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What can urban transport policy achieve? How transport-policy-invariant characteristics relate to city-level car ownership and car use

Isabelle Wachter *, Christian Holz-Rau, Eva Heinen

Mobility and Transport Group, Department of Spatial Planning, TU Dortmund University, August-Schmidt-Straße 10, 44227 Dortmund, Germany

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ABSTRACT

Most case and comparative studies discuss urban characteristics that can hardly be influenced by urban transport policies. However, these studies do not quantify the impact of the so-called contextual factors on car ownership and car use. This paper focuses on these contextual factors and their associations with car ownership and car use. Regression models show that contextual factors - such as city size, the share of households with children and the jobs-housing balance - explain a substantial part of the variance in car ownership and car trips in 44 German cities. Residual analyses reveal that neglecting contextual factors leads to biases in comparative studies and consequently in the evaluation of urban transport policies. Thus, there is a risk that cities with favourable contextual factors may be mistakenly viewed as successful examples of transport policy, whereas successful policies in cities with less favourable contextual factors may be overlooked.

1. Introduction

Most major cities suffer from negative transport externalities. These externalities are manifold and include air and noise pollution, traffic accidents, traffic congestion and the extensive use of space by motorized transport infrastructure (e.g. Van Essen et al., 2020). To reduce these negative externalities and to increase liveability, most cities strive to reduce the level of car ownership and car use. To achieve more sustainable transport systems, policy makers and their advisers often look to well-performing cities for guidance on transport policy (e.g. Civitas Initiative, 2021; Eltis, 2014-2022). Among the most prominent examples of “successful” cities are Copenhagen and Amsterdam for cycling (e.g. Gössling, 2013; Koglin, 2015; Nielsen et al., 2013; Pucher & Buehler, 2007; Zhao et al., 2018) as well as Hong Kong, Singapore and Zurich for their public transport (PT) (e.g. Bratzel, 1999; Ibrahim, 2003; Lo et al., 2008).

To identify these well-performing cities, indicators related to travel behaviour and urban transport systems are commonly benchmarked. A wide variety of city comparisons (tools) and indices from consultancy agencies, think tanks, government networks, and NGOs exist (e.g. Agora Verkehrswende, 2020; Arcadis, 2017; Deloitte, 2023; EPOMM (European Platform on Mobility Management), 2012; Kodukula et al., 2018). They aim to facilitate city officials and other stakeholder in comparing and evaluating urban transport systems and policies, as well as learning from well-performing cities. While some tools compare indicators alongside each other (Agora Verkehrswende, 2020; Deloitte, 2023), others explicitly rank cities (Arcadis, 2017; Kodukula et al., 2018).

The comparisons and case studies conducted to learn from well-performing cities tend to focus on things that can be changed. This includes administrative structures (e.g. Koglin, 2015), strategies and targets (e.g. Copenhagenize, 2023; Deloitte, 2023), implemented policies and transport services including infrastructure as well as potential outcomes of urban transport policies such as road safety, emissions and travel behaviour (e.g. Bratzel, 1999; Buehler et al., 2017; Buehler et al., 2017; Gössling, 2013; Nielsen et al., 2013). In this vain, the Deloitte City Mobility Index (Deloitte, 2023) assesses the performance of cities in the areas "performance and resilience", "vision and leadership" as well as "service and inclusion". The Sustainable Cities Mobility Index (Arcadis, 2017) evaluates transport systems according to their social and human implications, environmental impacts and the efficiency and reliability of their mobility systems. In the comparisons and in academic publications, travel behaviour indicators as transport policy outcome are especially frequently benchmarked. Modal share is a particularly common indicator of success (e.g. in Bratzel, 1999; Buehler et al., 2017; ICLEI, 2013; Kenworthy, 2019; Koglin, 2015; Palliyani & Lee, 2017). Other commonly used indicators include car ownership (e.g. in Buehler, 2011; Buehler et al., 2017; Palliyani & Lee, 2017) and the number of trips per person by mode (e.g. in Buehler et al., 2017; Buehler et al., 2017;

* Corresponding author.
E-mail addresses: isabelle.wachter@tu-dortmund.de (I. Wachter), christian.holz-rau@tu-dortmund.de (C. Holz-Rau), eva.heinen@tu-dortmund.de (E. Heinen).

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Kenworthy, 2019). Distance travelled by mode is also utilized, but somewhat less commonly (e.g. in Bratzel, 1999; Gössling, 2013; Nielsen et al., 2013; Palliyani & Lee, 2017).

In contrast, the comparisons and case studies tend to pay only limited attention to factors that are difficult to alter through policy action. In this study, we refer to these characteristics as "contextual factors", because they are completely or nearly invariant to local (transport) policies. They include sociodemographic, socioeconomic and certain spatial characteristics. Some case studies (e.g. Buehler, Pucher, & Altshuler, 2017; ICLEI, 2018; Kenworthy, 2017; Palliyani & Lee, 2017) discuss contextual factors, but they do not quantify their impact on travel behaviour. Arcadis (2017) argues that "geographical factors, such as location, climate, and access to resources can make like-for-like comparisons problematic (…)". Agora Verkehrswende (2020) points out the same with regard to topography, population density and development, and the number of jobs in a city. However, the majority of comparisons and rankings do not incorporate these or other contextual factors (Arcadis, 2017; Copenhagenize Design Co., 2023; Kodukula et al., 2018). Those that do tend to do so in a limited manner, such as comparing cities of different population sizes (EPOMM (European Platform on Mobility Management), 2012) or through a comparison tool that provides filtering options based on population size and density, area and wealth (Deloitte, 2023).

Numerous multivariate studies at the disaggregate individual and household levels show the importance of sociodemographic, socioeconomic and spatial contextual factors for car ownership (e.g. Ding et al., 2017; Giuliano & Dargay, 2006) and travel behaviour (e.g. Engebretsen et al., 2018; Stead, 2001). Some multivariate studies at the aggregate city and state level also point to the importance of single contextual factors, without focusing on them (e.g. McIntosh et al., 2014; Saeidizand et al., 2022). These factors include individual characteristics - such as age (Ding et al., 2017; Lee et al., 2022; Santos et al., 2013) and income (Ding et al., 2017; Pucher & Renne, 2003; Santos et al., 2013) - as well as city-level characteristics - such as population size (Scheiner, 2010; Tennøy et al., 2022) and topography (Holz-Rau et al., 2022; Sweet & Chen, 2011).

Few studies have comprehensively examined the importance of contextual factors at an aggregate city level. These studies are often based on cluster analyses that identify groups of cities, but they do not quantify the associations of the single contextual factors with car ownership and car use. Lee et al. (2022) considered contextual factors as prerequisites for urban transport policy and travel behaviour. They clustered 46 global cities based on their modal shares. By using decision trees, they found that sociodemographic variables, particularly the percentage of the population that is elderly and young, have the greatest impact on assigning a city to a particular modal share group. Based on their findings, Lee et al. (2022) argued that decision makers should consider contextual factors when developing modal share strategies. Klinger et al. (2013) and Holz-Rau et al. (2022) identified city clusters with typical combinations of urban characteristics, including urban form, socioeconomic characteristics and travel behaviour. Both studies found that contextual factors such as city size and income contribute substantially to the respective cluster formation. Holz-Rau et al. (2022) additionally included topography and students, which strongly contribute to the formation of these clusters. Like Lee et al. (2022), Holz-Rau et al. (2022) recommended that comparative studies and benchmarking, should take contextual factors of cities and their controllability into account.

To our knowledge, no study has quantified at the city level the associations between a rich set of contextual factors and car ownership and car use that are particularly relevant to the sustainability of urban transport systems. However, such quantification would be necessary to better incorporate contextual factors into the comparison and benchmarking of cities and their transport policies. It is reasonable to assume that neglecting contextual factors will lead to biases in comparative studies and thus to misjudgements. There is a risk that cities with favourable contextual factors will be mistakenly viewed as successful examples of transport policy. Conversely, successful policies in cities with less favourable contextual factors may be overlooked. We argue that the success of urban transport polices is not expressed in low car ownership and car use per se, but rather in lower car ownership and lower car use than expected based on urban contextual factors.

Therefore, the objective of this paper is to examine the associations of urban contextual factors with car ownership and car use at the city level. Moreover, we explore how neglecting these contextual factors affects city comparisons and thus the evaluation of urban transport policies. Based on the results, we draw implications for comparative and case studies as well as for policymakers and their advisers. In so doing, this paper addresses the following questions:

- To what extent are urban contextual factors associated with car ownership and car use at the city level?
- When contextual factors are taken into account, do the results challenge or confirm common expectations about which cities have particularly (un)successful transport policies?

By examining car ownership, car trips and car distances, our study goes beyond most previous multivariate studies at city level that only consider the modal share (e.g. Klinger et al., 2013; Lee et al., 2022; Santos et al., 2013)[1] or consider car use as driver based on trips (e.g. Holz-Rau et al., 2022).

2. Methods

2.1. Data and sample

This study uses two main datasets (1) the motor vehicles and motor vehicle trailers inventory of the German Federal Motor Transport Authority (2017) and (2) the survey Mobility in Germany 2017 (Mobilität in Deutschland, MiD 2017) and matches them with additional data. To ensure consistency between the datasets, we select the motor vehicle inventory data for 2017.

The motor vehicles and motor vehicle trailers inventory of the German Federal Motor Transport Authority (2017) contains the number of all registered motor vehicles for each municipality in Germany. This comprehensive data, i.e. not a sample, minimizes methodological errors and is particularly reliable. The data distinguish between private and commercial owned cars, but do not provide information on their actual use. It may be that private cars are also used for work purposes. The share of these cars is likely to be low as in Germany the employer has to bear the costs associated with frequent use of a private car for work purposes and a commercial car is often the more cost-effective solution even for self-employed persons.[2] Commercial cars include two types of cars. The available data do not allow to distinguish between them. The first type includes commercial cars used exclusively for business purposes, which May et al. (2019) refer to as service cars. The second type includes company cars that can also be used for private purposes. Only about 3 % of German households have access to a company car that can be used for private purposes (Öko-Institut, 2020). Moreover, the actual location of a car may differ from the location where it is registered. A representative study conducted in 2010 found that 94.3 % of privately owned cars matched their registered location, compared to 69.2 % of commercial cars (WVI & DLR, 2012). One explanation for this lies in internal fleet management systems, whereby entire commercial vehicle

[1] Santos et al. (2013) also consider motorization rate as an independent variable, however modal share is the dependent variable in their models.

[2] In the (unweighted) sample of the German Mobility Panel, which surveyed the use of around 1600 passenger cars in 2017, only 0.3 % of private cars were used exclusively for work purposes, and only 11.2 % were used for both private and work purposes (Eisenmann et al., 2018).

fleets are registered to a single address, even though the vehicles are located at different sites in Germany (WVI & DLR, 2012). In cities where car manufacturers like BMW (Munich), Audi (Ingolstadt), and VW (Wolfsburg) have their headquarters, the share of all commercial cars is therefore considerably greater than the average for all large German cities (30 %, 38 %, and 62 % vs. 15 %). The data do not allow us to determine how many commercial cars are actually located in each city nor how many residents have a company car for private use, which could affect private car ownership. However, it seems likely that there are some geographical differences between cities in terms of the prevalence of company cars.

The German national household survey MiD 2017 has a sample of 316,361 respondents from 156,420 households and is representative for Germany. For a more detailed description of the survey see Eggs et al. (2018). The MiD 2017 data include information about all trips made by the respondents on one survey day. It covers trips and trip segments within and outside the respective city of residence. Assuming that urban contextual factors have little influence on long-distance travel and to reduce the influence of outliers, we exclude the 3.8 % (weighted 3.3 %) of respondents with trips of at least 100 km. This distance threshold is commonly used to define long-distance travel in Europe (Mattioli & Adeel, 2021) and trips of 100 km extend well beyond the boundaries of the city of residence. Under the assumption of a constant travel time budget (Mokhtarian & Chen, 2004), we assume that trips on the same day influence each other. Therefore, we exclude individuals with at least one trip of 100 km or more (and all of their trips), rather than excluding single trips of 100 km or more.

We restrict the analyses to large cities. In Germany, large cities are defined as cities with at least 100,000 residents. Large cities are more often known as "well-performing cities" and there are only a few smaller cities in the MiD 2017 with a reliable sample size that enables the aggregation of the individual data at city level. To ensure the reliability of the data, we excluded cities with less than 500 respondents, resulting in 44 cities. Consequently, there is an overrepresentation of bigger large cities in the sample. The sample includes 22 of the 25 largest cities in Germany, but only 22 of the remaining 54 smaller large cities. The smallest city sample consists of 501 respondents from 313 households (Rostock), the largest of 15,149 respondents from 8195 households (Munich). With 44 cities, the sample is rather small in absolute terms, but as it includes 55 % of Germany's large cities in 2017, it enables reliable results.

In addition to the two main datasets, we use several other datasets (Table 1). Although we have retrieved data on the same variable from different authorities, the data has been collected with consistent methodology and reference dates, which avoids methodological biases. To provide a consistent temporal and spatial framework, we choose data from 2017 and data that refer only to the respective city, if possible. However, one dataset refers to 2011 (share of households with children) and another (share of full-time employees) does not refer to the city level, but to the next larger administrative unit of districts ("Kreise"). As most large cities in Germany are independent and form their own district, this only affects the values for two cities in the sample. At 44 % and 46 % respectively, these two cities compromise a substantial share of the population of their respective districts.

2.2. Dependent variables

This paper focuses on (1) car ownership and (2) daily car use as driver, measured by (a) trips and (b) distance in km. We focus on car use as driver because these trips and distances contribute substantially to the negative externalities of urban transport. One additional trip or kilometre as driver equates to one additional car on the road. Compared to car use as driver, car use as passenger (as an extra occupant) causes only minor negative externalities. Aggregating car use as driver and passenger would result in a loss of distinction between their negative externalities. The use of the same car would be counted multiple times, leading to inaccurate conclusions about the environmental sustainability of transport systems. To compare car ownership and car use across cities, we calculate the number of private cars per 1000 residents and the number of daily trips and daily distance by car as driver per capita.

The calculation of car ownership is based on the motor vehicles inventory and population data. Depending on the study, car ownership is considered as an exogenous variable for car use (Buehler, 2011; Ding et al., 2014; Santos et al., 2013) or as mediator between the built environment and car use (Ding et al., 2017; Ding et al., 2018; Scheiner & Holz-Rau, 2007; van Acker & Witlox, 2010). The associations between car ownership and car use are quite substantial. This also applies to our sample. The correlation coefficient between car ownership and car trips as driver is 0.727 and between car ownership and car distance as driver is 0.544. We restrict our analyses to private cars because of the discrepancy between the registered and the actual location of commercial cars and because of the lack of differentiation between commercial cars that are also used privately and those only used for business purposes (Section 2.1). Including commercial cars would distort the analysis, as it is intuitive that both the contextual factors of a city and its transport policy are unlikely to affect the fleets of large multi-site companies. However, restricting the analyses to private cars may also introduce bias due to potential geographical variations between cities in the prevalence of company cars, which could affect private car ownership.[3]

The calculation of car use is based on the MiD 2017.[4] The reported car use includes trips and distances of the respective city's residents. This means that it includes trips within and outside the city. Trips of non-residents are not included in the aggregated values of car use for a city. Another limitation is that the MiD 2017 asks only for the approximate trip lengths.

Unlike most other studies (Section 1), we do not consider (car) modal share. It does not provide direct information on the absolute number of car trips and distances as driver, which are crucial for the externalities of car use. In this respect, modal share without the reference to the total number of trips is of limited informative value (Gerlach et al., 2016; Holz-Rau et al., 2018; Wittwer et al., 2019).

2.3. Independent variables

We select the independent variables mainly based on previous studies and we supplement them with variables that seem to be important (Table 1). As we focus on urban contextual factors, we consider variables that urban transport policies cannot or can hardly influence and hypothesize their associations with car ownership and car use. The studies listed in Table 1 allow us to postulate these associations with car ownership and car use despite differences in scope, methodology and research focus. Although controllable factors such as infrastructure or PT are important regarding car dependency, we do not include them as they reflect outputs of urban (transport) policies.

We follow Lee et al. (2022) and categorize the independent variables according to their controllability through local policies. However, our categorization differs from that of Lee et al. (2022) in the number of categories, in part in their titles and in the assignment of certain variables.

The first category of environmental factors includes urban characteristics that are largely beyond the control of local policies. These characteristics have evolved over a long period of time (population, population growth, metropolitan urban region) or are geographical (topography). Environmental factors would also include climate-related

[3] The share of commercial cars in the sample of 44 German cities ranges from 9 % to 38 %, with a mean of 16% and a SD of 6 %.

[4] In the MiD, car trips and distances include all modes of private motorized transport. Since 99 % of motorized trips are made by car, we refer to them as car.

Table 1
Overview of independent variables and data sources.

Variable at aggregated city level	Operationalization	Reference year(s); data source; further description	Expected association with car ownership and car use		Min.	Max.	Mean	SD
1.Environmental factors								
Population	Ln transformed urban population	2017; Statistical Offices of the Federation and the Federal States (2022a)	–	Several studies report a negative association between city size measured by population and car ownership (Scheiner, 2010), car trips and distance travelled by car (Holz-Rau et al., 2022), individual car mode choice (Susilo & Maat, 2007) and car modal share (Scheiner, 2010; Tennøy et al., 2022).	11.6 (110 K)	15.1 (3.61 M)	12.6 (452 K)	0.8 (602 K)
Population growth (%)	Urban population in 2017/ urban population in 2011	2011 and 2017; Statistical Offices of the Federation and the Federal States (2022a); We chose the period 2011 to 2017 as there is a break in the time series in 2011.	–	It is plausible that a high increase in population leads to greater pressure on transport infrastructure, particularly on roads and parking spaces. Sweet and Chen (2011) found that traffic congestion leads to a modal shift from car to PT. Therefore, we hypothesize a negative association between population development with car ownership and car use.	1.02	1.14	1.06	0.03
Topography	Standard deviation of the digital terrain model in meters referred to the territory of the city	2017; Calculation based on Earth Resources Observation And Science (EROS) Center (2017)	+	Holz-Rau et al. (2022) found a positive association between varying topography (i.e. large differences in altitude across the municipality's area) and the number of car trips. Likewise, Rietveld and Daniel (2004) and Rodríguez and Joo (2004) found a positive association between flat topography and mode choice of non-motorized modes. Building on this, we hypothesize positive associations between varying topography car ownership and car use by residents.	0.60	31.59	8.85	7.64
Metropolitan urban region	Metropolitan urban region (Ref.: Regiopolitan urban region)	2017; Federal Office for Building and Regional Planning (2021); Metropolis as well as other large cities can belong to the category "metropolitan urban region". The category "regiopolitan urban region" comprises smaller large cities outside metropolitan regions that are centres of regional development in their mostly rural region. The classification is based on the differentiated regional statistical region type RegioStaR4		It is plausible that a city's location in a metropolitan urban region favours good (rail-based) PT. Given the finding by McIntosh et al. (2014) that rail-based transit services are particularly associated with lower VKT per capita, we expect negative associations between metropolitan urban regions and car use as well as car ownership.	26 cities (59.1%) located in a metropolitan urban region 18 cities (40.9%) located in a regiopolitan urban region			
2. Sociodemographic factors								
Share of elderly	Share of population over 65 years	2017; Statistical Offices of the Federation and the Federal States (2022b)	–	Although existing studies are not univocal, most studies indicate negative associations between elderly and car ownership (Ding et al., 2017; Nobis and Kuhnimhof, 2018) and car use (Engebretsen et al., 2018). Older people travel fewer trips and shorter distances overall than middle-aged people (Ding et al., 2017; Nobis & Kuhnimhof, 2018) and quite similar numbers of trips and distances as younger persons (Nobis & Kuhnimhof, 2018). Therefore, we hypothesize negative associations between the share of elderly and car ownership and car use.	0.16	0.24	0.19	0.02

(continued on next page)

Table 1 (*continued*)

Variable at aggregated city level	Operationalization	Reference year(s); data source; further description	Expected association with car ownership and car use		Min.	Max.	Mean	SD
Share of households with children	Share of households with at least one child	2011; Statistical Offices of the Federation and the Federal States (2023b)	+	Larger household size (Dargay & Hanly, 2007; Chen et al., 2008; Ding et al., 2017; Ding et al., 2018) and children in the household (Dargay & Hanly, 2007) are positively associated with car ownership. Engebretsen et al. (2018) found the trend of longer driving distances among individuals with children in the household. Therefore, we assume positive associations between the share of households with children and car ownership and car use.	0.20	0.33	0.26	0.03
3. Economic and long-term factors								
Share of full-time employees	Share of full-time employees among the population	2017; Federal Employment Agency (2022), Statistical Offices of the Federation and the Federal States (2023a)	+	Full-time employees travel a particularly large number of trips and long distances (Nobis & Kuhnimhof, 2018). They commute by car more often than part-time employees and are positively associated with household car ownership (Dargay & Hanly, 2007).	0.22	0.35	0.28	0.03
Income per capita	Average disposable household income in €1,000/ capita	2017; Federal Office for Building and Regional Planning (2021); Uniform data only available at county level	+	In general income increases car ownership (Pucher & Renne, 2003; Dargay & Hanly, 2007; Liu & Shen, 2011) and car use measured by mode choice (Boarnet & Sarmiento, 1998; Yang & Timmermans, 2013) and distance (Cervero & Murakami, 2010; Engebretsen et al., 2018).	1.46	3.42	1.86	0.32
Population density	Population/ ha used for human settlements and transport infrastructure	2017; Statistical Offices of the Federation and the Federal States (2022a, 2022c)	–	Numerous studies report negative associations of population density with car ownership (e.g. Dargay & Hanly, 2007; Liu & Shen, 2011; Ding et al., 2017; Ding et al., 2018).car trips (e.g. Holz-Rau et al., 2022) and distance travelled by car (e.g. Cervero & Murakami, 2010; McIntosh et al., 2014).	2568	6275	3862	923
Job density	Number of jobs/ ha used for human settlements and transport infrastructure	2017; Federal Employment Agency (2018), Statistical Offices of the Federation and the Federal States (2022c)	–	Various studies found a negative association between the employment density and car ownership and car use (e.g. Bhat & Guo, 2007; Ding et al., 2018; Ding & Cao, 2019).	1186	3888	2083	661
Jobs-housing balance	Employees working in the city/ employees living in the city	2017; Federal Employment Agency (2018)	–	In cities with jobs-housing balance less than 1, some of the employees living in the city have to commute to work in another municipality. This involves rather long distances. If the jobs-housing balance is greater than 1, the employees living in the city are theoretically not required to work in other municipalities. Moreover, residents of other cities have to commute into the respective city. The influx of commuters could lead to an increased strain on transport infrastructure. This may encourage residents with mainly short trips to use alternative modes of transport. As the dependent variables only capture car ownership and car use of the respective residents, we expect negative associations between jobs-housing balance and car ownership and car use.	0.87	1.95	1.42	0.28

(*continued on next page*)

Table 1 (*continued*)

Variable at aggregated city level	Operationalization	Reference year(s); data source; further description	Expected association with car ownership and car use		Min.	Max.	Mean	SD
Ratio of enrolled students to population	Number of enrolled students at local universities/ urban population. The enrolled students do not necessarily (officially) live in the city.	2017; Federal Office for Building and Regional Planning (2021), State Office for Information and Technology North Rhine-Westphalia (2022), State Office for Statistics Lower Saxony (2022), Federal State Statistical Office Saarland (2018), Statistical Offices of the Federation and the Federal States (2022a), Statistical Office of the Federal State of Baden-Wuerttemberg (2021)	–	Santos et al. (2013) found that the number of students is positively related to all modal shares except for car modal share. Likewise, Holz-Rau et al. (2022) report a negative association between university cities and car trips. Based on this, we assume a negative association between students and car ownership and car use.	0.00	0.29	0.10	0.07

characteristics, such as the number of rainy days (e.g. Lee et al., 2022; Santos et al., 2013), and other spatial characteristics. We do not consider climate-related contextual factors, as our sample includes only German cities and the differences in climate are rather small. We do not include additional spatial characteristics because of their low variance (e.g. all but one city are the main centre of their region) and the lack of consistent data on the spatial structure within cities (e.g., whether cities are monocentric or polycentric).

The second category is that of sociodemographic factors and includes the share of elderly and the share of households with children. Both are beyond the control of transport policies. The influence of general local policies and higher-level policies on those factors is also very limited. Although numerous studies at the individual level indicate that men are more likely to use cars than women (e.g., Engebretsen et al., 2018; Liu & Shen, 2011; Polk, 2004), we do not consider gender as the share of the male population varies only slightly across the cities (mean 49.1 %, SD 1.0 %).

The third category of independent variables includes economic and long-term factors. We consider the economic-related variables share of full-time employees, income per capita, job-density and the jobs-housing balance. (Supra)local policies can control these variables to a certain extent, but only in the long and medium term. The same applies to the ratio of enrolled students to population, which is also related to the economic prosperity of cities. Urban policies can also affect the long-term factors, including population density, job density and jobs-housing balance, e.g. by implementing the 15-minute city concept, attracting employers through lower business rates, designating or creating new development sites and encouraging infill development. However, these characteristics are the result of many years of development and subsequent changes to existing structures are only possible over a very long period of time and to a limited extent. Other plausible economic contextual factors might be fuel prices, taxes and insurance factors. As fuel prices do not vary systematically across German regions and car-related taxes are uniform across Germany, we do not includ them. The region of residence constitutes one of several determinants of the insurance price in Germany. Its impact varies across insurance providers and the type of insurance coverage. Given that total insurance expenditure is only one component within the total expenditure associated with car ownership and car use, it is intuitive that the region of residence plays a negligible role for car ownership and car use.

The distinction between the categories is not entirely straightforward. For example, the share of full-time employees and the ratio of enrolled students to population allow conclusions about the economic situation and the supra-local importance of a city, but full-time employees and students are also distinct sociodemographic groups. As not all enrolled students necessarily live and are officially registered in the city where they study,[5] information on the sociodemographic composition of the population is somewhat limited. Therefore, we assign them to the economic and long-term factors. Moreover, the expected associations between the independent variables and car ownership and car use are not necessarily direct. In Germany, for example, a high number of inhabitants is usually associated with high density, which favours the quality of PT and local services. This in turn may lead to shorter trips and encourages the use of alternative transport modes.

2.4. Analyses

We perform two types of analyses. First, we perform linear regression analyses, which provide answers to the research question "To what extent are urban contextual factors associated with differences in car ownership and car use across cities?". Second, we conduct residual analyses that address the research question "When contextual factors are taken into account, do the results challenge or confirm common expectations about which cities have particularly (un)successful transport policies?"

We estimate linear regression models to predict (1) car ownership and (2) daily car use as driver measured by (a) trips and (b) distance in km. For the residual analyses, it is crucial that the adjusted model fits of the regression models are as high as possible. Therefore, the models include only those factors that increase the model fit measured by the adjusted R2. The maximally adjusted models are the result of a manual stepwise and iterative process similar to the stepwise method. However, the criterion for the inclusion of factors is the increase in adjusted R2, rather than the p-value. This is due to the relatively small absolute sample size, which reduces the probability of identifying significant associations.

The maximally adjusted models fulfil the standard assumptions for linear regression models. The variation inflation factors (VIF) are below 2.5 (car ownership), 3.5 (car trips) and 2.0 (car distance) suggesting no issues with multicollinearity. The correlations between the independent variables are mostly below the threshold of 0.5 and none exceed the threshold for serious multicollinearity, which is typically defined as around 0.8 (Berry & Feldman, 1985). The residuals are fairly independent, normally distributed and do not exhibit homoscedasticity. We performed sensitivity analyses to validate the results (Appendix 1), including the calculation of the model using the "conventional" stepwise method. As an additional sensitivity analysis for private car ownership, we calculated the regression model for all 70 independent German cities, including the cities of Aachen and Hanover. We also performed a sensitivity analysis on total car ownership (including commercial cars). For the sake of brevity, we do not present the results in this paper. We only refer to the sensitivity analysis if there are substantial differences from the results presented here.

The second type of analysis are residual analyses based on the maximally adjusted models. A residual is the deviation of a value predicted by the regression model from the observed value. We interpret negative residuals as indicating rather successful urban transport policies, as the levels of car ownership and car use are lower than predicted

[5] As the MiD is restricted to the resident population, the results on car use do not reflect the travel behaviour of all enrolled students.

based on the urban contextual factors. Positive residuals indicate less successful transport policies, as the level of car ownership or car trips is higher than predicted based on the contextual factors. This residual-based approach evaluates transport policies by estimating their overall impact, with a particular focus on their environmental impact. This assessment does not gauge the achievements of city-specific targets, which often focus on inner-city areas and varies across cities. Although the residuals provide estimates of the impact of transport policy - e.g. due to a good PT system, cycling infrastructure or mobility management - it is important to bear in mind that the residuals are due to all unobserved factors. They are thus unlikely to be entirely attributable to transport policy, while other (contextual) factors not controlled for in the models may bias the results.

We focus on the residuals of car ownership, because the database is particularly reliable (Section 2.1) and the model fit is highest for car ownership. We conduct a sensitivity analysis on daily car trips as driver with the second highest model fit. We consider three different groups of cities. The first group consists of the cities with the lowest negative and the highest positive residuals. The second group consists of cities that are cited in the literature as rather successful examples of transport policy. This includes the three largest German cities Berlin (Buehler et al., 2017), Hamburg (Buehler et al., 2017), Munich (Buehler et al., 2017; Pucher, 1998) and the fifth largest city Frankfurt (Agora Verkehrswende, 2020), as well as the smaller cities of Bremen (Agora Verkehrswende, 2020; ICLEI, 2011), Hanover (Göbler, 2020), Münster (Pucher, 1998; ICLEI, 2013), Karlsruhe (Agora Verkehrswende, 2020), Aachen (Civitas Initiative, 2021), Freiburg (Agora Verkehrswende, 2020; Bratzel, 1999; Buehler, 2011; FitzRoy & Smith, 1998; Pucher, 1998) and Heidelberg (Agora Verkehrswende, 2020). The third group includes the cities with the highest and lowest actual car ownership. A conventional comparison based on observed values and without the consideration of contextual factors would classify these cities as rather (un)successful regarding their transport policies.

3. Results

3.1. Regression models

Tables 2 and 3 display the regression models for car ownership and car use respectively. The tables present the regression coefficients (B) and standardized coefficients (Beta) that enables the comparison of effect sizes. In the following, we focus on the effect size rather than the p-values. This is due to the rather small absolute sample size.

The sensitivity analyses (Appendix 1) lead to similar results. The conventional stepwise model is the same as the maximally adjusted model for car ownership. The model including all independent cities is also quite similar, underlining the robustness of the results for car ownership. The conventional stepwise models for car trips and car distance include two variables less than the corresponding maximally adjusted models because the p-values of these variables exceed the output criterion.

3.1.1. Car ownership

The maximally adjusted regression model for car ownership explains a substantial portion of the variance (adj. R2 = 71.5 %, Table 2). It includes only those variables that improve the model fit (see Section 2.4). The associations of the non-included variables in the univariate models are consistent with the hypotheses, except for the share of elderly.

The associations between most of the independent variables included in the maximally adjusted model and car ownership are consistent with the hypotheses. The factors of population, especially population growth and job density, are associated with lower car ownership, while the share of households with children and particularly the share of full-time employees are associated with higher car ownership. Contrary to our hypothesis, the ratio of enrolled students to population is positively associated with car ownership. This positive (non-significant) association does not exist in the univariate model and is due to the additional consideration of the interrelated factors of population growth, share of full-time employees and job density. In the maximally adjusted model, the effect sizes of population, share of households with children and share of full-time employees are notably different from the corresponding univariate models due to the correlation between the independent factors.

3.1.2. Daily car trips as driver

The adjusted R2 of the maximally adjusted model for car trips is quite high (51.6 %, Table 3). Consistent with the hypotheses, the factors of population and jobs-housing balance are negatively associated with car

Table 2
Regression models for car ownership (private cars per 1000 residents).

	Maximally adjusted model			Univariate models			
	B	Beta	p[a]	B	Beta	p[a]	adj. R2
1. Environmental factors							
Population (ln)	−11.98	−0.237	0.022	−29.09	−0.577	0.000	0.317
Population growth (%)	−581.18	−0.380	0.000	−607.31	−0.397	0.004	0.138
Topography	–	–	–	1.38	0.253	0.048	0.042
Metropolitan urban region (Ref: Regiopolitan urban region)	–	–	–	−23.90	−0.285	0.030	0.059
2. Sociodemographic factors							
Share of elderly	–	–	–	741.36	0.325	0.016	0.084
Share of households with children	493.40	0.351	0.001	770.95	0.548	0.000	0.283
3. Economic and long-term factors							
Share of full-time employees	660.09	0.463	0.000	405.21	0.284	0.031	0.059
Income per capita	–	–	–	20.31	0.157	0.155	0.001
Population density	–	–	–	−0.24	−0.541	0.000	0.276
Job density	−2.50	−0.396	0.001	−2.65	−0.420	0.002	0.157
Jobs-housing balance	–	–	–	−8.91	−0.060	0.350	−0.020
Ratio of enrolled students to population	140.39	0.242	0.026	−55.49	−0.096	0.268	−0.014
(Intercept)	883.62		0.000				
Adjusted R2	0.715						
N	44						

- Factor is not included, because its inclusion does not increase the adjusted R2.
[a] One-sided p-values except for intercept.

Table 3
Regression models for daily car use per capita.

	Daily car trips as driver per capita							Daily car distance as driver per capita (km)						
	Maximally adjusted model			Univariate models				Maximally adjusted model			Univariate models			
	B	Beta	p[a]	B	Beta	p[a]	adj. R2	B	Beta	p[a]	B	Beta	p[a]	adj. R2
1. Environmental factors														
Population (ln)	−0.043	−0.211	0.083	−0.096	−0.470	0.001	0.202	−0.916	−0.548	0.000	−0.999	−0.598	0.000	0.341
Population growth (%)	–	–	–	−2.104	−0.345	0.012	0.098	–	–	–	−2.452	−0.049	0.378	−0.022
Topography	0.005	0.214	0.036	0.010	0.440	0.002	0.174	–	–	–	0.056	0.313	0.020	0.076
Metropolitan urban region (Ref: Regiopolitan urban region)	–	–	–	−0.114	−0.337	0.014	0.092	–	–	–	−0.812	−0.292	0.029	0.063
2. Sociodemographic factors														
Share of elderly	4.049	0.437	0.001	4.199	0.453	0.001	0.186	7.789	0.101	0.234	16.371	0.213	0.085	0.022
Share of households with children	2.371	0.424	0.007	2.296	0.411	0.003	0.149	9.827	0.209	0.062	19.470	0.415	0.003	0.152
3. Economic and long-term factors														
Share of full-time employees	–	–	–	0.454	0.080	0.306	−0.018	–	–	–	5.958	0.127	0.209	−0.008
Income per capita	–	–	–	0.028	0.053	0.367	−0.021	–	–	–	0.372	0.087	0.290	−0.017
Population density	–	–	–	−0.001	−0.365	0.008	0.112	–	–	–	−0.004	−0.302	0.024	0.069
Job density	–	–	–	−0.012	−0.487	0.000	0.218	–	–	–	−0.001	−0.313	0.020	0.076
Jobs-housing balance	−0.142	−0.239	0.059	−0.160	−0.270	0.040	0.050	−0.766	−0.155	0.145	−0.612	−0.123	0.215	−0.009
Ratio of enrolled students to population	0.676	0.289	0.075	−0.366	−0.157	0.158	0.001	–	–	–	−1.441	−0.075	0.316	−0.019
(Intercept)	0.247		0.738					19.429		0.001				
Adjusted R2	0.516							0.398						
N	43[b]							43[c]						

- Factor is not included, because its inclusion does not increase the adjusted R2.
[a] One-sided p-values except for intercept.
[b] The city of Bremerhaven was excluded from the analysis of car trips as it is an outlier.
[c] The city of Dresden was excluded from the analysis of car distance as it is an outlier.

trips, while topography and especially the share of households with children are positively associated. Contrary to the hypothesis, the share of elderly is positively associated with car trips. Similar to car ownership, the effect of the ratio of enrolled students to population is positive in the maximally adjusted model, while the effect is negative in the univariate model. This is also due to the associations between the ratio of enrolled students to population with the share of elderly, the share of households with children and the jobs-housing balance.

3.1.3. Daily car distance as driver

The adjusted R2 of the maximally adjusted model for car distance is rather moderate (39.8 %, Table 3). The model includes only four factors: the environmental factor population, both sociodemographic factors and the economic and higher-level planning factor jobs-housing balance. The maximally adjusted model does not include the other contextual factors, as their inclusion does not improve the model fit. However, the associations between these factors and car distance in the univariate models are fairly consistent with the hypotheses.

In line with the hypotheses, population and jobs-housing balance are negatively and the share of households with children is positively associated with car distance. Thereby, the effect size of population is especially large. Similar to car trips, the share of elderly is associated with longer car distance, which is contrary to the hypothesis. Compared to the univariate models, the effect sizes of the sociodemographic factors are much smaller, due to the simultaneous consideration of population and jobs-housing balance.

3.2. Residual analysis

This section presents the residual analysis of the maximally adjusted models on car ownership (adj. R2 = 71.5 %) and a sensitivity analysis on daily car trips as driver (adj. R2 = 51.6 %). We focus on car ownership because the model fit is highest for car ownership. We interpret negative residuals as indicating rather successful transport policies, e.g. due to a good PT system, while positive residuals indicate less successful urban policies (see Section 2.4).

The predicted car ownership differs substantially from the actual car ownership in some cities (Table 4). For a better understanding of the residuals, Appendix 2 provides an overview of the contextual factors included in the maximally adjusted model of car ownership for the cities presented in Table 4. The five cities with the lowest negative residuals have between 20 and 40 private cars per 1000 residents less than expected, which is 5 % to 10 %. In a city as Rostock (population: 208,000), this means that there are about 8300 fewer private cars than one would expect based on the contextual factors. In the five cities with the highest positive residuals, the actual car ownership is 9 % to 12 % (35 to 47 private cars/1000 residents) higher than expected. In other words, in a city as Oldenburg (population: 166,000), the city with the highest positive residuals, there are around 7800 more private cars registered than expected.

The ranking based on actual car ownership and the ranking based on residuals do not correspond with each other. This was expected as the comparison based on residuals accounts for contextual factors. Only two of the five cities with the lowest actual car ownership (in bold in Table 4) are also among the five cities with the lowest negative residuals (Heidelberg, Hanover). The other cities with low levels of actual car ownership, which are generally cited in the literature as rather successful (marked with '*'), tend not to perform particularly well when their rather favourable contextual factors for low levels of car ownership are accounted for. These cities thus rank higher in terms of residuals than in terms of actual car ownership. This includes the cities of Freiburg and Berlin, both having above-average job densities and below-average

Table 4
Residual analysis of car ownership and car trips.

	Car ownership (private cars/1000 residents)					Daily car trips as driver per capita				
	Residuals		Observed values			Residuals		Observed values		
	Ranking	Residuals	Ranking	Observed values	Difference. to mean of all 44 cities	Ranking	Residuals	Ranking	Observed values	Difference to mean of 43 cities[a]
TOP 5 with the lowest negative residuals										
Rostock	1	−40	12	362	−26	1	−0.18	16	0.94	−0.07
Heidelberg[*]	**2**	**−31**	**2**	**305**	**−83**	**15**	**−0.05**	**11**	**0.90**	**−0.11**
Hanover[*]	**3**	**−29**	**5**	**335**	**−53**	**13**	**−0.06**	**4**	**0.78**	**−0.23**
Bremerhaven[a]	4	−21	20	382	−6	–	–	–	–	–
Darmstadt	5	−20	19	377	−11	4	−0.15	12	0.90	−0.11
…	…	…	…	…	…	…	…	…	…	…
Karlsruhe[*]	8	−19	16	368	−20	28	+0.04	25	1.02	+0.01
Ingolstadt	*9*	*−18*	*43*	*450*	*+62*	*25*	*+0.02*	*32*	*1.08*	*+0.08*
Hamburg[*]	10	−18	7	343	−45	18	−0.03	5	0.81	−0.20
…	…	…	…	…	…	…	…	…	…	…
Bremen[*]	12	−15	13	363	−25	3	−0.15	7	0.85	−0.16
Aachen[*]	13	−14	21	383	−5	39	+0.16	36	1.14	+0.13
…	…	…	…	…	…	…	…	…	…	…
Freiburg[*]	**16**	**−12**	**4**	**328**	**−60**	**16**	**−0.05**	**8**	**0.86**	**−0.15**
Berlin[*]	**17**	**−11**	**1**	**290**	**−98**	**8**	**−0.11**	**2**	**0.72**	**−0.29**
…	…	…	…	…	…	…	…	…	…	…
Heilbronn	*22*	*−3*	*42*	*449*	*+61*	*40*	*+0.17*	*43*	*1.38*	*+0.37*
…	…	…	…	…	…	…	…	…	…	…
Munich[*]	24	+0	8	348	−40	20	−0.02	3	0.75	−0.26
…	…	…	…	…	…	…	…	…	…	…
Münster[*]	30	+4	22	384	−4	22	−0.00	10	0.89	−0.12
Frankfurt[*]	**31**	**+5**	**3**	**321**	**−67**	**19**	**−0.03**	**1**	**0.68**	**−0.33**
…	…	…	…	…	…	…	…	…	…	…
Leverkusen	*37*	*+23*	*44*	*468*	*+80*	*35*	*+0.08*	*41*	*1.30*	*+0.29*
…	…	…	…	…	…	…	…	…	…	…
Bottom 5 with the highest positive residuals										
Bonn	40	+35	27	402	+14	24	+0.01	20	0.98	−0.03
Koblenz	*41*	*+38*	*40*	*440*	*+52*	*32*	*+0.06*	*38*	*1.26*	*+0.25*
Essen	42	+39	34	420	+32	41	+0.18	39	1.28	+0.27
Regensburg	43	+40	28	407	+19	43	+0.24	33	1.10	+0.09
Oldenburg	*44*	*+47*	*41*	*448*	*+60*	*36*	*+0.12*	*35*	*1.13*	*+0.12*

In Italic: The five cities with the highest level of actual car ownership.
In bold: The five cities with the lowest level of actual car ownership.
[*] Cities that are considered as rather successful examples in the literature.
[a] The city of Bremerhaven was excluded from the analysis of car trips as it is an outlier.

shares of full-time employees and a rather flat topography. Berlin's above-average population and population growth and below-average share of households with children are also negatively associated with car ownership. It is also worth noting that not all cities considered in the literature as rather successful examples have negative residuals (i.e., Münster, Frankfurt). In contrast, other cities that do have rather average levels of car ownership are among the five cities with the lowest negative residuals (Rostock, Bremerhaven, Darmstadt). These cities have contextual factors that favour higher levels of car ownership, including below-average population sizes and, for the cities of Rostock and Bremerhaven, below-average population growth and job densities.

Similar patterns as for the cities with the lowest actual car ownership exist for the cities with the highest actual car ownership (italicized in Table 4). Only two of the five cities with the highest actual car ownership are also among the five cities with the highest positive residuals (Koblenz, Oldenburg). In contrast to the cities with low actual car ownership, most cities with high car ownership rank better based on residuals. In fact, some of them (i.e. Ingolstadt, Heilbronn) have lower negative residuals than some of the cities identified in the literature as rather successful examples. Yet, the city of Ingolstadt has the highest share of commercial cars in the sample (38 %). In contrast to private car ownership, Ingolstadt is one of the cities with the highest positive residuals in the sensitivity analysis for total car ownership including commercial cars. Other cities with rather average levels of car ownership are also among the five cities with the highest positive residuals (e.g. Bonn, Regensburg). Their above-average population growth, rather flat topography and below-average shares of full-time employees favour low levels of car ownership.

The residuals for the daily car trips follow a similar pattern to the residuals for car ownership. They also range widely from −0.18 to +0.24 daily car trips per capita, corresponding to −22 % to +19 % of the predicted values. In a city as Rostock (population: 208,000), again with the lowest negative residuals, this means approximately 37,800 daily car trips less than expected based on contextual factors. In a city as Regensburg (population: 149,000), with the highest positive residuals, this corresponds to approximately 36,100 daily car trips more than predicted. Cities with low levels of car trips and those that are considered rather successful in the literature tend to rank less well in the ranking of residuals than in the ranking of observed values, while cities with a high level of car trips tend to rank better.

Moreover, it is noteworthy that not all cities that are considered successful in the literature have particularly low levels of actual car ownership (Münster) or of daily car trips as driver (Karlsruhe). With 5 private cars per 1000 residents below and 0.13 daily car trips as driver per capita above the average, the city of Aachen has neither.

4. Discussion

The residual analyses showed that neglecting contextual factors in city comparisons leads to a distorted view and assessment of the successes of urban transport policies. Many cities that are frequently mentioned as successful examples do not have transport policies that appear to substantially reduce car ownership and car trips. Conversely, the transport policies of many cities with high levels of car ownership and car trips do not seem to increase them considerably. Cities with low observed values tend to perform less well in terms of residuals than in terms of observed values, while cities with high observed values tend to perform better based on residuals. This suggests that the particularly high and low levels of actual car ownership and car trips are (mainly) due to urban contextual factors. Indeed, some cities not generally known for their successful transport policies, such as the city of Rostock, appear to be more successful when contextual factors are taken into account and therefore perhaps better role models than the well-known examples. The success of these cities runs the risk of being overlooked, because their contextual factors tend to be rather unfavourable to low levels of car ownership and car trips.

We found that contextual factors explain car ownership and car use to a large extent (40–72 %). This suggests that the average impact and thus the ability of urban transport policies to influence car ownership and car use may be limited, especially in the short term. However, the impact of urban transport policies implied by the residuals differ across cities and the potential impact of some urban transport policies are yet noteworthy. This includes the transport policy of the city with the lowest negative residuals (Rostock), where the actual car ownership and car trips are 12 % and 24 % lower than expected due to the contextual factors, as well as the cities with the highest positive residuals. Although the residuals approach presented allows for a more accurate assessment of urban transport policies than conventional comparisons and rankings, it is possible that other (contextual) factors influence the results. These include factors that are not generalizable, quantifiable or city specific. They also include the potential geographical variations in the availability of company cars. For example, the city of Ingolstadt, headquarters of one of Germany's largest car manufacturers (Audi), performs much better in terms of the residuals of car ownership than in a conventional comparison based on actual private car ownership. Yet, this city has a particularly high share of commercial cars and performs much weaker in the sensitivity analysis of total car ownership and rather average for car trips. The share of households with access to company cars for private use may be higher in Ingolstadt than in other cities. This may also affect the private car ownership and car use. However, only a few cities with an exceptionally high or low share of commercial cars may be affected by these circumstances. Due to the lack of data on the actual location and use of commercial cars (see Section 2.1), we are not able to investigate this further.

The regression analyses suggest that urban contextual factors are more relevant to car ownership and car trips than to car distance as the model fits of car ownership (72 %) and trips (52 %) are higher than for distances (40 %). Yet, distance travelled by car as driver are most directly linked to many negative impacts of car use. The different model fits are consistent with the literature in the sense that population and job densities are considered the main correlates of car trips and car ownership (see e.g. Ding & Cao, 2019 for a literature review). Findings on the impact of compact development, including population and job densities, on vehicle miles travelled vary across studies (Stevens, 2016), and meta-analyses suggest rather small elasticities of vehicle miles travelled with population and job densities (Ewing & Cervero, 2010; Stevens, 2016). There may be several reasons for this and for the different levels of model fit. One might be the high relevance of the many shorter trips to the average car trips, while the few longer trips have a high relevance to the average distance (even though we excluded respondents with trips over 100 km). Shorter trips are more likely to start and end within the city of residence and urban contextual factors are more likely to affect these trips, such as topography, which is included in the maximally adjusted model for car trips but not for car distance. For longer trips, the destination is more likely to be outside the city of residence and the urban contextual factors considered here do not capture the characteristics of the destination. Yet, the characteristics of the destination, such as the workplace location also influence travel behaviour (e.g. Ding et al., 2014; Vanoutrive, 2015; Vermesch et al., 2021). Regional contextual factors and policies that favour, for example, transit-oriented development (Staricco & Vitale Brovarone, 2018), may be more important than urban contextual factors and policies. Another reason for the differences in the model fits may be the reliability of the data. The indicator of car ownership is particularly reliable as it is based on a comprehensive survey, whereas daily car trips and distance are based on a sample. In addition, both car trips and distances are self-reported. Apart from the fact that distances are often rounded (Witlox, 2007), the respondents of the MiD 2017 were explicitly asked to report the trip distances only approximately.

The regression analyses underline the importance of adapting transport strategies to city size and to households with children, for example through mobility management, as all maximally adjusted regression models include population and the share of households with children. Moreover, all models include either job density (car ownership) or jobs-housing balance (car use). It could be argued that, in the long run, local policies should increase job density or jobs-housing balance to reduce car ownership and car use. Following Holz-Rau and Scheiner (2019), we argue that this is not feasible for all municipalities, as the surplus of this central-location function depends on the deficit in other municipalities.

The negative associations of car ownership and car use with job density, jobs-housing balance and population size, which is positively associated with population density, highlight the relevance of these contextual factors as preconditions and covariates for PT systems and accessibility (see Chen et al., 2008 for a detailed discussion). German cities with high population and job densities have on average a higher quality, efficiency and coverage of PT than cities with lower population and job densities. Thus, the effects of population and job density partly reflect the impact of PT systems and therefore partly the outcome of transport policies. However, it is intuitive that contextual factors actually facilitated, and in some cases even forced, the introduction of PT systems. The predecessors of today's urban tram systems have been in operation in most German metropolises since the 1870s and 1880s, long before mass motorisation. These systems were introduced to ensure the functionality of the cities, particularly in economic terms, and were not primarily the result of a deliberate transport policy. As the analyses only capture the average effects of PT systems for cities in terms of population size and job density or jobs-housing balance, the residuals reflect possible impacts of above- or below-average quality of PT systems, controlling for these contextual factors.

A key strength of this paper is that its sample contains data on an urban level, which has been collected with consistent methodology and reference dates. This reduces data limitations that often occur such as when comparing international cities as the scale, moment, and method of data collection differ (e.g. Buehler et al., 2017; Lee et al., 2022; Santos et al., 2013). Moreover, our data allowed for the simultaneous consideration of car ownership (for which we had particularly reliable data), daily car trips and car distance as driver. Another strength is that by considering only German cities with similar cultural backgrounds, overarching legislation and related urban transport policy responsibilities, the potential influences of contextual factors not considered here are limited. It is likely that the contextual factors considered and not considered in this study, including climate-related characteristics, fuel prices, and taxes associated with car use (e.g. Lee et al., 2022; Saeidizand et al., 2022), vary more across countries and are therefore even more important to consider in international comparisons. Moreover, it is plausible that other contextual factors may be more important when comparing cities in a country other than Germany. This could be the case for fuel prices and climate-related characteristics, which differ more in other countries such as the US or Canada.

However, our study has several limitations. The focus on large German cities allows for a consistent database, but limits the sample to 44 large cities, with larger cities being overrepresented. A larger sample would improve the estimation of effects and therefore lead to a more precise identification of cities with higher or lower car ownership and car use than expected based on contextual factors. Despite the relatively small absolute sample size, it is noteworthy that a considerable number of the associations are statistically significant. Furthermore, the sensitivity analysis with all 70 independent German cities, which we were only able to perform for car ownership due to limited data availability, underlines the robustness of the results. Another limitation is that the results do not include commercial cars that are actually located in the cities, and that the results refer only to car ownership and car use of the respective residential population. As with most other studies based on travel diaries, the data do not allow for the inclusion of car use by non-residents. It is possible that the car use of non-residents, not captured in this study, compensates for the low car use of the residential population. Moreover, it is possible that other unobserved (contextual) factors have an impact on the results. A final limitation is that, the presented findings do not provide information on the (in)direct effects of the contextual factors on car ownership and car use, nor on the interaction between the contextual factors.

Although the comparisons based on residuals are more informative than conventional ones, further research is needed to examine the transport policies of the cities with the lowest negative residuals before these cities can be proclaimed as new or "better" examples of successful transport policies. Moreover, our analyses could be used for other transport policies. For example, the use of other transport modes could be similarly analysed, which would lead to a more comprehensive understanding. In this light, non-residential car use also seems of interest. As household surveys for functional regions (beyond the city boundaries) are rather rare, these analyses could rely on car inventory data. They are available for all German municipalities and allow the analysis of functional regions. The consistency of findings between car ownership and car use (including car use of commercial cars) measured by trips as driver, as well as the strong correlation between car ownership and car trips, underlines the reliability of car ownership as a proxy for car use. However, it would be useful if the car inventory data could include information on the actual location of the cars. It would also be beneficial to distinguish between commercial cars exclusively used for business purposes and company cars that are also used privately. This could provide further insights as in many countries (Börjesson & Roberts, 2023; May et al., 2019; van Eenoo, Fransen, & Boussauw, 2022), including Germany (Vallée, Ecke, Chlond, & Vortisch, 2022), company cars are used more intensively than private cars, which can be (partly) explained by the tax advantages of company cars. It is therefore likely that the possible geographical differences in access to company cars could have an impact on car use, e.g. that a high access rate to company cars is associated with higher car use. Future studies could also investigate causalities between the contextual factors, transport infrastructure and car ownership and car use in more detail, e.g. using structural equation modelling.

This study has clear relevance to policymakers and their advisers. Based on our findings, we recommend that cities look beyond the currently considered best practice cases when developing policies. Rather than evaluating transport policies solely based on indicators that urban transport policies can change, we recommend to take contextual factors (more) into account. This implies focusing on and learning from cities where car ownership and car use, which are key indicators of the impact of transport policies, are lower than predicted based on contextual factors. This would allow a more "fair" comparison, a better assessment of the impact of transport policies and therefore a better choice of role models. In this sense, it would avoid focusing on less "suitable" examples, such as cities with favourable contextual factors for low car ownership and car use, but with less effective transport policies. Instead, it could include cities with actual high levels of car ownership and car use, but with unfavourable contextual factors, where transport policies are still appear to be effective. In addition, we recommend that policymakers and policy advisers consider contextual factors in terms of differences between cities and the transferability of policies. Moreover, policy design should reflect the respective contextual factors and the potential to change or respond to them, e.g. through targeted mobility management for households with children.

5. Conclusion

This study investigated the relationship between urban contextual factors, which are difficult or impossible to influence through urban transport policies, and car ownership and car use at the city level. To draw conclusions concerning the effects of neglecting contextual factors in city comparisons, we investigated whether the results of city comparisons that take into account urban contextual factors, challenge or confirm common expectations about cities with particularly (un)successful transport policies. For this, we conducted regression and residual analyses on a sample of 44 German large cities.

The results indicate that urban contextual factors are strongly associated with car ownership and car trips, while they are less associated with car distances. The study showed that neglecting contextual factors may lead to biases in city comparisons. Cities with more favourable contextual factors for low levels of car ownership and car trips are more likely to be seen as rather successful examples of urban transport policy, while the results point to the risk of underestimating the success of transport policy in cities with less favourable contextual factors. This leads to biased assessments of the success of urban transport policies. We therefore recommend that case studies, comparative studies, and policy makers should not solely focus on indicators that can be influenced by urban (transport) policies including actual travel behaviour, for example measured by low levels of car ownership and car use. Instead, we advise to take contextual factors (more) into account, and focus on cities that have lower levels of car ownership and car use than would be expected based on their contextual factors. This allows for a better assessment of the actual success of urban transport policies and avoids focusing on less "suitable" examples of (un)successful transport policies.

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CRediT authorship contribution statement

Isabelle Wachter: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Christian Holz-Rau:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Eva Heinen:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix 1. Sensitivity analyses

	Car ownership (private cars/1000 residents)				Daily car trips as driver per capita			Daily car distance as driver per capita (km)		
	"Conventional" stepwise model[a]	Model for all German independent cities			"Conventional" stepwise model[a]			"Conventional" stepwise model[a]		
		B	Beta	p[b]	B	Beta	p[b]	B	Beta	p[b]
1. Environmental factors										
Population (ln)	Equals the maximally adjusted model in Table 2	−14.14	−0.214	0.005	−0.057	−0.280	0.014	−1.080	−0.646	0.000
Population growth (%)		−628.10	−0.389	0.000	–	–	–	–	–	–
Topography		–	–	–	0.005	0.236	0.025	–	–	–
Metropolitan urban region (Ref: Regiopolitan urban region)		–	–	–	–	–	–	–	–	–
2. Sociodemographic factors										
Share of elderly		–	–	–	3.920	0.423	0.000	–	–	–
Share of households with children		606.36	0.400	0.000	1.652	0.296	0.008	–	–	–
3.Economic and long-term factors										
Share of full-time employees		483.81	0.275	0.000	–	–	–	–	–	–
Income per capita		–	–	–	–	–	–	–	–	–
Population density		−0.013	−0.243	0.002	–	–	–	–	–	–
Job density		–	–	–	–	–	–	–	–	–
Jobs-housing balance		−45.75	−0.293	0.000	–	–	–	−1.236	−0.249	0.025
Ratio of enrolled students to population		125.36	0.184	0.030	–	–	–	–	–	–
(Intercept)		1043.82		0.000	0.500		0.280	26.214		0.000
Adjusted R2		0.764			0.500			0.388		
N		70			43[c]			43[d]		

[a] Given the directed hypotheses (Table 1), we set the threshold to 0.10 as the enter criterion and 0.20 as the output criterion.
[b] One-sided *p*-values except for intercept.
[c] The city of Bremerhaven was excluded from the analysis of daily car trips as it is an outlier.
[d] The city of Dresden was excluded from the analysis of daily car distance as it is an outlier.

Appendix 2. Overview of the contextual factors included in the maximally adjusted model of car ownership (private cars per 1000 residents) and daily car trips as driver

	Population	Population (ln)[a]	Population growth (%)[a]	Topography[b]	Share of elderly[b]	Share of households with children[a, b]	Share of full-time employees[a, b]	Job density[a]	Jobs-housing balance[b]	Ratio of enrolled students to population[a, b]
TOP 5 with the lowest negative residuals										
Rostock	208,409	12.25	1.03	11.03	0.24	0.22	0.27	1189	1.14	0.07
Heidelberg[*]	160,601	11.99	1.08	20.31	0.16	0.24	0.22	2749	1.78	0.22
Hanover[*]	535,061	13.19	1.05	4.22	0.19	0.23	0.27	2245	1.57	0.08
Bremerhaven[a]	113,026	11.64	1.05	2.91	0.22	0.26	0.25	1189	1.33	0.03
Darmstadt	158,254	11.97	1.09	5.08	0.17	0.27	0.26	2352	1.67	0.29
…										
Karlsruhe[*]	311,919	12.65	1.07	7.48	0.18	0.26	0.28	2175	1.49	0.13
Ingolstadt	135,244	11.81	1.07	2.20	0.18	0.33	0.35	2138	1.75	0.05
Hamburg[*]	1,830,584	14.42	1.07	4.00	0.18	0.25	0.29	2139	1.30	0.06
…										
Bremen[*]	568,006	13.25	1.04	3.39	0.21	0.26	0.24	1413	1.36	0.06
Aachen[*]	246,272	12.41	1.03	11.80	0.18	0.22	0.25	2023	1.51	0.23
…										
Freiburg[*]	229,636	12.34	1.07	11.22	0.16	0.25	0.22	2499	1.54	0.14
Berlin[*]	3,613,495	15.10	1.09	0.60	0.19	0.24	0.24	2271	1.10	0.05
…										
Heilbronn	125,113	11.74	1.07	14.37	0.20	0.32	0.32	1956	1.37	0.07
…										
Munich[*]	1,456,039	14.19	1.07	2.57	0.18	0.23	0.34	3665	1.32	0.07
…										
Münster[*]	313,559	12.66	1.07	1.69	0.17	0.24	0.25	1622	1.45	0.19
Frankfurt[*]	746,878	13.52	1.10	3.30	0.16	0.26	0.29	3888	1.90	0.10
…										
Leverkusen	163,577	12.01	1.03	8.28	0.22	0.30	0.28	1348	1.02	0.01
…										
Bottom 5 with the highest positive residuals										

(*continued on next page*)

(*continued*)

	Population	Population (ln)[a]	Population growth (%)[a]	Topo-graphy[b]	Share of elderly[b]	Share of households with children[a, b]	Share of full-time employees[a, b]	Job density[a]	Jobs-housing balance[b]	Ratio of enrolled students to population[a, b]
Bonn	325,490	12.69	1.06	8.11	0.18	0.27	0.25	2415	1.52	0.12
Koblenz	113,844	11.64	1.05	21.69	0.22	0.27	0.25	1888	1.80	0.13
Essen	583,393	13.28	1.03	17.35	0.22	0.26	0.25	1706	1.21	0.05
Regensburg	150,894	11.92	1.11	7.69	0.17	0.22	0.30	2600	1.95	0.21
Oldenburg	167,081	12.03	1.06	2.10	0.19	0.26	0.25	1332	1.31	0.10
Mean (44 large German cities)	452,028	12.60	1.06	8.85	0.19	0.26	0.28	2083	1.42	0.10

In Italic: The five cities with the highest level of actual car ownership.
In bold: The five cities with the lowest level of actual car ownership.
[a] Contextual factor included in the maximally adjusted model for car ownership (private cars per 1000 residents).
[b] Contextual factor included in the maximally adjusted model for daily car trips as driver per capita.
[*] Cities that are considered as rather successful examples in the literature.

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