as the old cities, which in comparison to the other cities is a very small area, rendering the observation less obvious. Nevertheless, a similar effect is observable in that station hotspots close to the city centre are the focus of development in the early years.

In Mannheim, Heidelberg and Stuttgart, the fringes are increasingly occupied, yet growth slows down severely. In Karlsruhe we observed steady growth in the inner city and outer city, however the majority of cars remain in the inner-city area. Freiburg is an outlier, as a lot of stations are opened and closed between 2014 and 2019, and cars are redistributed more evenly between stations. However, carsharing stations and cars remain centred around the old city. Building on Martin, Shaheen and Lidicker (2010), we expected that carsharing cars would replace private cars – especially in the city centre. However, although there were reductions between 2009 and 2014, the number of cars per 1,000 inhabitants increased in most inner cities between

2014 and 2019 and steadily increased in all cities if the whole city is considered in the same period.

6 Carsharing processual patterns: a comparative perspective

We collected empirical material that could give an insight on events that structure the carsharing policy development in each municipality. In using grounded theorization (Glaser/Strauss 1967), we followed its two key concepts of constant comparison and theoretical sampling. We documented our coding process until we reached category saturation (Suddaby 2006). Beginning with the webpages of the companies, the Bundesverband Carsharing and the city councils, we gradually broadened our research. We collected governmental and regulatory documents, press releases, legal documents, corporate documents, scientific


Figure 1 Karlsruhe station and car development

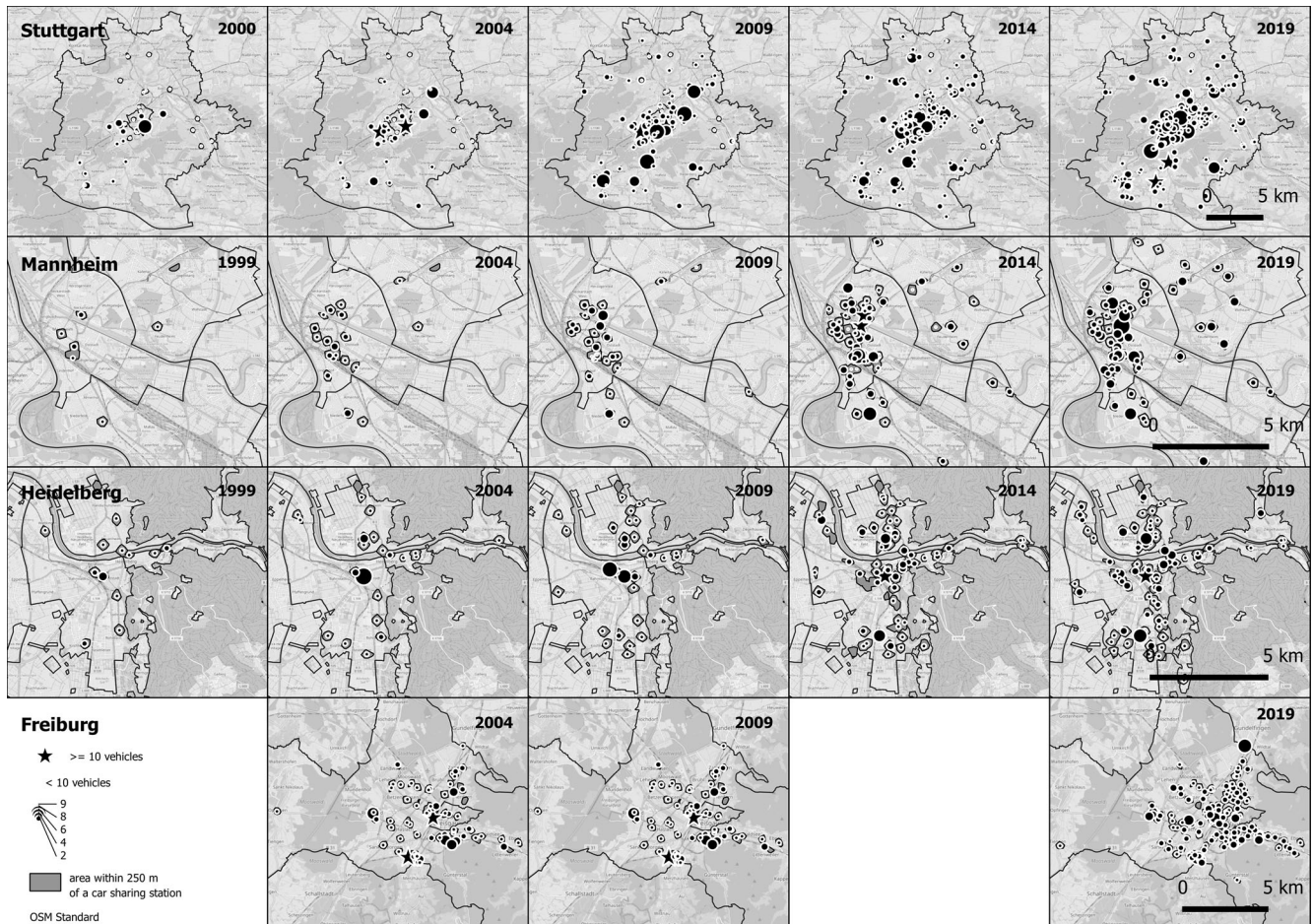


Figure 2 Cities' station and car development

writings, newspaper articles and lobby group documents. Our sample totals 894 documents.

The sample texts were analysed to identify causes that structure processual patterns. We created a timeline of events, describing in detail which entity performed which action in which order. Following visual mapping techniques, we created schematic representations of these chronologies. Thereby, we had to find a similar abstraction level of events that had an influence on carsharing policies in the municipalities. This we achieved by highlighting events in our timelines that were referenced more than once by actors or marked a decision or contract by an actor or group of actors. Thematically similar events were abstracted into the following five causes, which are also regularly found in the carsharing literature.

Space Station-based carsharing operators need sufficient parking space, which should be easily accessible in commercially interesting areas. These characteristics are often only available in public space (Rid/Parzinger/Grausam et al. 2018: 84). Cities could support carsharing by offering park-

ing spaces for carsharing cars in developed areas, as well as by including carsharing in city planning. Whereas the latter requires city administrations to acknowledge carsharing as a necessity in city planning (Cohen/Shaheen 2016; Bocken/Jonca/Södergren et al. 2020), the former reassigns or rededicates public space to private companies (Rid/Parzinger/Grausam et al. 2018: 84–85). In Baden-Württemberg, the provision of carsharing parking spaces in public space was not possible until 2019, when the state changed its road laws to adopt changes in the national carsharing act of 2017.⁶

Rights and Control Station-based carsharing operators need carsharing parking lots that are protected against parking offences. In 2021, street signs and carsharing were

⁶ <https://vm.baden-wuerttemberg.de/de/mobilitaet-verkehr/auto-und-motorrad/carsharing/> (02.05.2023).

defined to recognize this distinct vehicle class⁷, which allowed policing of parking offenders. Furthermore, a city's parking management policy influences carsharing (Rid/Parzinger/Grausam et al. 2018: 77). In our sample, cities handed out parking permits for carsharing cars in the city centre and exclusive resident-parking areas.

Public Transportation Policy includes various behavioural change initiatives that position carsharing as an extension of public transportation and a sustainable transport mode (Dowling/Kent 2015). As carsharing users are seen as public transportation users who sometimes need a car (Kopp/Gerike/Axhausen 2015), carsharing providers have an interest in being included in public transport ticketing, as well as having stations near public transport hubs. Municipalities have an interest in public transportation being expanded and supplemented, especially if carsharing is active in areas underserved by public services (Rid/Parzinger/Grausam et al. 2018: 28, 75).

Municipal Fleet Organizational customers like city administrations could be valuable assets in balancing the underutilization of station-based carsharing systems on workdays (Loose 2018). By substituting their municipal fleets with carsharing cars they could provide political leadership in challenging car ownership culture, increase the visibility of carsharing practice and reduce administrative costs (Akyelken/Givoni/Salo et al. 2018; Rid/Parzinger/Grausam et al. 2018: 26, 76).

E-Mobility Carsharing is seen as a means to introduce e-mobility, familiarizing customers with e-cars (Göhlich/Raab 2021). Currently, the increased operation and infrastructure costs, recharging needs and reduced range of e-cars hinder carsharing providers from switching to e-mobility (Rid/Parzinger/Grausam et al. 2018: 88; Göhlich/Raab 2021: 67).

In a next step, we condensed the sequences of events in the temporal flow (Langley/Smallman/Tsoukas et al. 2013) into processual patterns based on the five causes (Fig. 3), visualizing causes that follow each other through an arrow (for details see online supplementary material).

In Freiburg and Karlsruhe, public transportation is dominant and discussed in connection to space, which is the second most important cause shaping the pathway. However, the dominance of public transportation seems to shape the

causal pathway in Freiburg more than in Karlsruhe, whereas in Karlsruhe the municipal fleet has more influence on the pathway than in Freiburg. E-mobility has a high presence in both Freiburg and Karlsruhe, but is discussed in connection to public transportation in Karlsruhe and in connection to space in Freiburg. The cause rights and controls has almost no influence on the pathways.

In Stuttgart, public transportation and space are the dominant causes. However, the dominance is very pronounced in comparison to the other three causes, which are almost non-existent. Space clearly dominates public transportation and shows signs of a self-referential debate in that there are barely any connections to other causes. Heidelberg and Mannheim share similar patterns: rights and control has a comparably high influence on the pathway in both cases. Surprisingly, the connection between public transportation and space is not visible in the pathway pattern. In contrast to the other cities, the connection between space, rights and control, and e-mobility is comparably strong. While for both cities public transportation is visible, it has comparably little influence on the overall pattern.

By using temporal bracketing, events are highlighted that mark a changed understanding of carsharing policies. These discontinuities in the temporal flow mark the transition between market phases (Langley/Smallman/Tsoukas et al. 2013: 7). In the "market introduction phase" carsharing companies professionalized and introduced carsharing as a topic that required an opinion from the city administration. In the "administrative resistance phase" carsharing was recognized as a political topic of meagre importance that only needed limited political attention. In the "political support phase" carsharing companies gathered enough political support to be mentioned regularly in environmental reports, strategy papers and traffic development plans. In the "topic decline phase" carsharing vanished from the council agenda and remained unmentioned in important conceptual papers and plans.

In the first two market phases, most carsharing companies followed a similar processual pattern in first negotiating with the public transport provider, then winning the administration as a customer, and finally pushing the need for stations in the city centre. In most cities, there were successful negotiations for a marketing and discount relationship with the public transportation provider and the administration was convinced to test carsharing for the municipal fleet. In response to demands for space, the municipalities and their administrations used the lack of a national carsharing law as justification for non-action. The administrative resistance phase ended with the inclusion of carsharing in an environmental plan (Mannheim 2009: Sustainable Energy Action Plan 2020; Karlsruhe 2009: Climate Protection Report; Heidelberg 2014: Masterplan Climate Protection) or a mobility

⁷ <https://carsharing.de/themen/politik-gesetze/stvo-novelle-verwaltungsvorschriften-werden-endlich-verabschiedet> (02.05.2023).

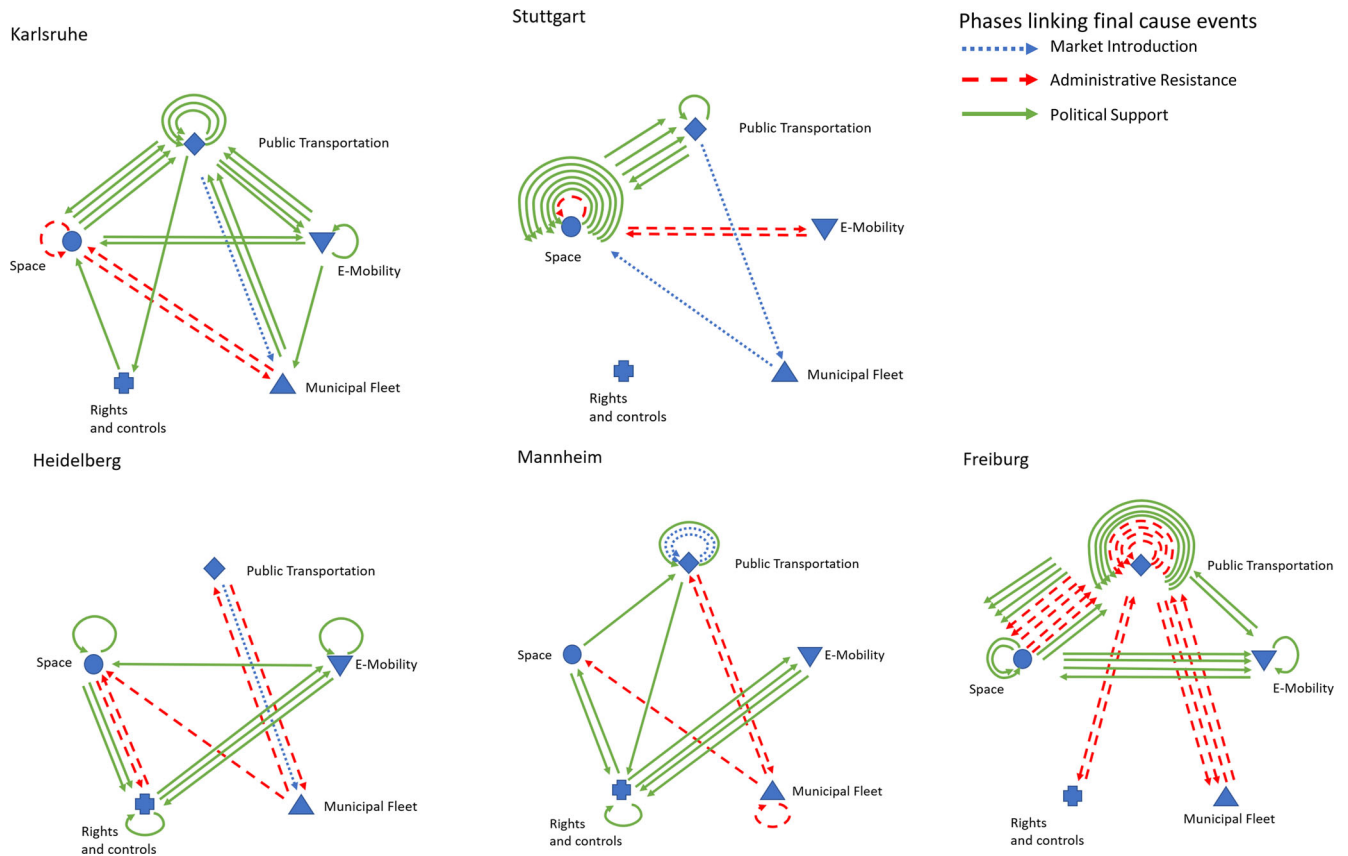


Figure 3 Processual patterns in the five municipalities

development concept (Stuttgart 2014: Traffic Development Plan 2030; Freiburg 2008: Traffic Development Plan 2020) with clear goals and actions. The cause municipal fleet vanished from all agendas except in Karlsruhe. In Stuttgart all five causes were introduced early in the policy discussion; besides space and public transportation, however, they disappeared after the administration took up carsharing as a mobility transformation topic.

Company reactions to administrative resistance varied across the municipalities, although all were successful in pushing the municipalities towards the political support phase. In Stuttgart, the carsharing companies pushed space demands via the oppositional Left and Green parties. This strategy bore fruit with the election of a Green mayor, who made city traffic the main topic in his election campaign. Once elected, he changed the municipal policy to one fostering multimodality and supporting a city-wide carsharing concept. In Heidelberg and Mannheim, the administrations perceived carsharing as an environmental topic with a limited impact on CO₂ emissions on a city scale. Thus, the administrations had comparably low levels of activity in the causes of space and public transportation. The carsharing companies reacted by developing a free-floating concept to

escape parking space scarcity and focused on rights and control with the aim of getting permits for resident parking. In Freiburg and Karlsruhe, carsharing companies focused on the public transport provider in marketing and developing together a unified mobility card and joint mobility points. In Freiburg, a change at the head of the civil engineering department allowed the amendment of public space for carsharing stations and led to the development of a city-wide carsharing concept. In comparison, the administration in Karlsruhe repeatedly stated their willingness to offer space, but only after a national legal basis was established. In Karlsruhe, carsharing was seen as a mobility development project, developed in partnership with the local public transport provider, which translated into the traffic development plan (2013) and into multimodality projects (2017).

In the topic decline phase, carsharing vanishes or diminishes as a political topic. In Heidelberg and Mannheim, carsharing is barely present in the joint Climate Adaptation Plan (2019) or in the joint Masterplan Sustainable Mobility. In Freiburg the importance of carsharing vanished behind the general electrification goals in the city’s Masterplan Green City (2018) and is absent from the updated

Climate Protection Concept (2019). The cities of Karlsruhe and Stuttgart seem not to have entered the decline phase.

7 Processual and spatial patterns: signs of an urban mobility transition?

Different levels of success in the policy arena, as well as differences in city structure, should translate into different processual and spatial growth patterns. Cities with carsharing-friendly structural characteristics should have a higher diffusion rate of carsharing services. However, Karlsruhe has by far the most carsharing cars per 1,000 inhabitants, even though we could only find a mix of supporting and hindering structural characteristics. In contrast, Stuttgart and Heidelberg, which have structural characteristics supportive of carsharing, are lagging in carsharing diffusion. Additionally, as carsharing is seen as a disruptive innovation (Sprei 2018), we expected an increasing speed of growth or at least steady growth in spatial patterns. However, the growth of the spatial patterns slowed down in most cities after 2014. As the structural characteristics alone cannot answer why the cities developed so differently, the reasons could lie in the differences in the cities' processual patterns.

The processual patterns of the most successful cities, Freiburg and Karlsruhe, have similar strong connections between the causes public transport, space and e-mobility. The less successful cities either have few connections between these three causes (Heidelberg, Mannheim) or have weak connections to e-mobility (Stuttgart). Although municipal transitions are place-specific, these observations suggest that increasing market diffusion requires companies to successfully negotiate similar processual patterns with municipalities. The importance of e-mobility is surprising, especially as it is primarily pushed by municipalities while e-mobility is perceived as an economic risk for carsharing companies (Styri-Hipp/Sprengher/Nguyen et al. 2021: 67). As carsharing customers are regularly described as environmentally concerned consumers (Münzel/Boon/Frenken et al. 2020; Richter/Södling/Christmann 2020), fostering the image of carsharing by signalling environmental responsibility through e-cars (Kuhn/Marquardt/Selinka 2021) could explain the higher diffusion rates.

The future of carsharing and its sustainability implications depend on how important sharing systems are in the urban mobility agenda (Akyelken/Banister/Givoni 2018). Thus, we would expect that carsharing had its major growth during the political support phase, which should be visible in the spatial patterns. The spatial patterns of carsharing stations and cars spread with an increased pace between 2009 and 2014, and a second growth phase between 2014 and

2019 that was slower in most cities. Cities with supportive structural characteristics that were unable to develop processual patterns supportive of carsharing could not catch up to cities with less supportive structural characteristics that developed processual patterns supportive of carsharing. Contrary to our expectations, in Heidelberg and Stuttgart significant carsharing growth started much earlier than the political support phase. In all five cases, the station networks began in or near the city centre, developing outwards. Surprisingly, even with the support of the city administrations, the growth of carsharing systems slows down as it does in cases where growth started with or without municipality support in 2009. The early start of the growth of spatial patterns and the limited influence of processual patterns on growth trajectories allows the conclusion that political influence was of minor importance.

Carsharing research and market predictions regularly evaluate carsharing as a fast-growing market, both nationally and globally (Phillips 2019; Lukasiwicz/Sanna/Alves Perreira Diogo et al. 2022). Carsharing is perceived as a radical niche innovation (Geels 2019) that is on a pathway to disrupt the private car ownership regime (Schiller/Scheidl/Pottebaum 2017) and with it the urban mobility system. Carsharing companies and their lobby organization have the aim to decouple car ownership from mobility needs.⁸ However, carsharing can actually preserve high-carbon mobility if it replaces public and non-motorized transport while car ownership levels remain similar or increase (Akyelken/Givoni/Salo et al. 2018). As, in general, use patterns of station-based carsharing tend to cover mid-range distances and times (Bogenberger/Weikl/Schmöller 2016), it is likely that carsharing substitutes or supplements public transit to the urban outskirts and surrounding destinations (Ye/Wang/Jia et al. 2022). In order not to just add to a growing car stock, growing spatial patterns of carsharing stations and cars should lead to a decrease in car ownership per 1,000 inhabitants.

In most cities (except Stuttgart) the number of cars per 1,000 inhabitants in the inner city dropped in the period between 2009 and 2014. One explanation of this development could be that customers replaced their privately owned cars with carsharing vehicles. However, this reduction was not permanent and despite the carsharing car growth in the companies, the majority of which happened in the inner city, the ownership of cars increased between 2014 and 2019. Despite this limited effect in the inner city, the number of privately owned cars per 1,000 inhabitants increased in all five cities, if the whole city is taken into consider-

⁸ <https://carsharing.de/verband/wir-ueber-uns/bundesverband-carsharing-stellt-sich> (02.05.2023).

ation. Thus overall, the cities show similar patterns to regional and national statistics in that an increase in private car ownership is observable.⁹ A systemic transformation of the mobility system based on carsharing is not observable in the data. While carsharing could in theory impact private vehicle ownership, the effects were minor in all five cases. Despite the growing support from municipalities shown in the processual patterns, the spatial patterns consolidate in most cases. As such, our study casts doubt on carsharing's systemic impact on municipal mobility systems.

8 Conclusion

This paper takes a close look at the market diffusion pathways of station-based carsharing systems in five German cities. We chose a causal pathway approach to explore if station-based carsharing networks showed similar spatial and processual patterns in the selected cases. Differences in structural characteristics between cities should translate to differences in carsharing diffusion statistics. According to our structural characteristic analysis, Karlsruhe overperformed in the spread of carsharing, whereas Heidelberg and Stuttgart underperformed. Our research shows that carsharing companies followed similar processual patterns at the beginning, pushing carsharing in city policy agendas; as municipal reactions varied, the strategies differentiated quickly. The analysis hints at a pattern that fosters carsharing diffusion – a combination of the causes public transportation, space and e-mobility. However, the spatial patterns of carsharing stations developed from the inner city to the outskirts between 2009 and 2014 and tended to stabilize between 2014 and 2019, with or without political support. While municipalities are often understood in the literature as enablers of mobility transitions, we observed that political influence was of minor importance for the carsharing companies. Furthermore, we were unable to track a consistent reduction in cars for any of the five cities. The evidence suggests that carsharing, at least currently, is unable to change urban mobility on a system scale and is just another business.

A limitation to the causal pathway analysis is that only recorded textual material is included, leaving out negotiations and meetings that were unrecorded. However, as every event can be further analysed in terms of smaller events (Cobb 2007), our focus on textual data reduces complexity with-

out distorting the crafted causal pathways. Furthermore, in researching an unfolded pathway, we have no access to counterfactuals (McMullen/Dimov 2013). By comparing the different city pathways, we get a glimpse of other potentialities that could have developed. Moreover, we abstained from differentiating between competitors in our analysis. However, additional competitors could lead to a faster spread of spatial patterns as companies are eager to occupy the most interesting locations first – a situation that could have influenced the cases of Stuttgart and Freiburg.

Any process research is no more than a temporary hold on ongoing processes that are in a state of becoming (Langley/Smallman/Tsoukas et al. 2013). Following this thought, station-based carsharing could support a transitional movement in the future. On a municipal level, research should investigate if a push from the demand side to decrease the private car's attractiveness (Göddeke/Krauss/Gnann 2022) could lead to a car-reduced mobility system that is supported through carsharing. Possible policies on the local level are costly parking areas, reduced traffic speeds, car bans in the inner city, and traffic calmed areas. Additionally, safe and efficient public transport, cycling and pedestrian infrastructure could foster more sustainable transport behaviour (Göddeke/Krauss/Gnann 2022; Kuss/Nicholas 2022). Furthermore, the carsharing sector could be affected by national policy changes like the kilometre allowance paid to employees for the use of private cars, government support for company cars and the taxation on carsharing (Akyelken/Givoni/Salo et al. 2018). Notably, in February 2019, a new national carsharing law was implemented on state level. This could lead to new municipal carsharing policies and could rejuvenate carsharing as a political topic in cities where it has entered into a decline phase. As our data did not include developments on carsharing stations and cars after 2019, it remains for future studies to evaluate whether this new legislation has had any effect on the mobility transition.

Competing Interests The authors declare no competing interests.

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⁹ <https://www.statistik-bw.de/Verkehr/KFZBelastung/LRt1503.jsp> (02.05.2023); <https://www.umweltbundesamt.de/daten/private-haushalte-konsum/mobilitaet-privater-haushalte#verkehrsleistung-im-personentransport> (02.05.2023).

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Hier steht eine Anzeige.