Journal of Transport Geography 118 (2024) 103918

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Analyzing shared mobility markets in Europe: A comparative analysis of shared mobility schemes across 311 European cities

Elnert Coenegrachts [*], Thierry Vanelslander, Ann Verhetsel, Joris Beckers

Department of Transport and Regional Economics (TPR), University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium

A R T I C L E I N F O

Original content: Shared mobility provision in European cities (Original data)

Keywords:
Shared mobility
Micro-mobility
Market analysis
Latent class clustering analysis
K-means clustering

A B S T R A C T

The progression of shared mobility across Europe is remarkable. While station-based car and bike sharing have a more extended history, particularly in major European (capital) cities, recent advancements in modal types and operational models have significantly transformed the shared mobility landscape. Rapid expansion by private organisations has broadened access to shared mobility services across Europe. However, not all European cities are considered potentially viable markets due to local factors such as stringent regulatory frameworks and unfavourable economic conditions. The composition of the local offerings influences how citizens use these services, impacting travel behaviour and the local transport networks differently. Therefore, understanding the availability of various shared mobility schemes across Europe is essential for comprehending the market structure, its development, the providers' decision drivers, and the potential consequences for local transportation systems.

First, this paper presents data on various segments and features of the shared mobility market across European cities with more than 100.000 inhabitants. Second, two cluster approaches, i.e. k-means and latent class clustering analysis (LCCA), are conducted to structure this European market. Third, the contextual characteristics, such as socio-demographics, the built environment and the geography, are compared among the clusters using Dunn testing.

The results depict that the market is very fragmented, ranging from cities with a minimal offer (i.e. one type of modality available) to cities with a very competitive market consisting of numerous modalities and operators.

As expected, the most comprehensive offer of shared mobility is found in cities with the highest economic potential, measured by GDP per capita and population size. However, these cities tend to impose stricter regulations and invest in public schemes, especially for bike and car sharing, affecting the share of private operators. This may explain why private scooter sharing companies are willing to operate in smaller cities that initially seem to lack the economic conditions to accommodate a profitable sharing scheme. In cities where scooters are absent, mainly in Dutch cities, free-floating moped- and bike-sharing schemes have acted as a surrogate. Still, the comprehensiveness of the offer in these cities is considerable, suggesting that even with strict regulatory frameworks, other factors like infrastructure can create an attractive environment for operators. Overall, shared mobility is well-developed in European cities, meaning that many people are already aware of or have access to some form of shared mobility. This provides opportunities for other less-developed modalities, such as cargo bicycles, to further expand and offer specific use cases for car replacement. Therefore, future research could follow up on market developments to understand how various segments evolve and to examine the role of different policy frameworks more thoroughly.

1. Introduction

Europe is committing to reduce the transport sector emissions by 90% in 2050 and for cars and vans by 100% in 2035 (European Commission, 2021). One of the milestones in achieving this is to realise 100 climate-neutral European cities by 2030 (European Commission, 2019). Cities and urban environments are highlighted as essential to reach the goals of Europe's Green Deal. In this regard, Europe's Smart

* Corresponding author.
E-mail addresses: elnert.coenegrachts@uantwerpen.be (E. Coenegrachts), thierry.vanelslander@uantwerpen.be (T. Vanelslander), ann.verhetsel@uantwerpen.be (A. Verhetsel), joris.beckers@uantwerpen.be (J. Beckers).

https://doi.org/10.1016/j.jtrangeo.2024.103918
Received 21 July 2022; Received in revised form 26 May 2024; Accepted 8 June 2024
Available online 20 June 2024
0966-6923/© 2024 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

and Sustainable Mobility strategy (European Commission, 2020) stresses the importance of shared and collaborative mobility services to reduce the pressure on passenger transport systems. Shared mobility is a broad term that encompasses different services, such as bicycle, car, and scooter sharing. The first sharing schemes, such as station-based bike and car sharing, have already been available in several larger European cities. However, since 2017, the market has changed significantly, with private organisations expanding the number of sharing schemes across Europe. This expansion has made various sharing schemes widely available to citizens in European cities, including free-floating and hybrid schemes, as well as new modes like mopeds and cargo bicycles. Currently, there is no reference overview of the various sharing modalities and schemes across Europe. This lack of data makes it difficult to study the overall development of the shared mobility market and compare advancements among cities.

Based on the type of sharing scheme and the context of the place where it is available, a shared mobility scheme provides different use cases for various types of potential users. This results in diverse travel patterns and trip purposes, leading to varying impacts on mobility indicators. Numerous studies have documented the effects of different sharing schemes on travel behaviour (e.g. Chen et al. (2020); Fishman (2016); Teixeira et al. (2020)). Therefore, the composition of shared mobility services within a particular city will partly determine their impact on the local transportation network.

The local shared mobility mix is composed of a combination of different providers, both private and public actors, who decide upon the expansion towards new markets or retraction from existing ones. These decisions are guided by their objectives and the contextual factors of the market they are considering. In the micro-mobility segment, which includes smaller types of vehicles such as (cargo-)bicycles, scooters and mopeds, the market initially developed slowly. Public authorities first introduced station-based bicycle-sharing systems as an addition to the public transport system. However, since the entrance of private organisations, the market rapidly changed and expanded, with free-floating schemes, especially scooters, becoming dominant. These private operators require financial viability to continue operations, so they are expected to enter markets with favourable conditions, such as prosperous, densely populated urban areas with less reliance on cars. However, as shared mobility is inherently situated in the public domain, the decision to open the market to private organisations depends upon local authorities. As the market matures, local authorities aim to reduce the externalities associated with free-floating schemes, such as cluttering and modal shifts away from walking, cycling and public transport, by imposing stricter regulations. It is assumed that this regulatory pressure will have an impact on the dominant role of scooters in certain cities. For example, Paris has excluded scooter-sharing schemes. Additionally, larger cities are limiting the number of operators allowed to serve their market, and local authorities are increasingly taking active roles in managing, operating or funding shared schemes. This raises the question of whether the share of privately operated schemes will decline and how the shared mobility mix will change in European cities, particularly concerning scooter-sharing schemes. Along with the rise of free-floating private micro-mobility schemes, free-floating car sharing has also become widely available across Europe. Car sharing involved a mix of public and private organisations, but mainly operating a station-based model. With the increased prevalence of free-floating models in shared mobility, it is assumed that free-floating operators will also become dominant in the car-sharing segment.

It is important to map the availability of shared mobility schemes across Europe, as it allows the development of a reference dataset of shared mobility provision. This helps assess the expected usage of a local shared mobility mix and better understand the contextual factors considered by the providers of these services. Therefore, this paper addresses the following research questions: Where is shared mobility available in Europe? Which European countries, regions and cities are at the forefront of this market or are lagging behind? Which type of shared mobility is available in different locations? Which (kind of) operators are active in which cities? Where are public authorities primarily involved? And what contextual factors could explain the structure of this market?

This paper examines the geographical structure of shared mobility provision across European cities. A dataset has been created, containing information about the local shared mobility markets in all European cities with populations above 100,000. This dataset includes details about different public and private operators, the business model they are operating and the mode(s) they provide. To group similar market segments and cities, different cluster analyses are carried out. The characteristics of the clusters will help us understand the current dynamics of the shared mobility market in Europe and better assess the potential challenges and opportunities within the current landscape.

The remainder of this paper is organised in the following way. Section 2 elaborates on the evolution of the various shared transportation modes and the contextual elements affecting their usage. Section 3 describes the methodology, including k-means and latent class cluster analysis, as well as the comparative analysis. This is followed by a results section, which details both the market indicators and contextual characteristics of the clusters. The final section concludes the research, highlighting opportunities and challenges for the further advancement of shared mobility and the policies that can steer an advantageous development.

2. Literature review

This section addresses the evolution of shared mobility, elaborating upon its current implementation and adoption across European cities. In addition, it explores the potential impact of various types of shared mobility on current mobility behaviour and identifies confounding variables that could affect the availability of these schemes. These variables are identified based on a literature review that considers the factors influencing the adoption and usage rate of shared mobility, under the assumption that providers consider these factors when deciding upon their markets.

Shared mobility has seen a remarkable evolution across Europe. Initially, public authorities launched shared mobility initiatives, in particular car or bike sharing, as part of the local transport mix. Today, these public sharing schemes are increasingly being regarded as integral components of the public transport network, with efforts to digitally and physically integrate them, for example through infrastructural developments such as mobility hubs (Coenegrachts et al., 2021). Since 2017, private organisations have entered the shared mobility market with new vehicle types (e.g. scooters and mopeds) and operational models (i.e. free-floating). These private entities aim for profitability, guiding their decisions on pricing, deployment and operational strategies. Venture capital engaged in the free-floating sharing market, seeking interesting market opportunities, therefore first targeting the major developed cities (Han, 2020). This has led to high competition in these areas, with multiple schemes operating simultaneously. In contrast to the strategy of this purely commercial model, station-based bike-sharing schemes, primarily operated by a public or public-private entity, are also being established in smaller municipalities. It is argued that these systems are favoured by policymakers due to their environmental and social benefits and the relatively uncontroversial nature of these policy measures, compared to other transportation policies such as congestion charging schemes, low-emission zones or large public transport projects (Parkes et al., 2013). However, the performance of these systems varies significantly across cities, though public support often keeps less efficient schemes operational (Todd et al., 2021). Shared vehicles are more often concentrated in dense urban areas, resulting in limited accessibility to these sharing schemes in other, less central, urban areas. If several operators are present and competition is high, this could lead to an abundance of vehicles on the street, causing external effects such as cluttering and obstruction of sidewalks. Consequently, some cities have imposed stricter regulations towards free-floating vehicles to mitigate these effects (Gössling, 2020; Schönberg, 2018), while preserving the advantages of the new vehicle types, such as increased flexibility. This does not seem to hinder the quick expansion of scooter schemes. In most European cities, shared scooters constitute the majority of the shared vehicle fleet (Fluctuo, 2021b). Part of the reason why scooter operators are rapidly expanding lies in their scalable model. Their upfront investment cost in vehicle assets is lower compared to other modes, such as cars, mopeds and bikes (Heineke et al., 2019). Some research has examined the diffusion of shared mobility across urban areas but these studies often focused on one subdivision of the market (e.g. Münzel et al. (2019) considered car sharing, while Todd et al. (2021), Parkes et al. (2013) and Han (2020) investigated bike-sharing schemes). The market is thus still evolving, resulting in a heterogeneous local shared mobility mix across European cities, which in turn may have varying impacts on the local transport networks.

Considering the possible effects on mobility patterns of shared mobility services, a considerable amount of literature has studied related aspects, such as the characteristics of the users, the trip purposes and the substituted mode (e.g. for a review concerning bike sharing, see Fishman (2016); Teixeira et al. (2020); Zhang and Kamargianni (2023), concerning car sharing, see Ferrero et al. (2018), concerning scooters, see Badia and Jenelius (2023); Wang et al. (2023)). The picture is ambiguous, as the impact of specific shared mobility modalities on urban mobility patterns is complex and varies by context, making it difficult to draw general conclusions. However, it seems that station-based bike sharing is more embedded in daily commuting behaviour, while free-floating micro-mobility vehicles are often used for recreational purposes and frequently replace public transport, walking and cycling trips. Shared cargo bicycles and cars, on the other hand, have the capability to accommodate use cases for which the private car was typically adopted, thereby increasing their potential for car substitution.

Additionally, it is important to consider the geographical context in which the market is developing. First, the effects of shared mobility services on mobility patterns depend on the local characteristics of the areas where they are implemented. Subsequently, as stated above, private operators typically focus on potentially profitable markets, while public actors have a varying levels of resources available to invest in a public sharing scheme. Public entities also have different perspectives on the role of shared mobility in their sustainable urban mobility plans and varying degrees of openness towards allowing private players in the public domain. Therefore, it is interesting to examine the characteristics of the cities that could impact the presence of private and/or public sharing schemes. While existing literature has not yet studied the contextual factors organisations consider when selecting their markets, we assume that these shared mobility providers will opt for markets that have favourable conditions for high adoption rates.

When considering the factors that could influence providers' decision to initiate a sharing scheme, we examine the literature on elements affecting the adoption rate and usage intensity of shared mobility services, as these two aspects are assumed important for establishing an economically viable scheme. First, socio-demographic factors such as age, income, gender, educational level and car ownership rate, are relevant determinants for membership levels in bike sharing (Fishman, 2016), car sharing (Golalikhani et al., 2021), moped sharing (Aguilera-García et al., 2020), scooter sharing (e.g. Christoforou et al., 2021; Mitra and Hess, 2021; Reck and Axhausen, 2021) and cargo bike sharing (Becker and Rudolf, 2018). Additionally, there are specific target groups who could be susceptible to using sharing services, such as tourists (Arias-Molinares et al., 2021; Esztergár-Kiss and Lopez Lizarraga, 2021), families (Coll et al., 2014; Hess and Schubert, 2019) and students (Aguilera-García et al., 2020; Reck et al., 2021). A high presence of these target groups can enhance the city's attractiveness for shared mobility services. Beyond socio-demographic variables, which are related to the users' characteristics, the city's built environment influences the adoption rate of shared mobility schemes. For instance, bike-sharing usage is affected by cycling infrastructure, public transport infrastructure and population density (El-Assi et al., 2017; Faghih-Imani and Eluru, 2016; Mateo-Babiano et al., 2016; Médard De Chardon et al., 2017). Similarly, car sharing adoption is influenced by population density (Müller et al., 2017; Stillwater et al., 2009), parking pressure (Müller et al., 2017; Shaheen et al., 2010), public transport infrastructure (Celsor and Millard-Ball, 2007), public transport accessibility (Ye et al., 2019) and modal split (Münzel et al., 2019). Factors tending to impact on the success of scooter-sharing schemes include public transport infrastructure (Bai and Jiao, 2020; Huo et al., 2021), bicycle infrastructure (Caspi et al., 2020), population and employment density (Huo et al., 2021). Lastly, geographical elements such as local climate (temperature and precipitation levels (Bean et al., 2021; Shen et al., 2018; Zhu et al., 2020)) and topography (Hosseinzadeh et al., 2021; Mateo-Babiano et al., 2016) also affect usage intention for several sharing schemes. These factors will serve as the basis for selecting relevant city characteristics this research will collect data about.

In the context of European cities facing significant challenges to create sustainable and safe urban transportation systems, it is interesting to focus on larger cities and their shared mobility offerings. These cities also constitute the majority of participants in Europe's Cities Mission, which aims to deliver 100 climate-neutral and smart cities by 2030 (European Commission, 2024). However, there is a lack of understanding regarding the current provision of shared mobility across large European cities. This gap makes it difficult to assess whether the availability of public and private schemes, various modalities and multiple operators is limited to certain cities. Furthermore, limited research exists on why these particular shared mobility mixes are present in specific segments of the European market. This paper addresses these research gaps by mapping and explaining the geography of shared mobility services across a specific set of European cities, structuring the current shared mobility market in European cities with populations over 100,000, and studying the characteristics of these cities. This approach facilitates a comparison of the diffusion of different shared mobility innovations in various contexts.

3. Methodology

This section consecutively discusses the data utilised and the clustering approach applied.

3.1. The dataset

This study considers all shared mobility schemes provided by private or public operators (peer-to-peer schemes are not included), i.e. scooter sharing (SS) (free-floating (FF)), bicycle sharing (BS) (station-based (SB), free-floating and hybrid), car sharing (CS) (station-based and free-floating), moped sharing (MS) (free-floating) and cargo bicycle sharing (CBS) (station-based and free-floating). The data includes information for every scheme on the city, the operator, the specific shared modality, the associated business model (i.e. station-based, free-floating or hybrid) and whether it is public or private. A scheme is defined as public when a public entity, such as a local public transport authority or municipality, is funding or (co-)operating in the scheme. This research only includes sharing schemes in European cities with a population greater than 100,000, as data availability for the contextual variables characterising the city is restrained for smaller municipalities and mobility challenges are more pertinent in larger urban areas.

The data on shared mobility provision were collected through a) local (transport) authority's webpages, b) national interest organisations around shared solutions (e.g. CoMoUK (UK), Autodelen.net (Belgium), Bundesverbund Carsharing (Germany)), c) other secondary sources mapping shared mobility services (e.g. 'Bike-sharing World Map' (Meddin et al., 2021), 'Global Moped Sharing Map' (Howe, 2021), 'Free-floating MicroMobility Map Europe' (Friedel, 2021), 'City Dive' (Fluctuo, 2021a) and 'New Mobility Atlas' (Numo, 2021)) and d)

Table 1
Confounding variables.

Variables	Indicator	Data source
Socio-demographics		
Age	Proportion of young aged people (15–34 years) (%)	Eurostat
	Proportion of middle-aged people (35–54 years) (%)	
		Eurostat
Population	Number of inhabitants	JRC[a]
Income	GDP per capita (€/Inh.)	JRC[a]
Education level	Proportion of population aged 24–64 qualified at higher education (%)	Eurostat
Car Ownership level	Number of registered cars (per 1000 inhabitants)	Eurostat
Specific target group		
Tourists	Number of tourist nights in touristic establishment (per inhabitant)	Eurostat
Students	Share of students in higher education in the total population (per 1000 inhabitants)	Eurostat
Families	Proportion of households with children aged 0–17 years (%)	Eurostat
Built environment		
Land area	City area (km^2)	JRC[a]
Population density	Population/Land area (Inh./km^2)	JRC[a]
Cycling infrastructure	Cycling network density (meters of dedicated cycling infrastructure/km^2)	OpenStreetMap[b]
Weather		
Temperature	Average temperature (°C)	JRC[a]
Precipitation	Average precipitation (mm)	JRC[a]
Topography		
Elevation	Average elevation (m)	JRC[a]

[a] Florczyk, A.J., Corbane, C., Schiavina, M., Pesaresi, M., Maffenini, L., Melchiorri, M., Politis, P., Sabo, F., Freire, S., Ehrlich, D., Kemper, T., Tommasi, P., Airaghi, D. and L. Zanchetta. 2019. GHS Urban Centre Database 2015, multitemporal and multidimensional attributes, R2019A. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/53473144-b88c-44bc-b4a3-4583ed1f547e

[b] Boeing, G. 2017. OSMnx: New Methods for Acquiring, Constructing, Analyzing, and Visualizing Complex Street Networks. *Computers, Environment and Urban Systems* 65, 126–139. doi:https://doi.org/10.1016/j.compenvurbsys.2017.05.004

operators' own websites, their smartphone applications and their social media channels. The dataset was last updated in October 2023.

To account for the different contextual settings of each city, additional variables were collected or calculated for every city. These variables were selected based on the literature review. As mentioned, we assume that private operators, whether explicitly or implicitly, consider these factors when deciding on their operational areas, as they can impact the adoption rate and usage intensity of the service.

Table 1 provides an overview of variables and the data sources from which they were extracted. This study prioritised the variables that consistently impact the sharing schemes and could be collected or calculated for every city in our dataset. This includes socio-demographics (i.e. age, population, income, educational status and car ownership), target group (i.e. number of tourists, share of students, share of families), built environment (i.e. land area, population density and cycling infrastructure), weather (i.e. precipitation and temperature) and topography (i.e. elevation). However, variables related to the current transportation system of a city, such as modal split, public transport performance, parking infrastructure and parking pressure, are not available for the majority of the cities in our dataset. Additionally, the policy setting for shared mobility in a regarded city could also not be addressed, as there are currently no measures or comparisons available that give an indication of the strictness of regulations towards a certain shared modality. Therefore, it has been decided not to include these variables in our analysis, as it would lead to many missing data points.

Following the data collection, a descriptive analysis was conducted to obtain an initial understanding of the market. This analysis focused on the share of private versus public schemes, the dominant operators, the countries with high shared mobility availability, and the significance of different modalities and business models. To further structure the market and group cities with similar shared mobility mixes, two cluster analyses were carried out.

3.2. K-means and latent clustering

Clustering is an unsupervised method to connect data points that have similar characteristics to each other, thereby identifying an underlying structure in the dataset (Everitt et al., 2011). Observations that have large similarities will form clusters. For this paper's purpose, this method allows for classifying cities with similar shared mobility provisions. The characteristics of the clusters can provide insights into why certain cities (i.e. observations) in a certain cluster resemble each other and differ from cities in other clusters. This study employs two different cluster analyses to reveal the segments in the European shared mobility market, allowing for cross-validation of the results. As highlighted by (Jain, 2010), the choice of variables to be used in the cluster analysis is a very important aspect, as they must provide a good representation of the data itself. After several rounds of experimentation, the following variables were chosen: 'number of distinct operators', 'number of distinct modalities', 'number of scooter-sharing operators', 'number of car-sharing operators' and 'number of bike-sharing operators'. These variables represent the competitiveness, comprehensiveness and composition of the local shared mobility provision. Moped and cargo bicycle schemes are left out, because many observations do not contain any of these schemes, resulting in zero-inflated data that complicates heuristic and model-based clustering (Thanataveerat, 2020). However, the variable 'number of distinct modalities' includes information on the comprehensiveness of the supply, so data on moped and cargo bicycle schemes are still indirectly incorporated.

We employed two clustering approaches: k-means and latent class clustering. K-means is a widely known and used partitioning algorithm that is more robust to outliers than the hierarchical clustering approach (Mehta et al., 2020). K-means reiteratively assigns observations to k number of clusters, based on minimising the sum of the squared error, over all clusters k, between the centre of the cluster and the observations belonging to the cluster. The Euclidian distance metric has been used to

Table 2
Summary of shared mobility schemes and providers in Europe.

Data component	Absolute number		
No. cities	311		
No. cities with at least one bike-sharing scheme	220 (70.7%)		
No. cities with at least one car-sharing scheme	233 (74.9%)		
No. cities with at least one scooter-sharing scheme	191 (61.4%)		
No. cities with at least one moped-sharing scheme	51 (16.4%)		
No. cities with at least one cargo bike-sharing scheme	49 (15.8%)		
No. operators	180		
No. bike-sharing operators	56		
No. car-sharing operators	92		
No. scooter-sharing operators	28		
No. moped-sharing operators	19		
No. cargo bike-sharing operators	21		
No. shared mobility schemes	1397		
No. bike-sharing schemes	337		
	Station-based	Free-floating	Hybrid
	180 (53.4%)	137 (40.7%)	20 (5.9%)
Public	**178 (98.9%)**	11 (8%)	**20 (100%)**
Private	2 (1.1%)	**126 (92%)**	0
No. car-sharing schemes	488		
	Station-based	Free-floating	
	319 (65.4%)	169 (34.6%)	
Public	69 (21.6%)	4 (2.4%)	
Private	**250 (78.4%)**	**165 (97.6%)**	
No. scooter-sharing schemes	424		
	Station-based	**Free-floating**	
	2 (0.5%)	**422 (99.5%)**	
Public	1 (50%)	3 (0.7%)	
Private	1 (50%)	**419 (99.3%)**	
No. moped-sharing schemes	86		
	Station-based	**Free-floating**	
	1 (1.2%)	**85 (98.8%)**	
Public	0 (0%)	0 (0%)	
Private	**1 (100%)**	**85 (100%)**	
No. cargo bike-sharing schemes	62		
	Station-based	Free-floating	
	58 (93.5%)	4 (6.5%)	
Public	21 (36.2%)	1 (25%)	
Private	**37 (63.8%)**	**3 (75%)**	

calculate the distance between the mean of the cluster and the observations in the clusters. The algorithm requires an initial value of k, which was determined using the Caliński and Harabasz (1974) index. This index is recognised as one of the most consistent and well-performing indices according to an assessment study by Milligan and Cooper (1985).

In order to validate the structure that has been discovered by using k-means, a latent class cluster analysis (LCCA) has been conducted. This approach is similar to k-means as it also allocates the observations to classes by optimising a certain criterion. However, it is less arbitrary as it uses a statistical model to estimate the parameters (Vermunt and Magidson, 2002). This means that, in contrast to k-means, LCCA assigns a probability to an observation whether it belongs to a certain class, whereas k-means is deterministic and assigns an observation to one cluster only. It presumes that there are latent classes (LC), each having a certain probability density function, that can capture the association between the observations based on their values on a set of indicator variables (Vermunt and Magidson, 2002). In our case, the latent variable is the market structure of shared mobility, which indicates how the local markets for shared mobility in Europe are structured. The mathematical formulation of the latent class cluster model is

$f(y_i|\theta) = \sum_{k=1}^{K}\pi_k \prod_{j=1}^{J} f_k\left(y_{ij}|\theta_{jk}\right)$. It denotes the distribution of an observation's values on a set of indicators, y_i, given the model parameters θ. K is the number of classes or clusters, J is the number of indicators, and π_k denotes the prior probability of belonging to latent class k. As can be seen, the probability distribution is assumed to be a mixture of densities of latent classes k, $f_k\left(y_{ij}|\theta_{jk}\right)$ (Vermunt and Magidson, 2003). An observation will be assigned to the class with the highest posterior probability $\pi_{k|y_i}$. The estimation of this model only includes the indicators, which are depicted above and are the same as the ones being used in the k-means clustering. Selecting the optimal model means that the optimal number of classes and the form of the model, given the number of clusters, should be determined. An advantage of the LC statistical model is that it can select the optimal model based on statistical information criteria, such as Bayesian Information Criterion (BIC) and Integrated Completed Likelihood (ICL) (Fraley and Raftery, 1998). This study uses the BIC and ICL to decide upon the optimal number of classes, as it has been proven a good indicator by several studies (Magidson and Vermunt, 2004; Nylund et al., 2007).

Subsequently, it is possible to cross-validate with the optimal number of clusters determined by the Calinski and Harabasz index during the k-means clustering approach. We used the R-package *mclust* (Scrucca et al., 2023) to estimate and select the appropriate LCCA model. This package employs the widely used Expectation-Maximisation (EM) algorithm (Dempster et al., 1977) to estimate the parameters based on the maximum likelihood method.

The resulting clusters and classes from the k-means and LCCA, respectively, are compared by assessing the number of clusters and the assignments of observations to specific clusters. The clustering approach that yields the most interpretable results is selected for further analysis.

After this clustering and validation stage, the comparison between the clusters is done based on their contextual characteristics. The median values of the covariates, together with the shares of the local shared mobility mix are used as basis to interpret the results. We assess the significance of the covariates between the clusters using the nonparametric statistic Dunn's test, a multiple comparison test, to identify which clusters are significantly different from each other for a given covariate (Dunn, 1964).

4. Results

This section consists of two parts. First, descriptive statistics regarding the dataset are presented, offering an overview of the European shared mobility landscape. Second, the results of the clustering and comparative analysis are described.

4.1. Diffusion of shared mobility systems in European cities

After the data preparation, which involved removing cities with a population under 100,000, the final dataset comprises 311 cities with at least one sharing scheme. This represents 80.4% of European cities with populations exceeding 100,000, according to the dataset of the Joint Research Centre (JRC) (Florczyk et al., 2019). The dataset encompasses 180 unique shared mobility operators, consisting of 56 bike-sharing, 92 car-sharing, 28 scooter-sharing, 19 moped-sharing and 21 cargo bike-sharing providers. Additionally, 30 operators are multimodal, meaning they have more than one modality in their offering. In total, the dataset includes 1397 shared mobility schemes, encompassing 337 bike schemes, 488 car schemes, 62 cargo bike schemes, 86 moped schemes and 424 scooter schemes.

Table 2 summarises the dataset, further indicating the share of station-based, free-floating and hybrid schemes, and the division between public and private operations. To increase the readability of the table, the highest numbers are marked for each category of modality.

Bike sharing is mainly provided in station-based form, which is characterised by nearly exclusive public sector involvement. In contrast, free-floating, which also holds a significant market share, is dominated by private actors. Similarly, car sharing is primarily station-based, having a rather high share of private involvement. Free-floating car sharing, however, is almost solely provided by private actors. Regarding scooters and mopeds, the free-floating model is almost exclusively adopted, with operations primarily managed by private organisations. Cargo bike sharing, on the other hand, relies heavily on a station-based model, with a more balanced involvement of both public and private actors, albeit with a predominant presence of private operators. Overall, private operators are providing the majority of shared mobility schemes across Europe, except in the case of station-based and hybrid bike sharing, and to a lesser extent, station-based car and cargo bike sharing.

When examining the operators, it is remarkable that there are relatively few providers for scooters and free-floating bicycles, while there is a high number of car sharing providers, taking into consideration the number of schemes (see Fig. 1). This suggests a certain concentration of larger players in the scooter and free-floating cycling market.

When examining the five largest operators for each modality, the indications from Fig. 1 are confirmed. Appendix A presents the distribution of provided schemes by these major operators. The large operators dominate the scooter-sharing market, along with the cargo bike-sharing market and, to a lesser extent, the moped-sharing market. Furthermore, it is remarkable that the largest car- and bike-sharing organisations often operate with public involvement. Notably, the largest free-floating bike-sharing operators are also prominent in the scooter-sharing market, suggesting a synergy between these two modalities.

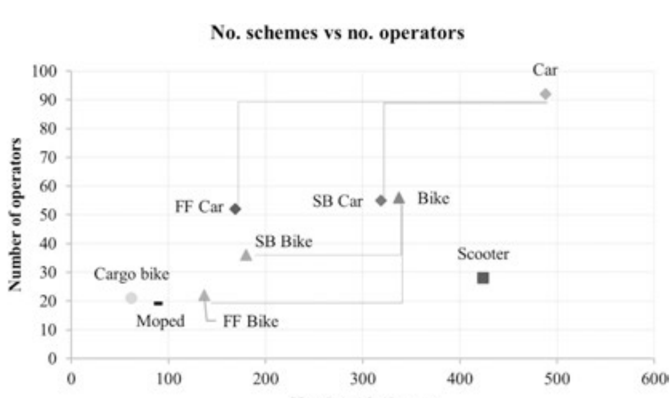


Fig. 1. The share of modes in total schemes and operators.

Fig. 2 illustrates the geographical distribution of these major operators per modality. In the scooter-sharing market, the five largest operators are spread across Europe, competing in the same markets without limiting their operations to certain parts of Europe. Regarding bike sharing, there is a division between SB and FF operators. While one SB operator, Nextbike, operates across Europe, Call-a-bike is limited to Germany. The remaining three FF operators are spread across Europe, except for Eastern Europe, where there is almost no presence of FF bike-sharing operators. The five largest cargo bike-sharing operators primarily operate within their respective countries, notably in the Netherlands, Belgium, Germany, Switzerland and Austria. In most cities, only one of the CBS operators is active. Similarly, moped-sharing operators focus on a limited number of countries, with two operators active in Southern and Western European countries, such as Spain, Portugal, France and Italy, and the remaining three operators heavily focused on the Netherlands. The five largest car-sharing operators also do not operate cross-border. There are local champions in the Netherlands, France, UK and Germany, only operating in those countries. In summary, while the largest operators in scooter and bike sharing span several parts of Europe, there is a more localised focus for major operators in the other modalities. The subsequent section delves into the results of the cluster analyses, contributing to a better understanding of the market structure.

4.2. Nine clusters segmenting the European market of shared mobility

Both latent and k-means clustering analysis found nine clusters as optimal solution.

Table 3 presents the results of the indices used to estimate this optimum, being the Bayesian Information Criterion (BIC) and Integrated Completed Likelihood (ICL) for LCCA and Calinski and Harabasz-index for the k-means clustering. However, the actual assignment of observations (i.e. cities) to a cluster differed between the results of the LCCA and k-means. There were 283 observations placed in the same cluster by both approaches, meaning only 28 observations were assigned to a different cluster and an overlapping share of 91%. This high percentage demonstrates the robustness of the clusters. When considering the observations that were not assigned to the same cluster, the k-means results proved to be more interpretable. Therefore, the results of the k-means clustering are being adopted. The values for the different characteristics in terms of shared mobility offer and the median values of the contextual characteristics are presented in Table 4. The clusters are labelled according to the distribution of the various shared modalities, the comprehensiveness of the offer and the competitiveness. The first term of the label indicates the dominant modality(ies) and scale of the offer, while the second term indicates the extent of the number of operators. The clusters' labels are the following: 'Minor BS, minimal competition', 'Minor CS, minimal competition', 'Minor SS, minimal competition', 'Minor BS+CS, minimal competition', 'Minor BS+SS, average competition', 'Minor CS+SS, average competition', 'Encompassing multimodal, average competition', 'Encompassing multimodal excluding SS, large competition' and 'Comprehensive multimodal, large competition'. The geographical location of the clusters is presented in *Fig. 3*. The following paragraphs describe both the indicators of the local shared mobility provision and the contextual characteristics of the clusters, for which the difference between the clusters has been assessed using Dunn's test (see **Appendix B – Covariates Dunn test**).

4.2.1. Minor car sharing (SB), minimal competition

This cluster comprises 40 cities, representing 12.9% of the dataset. The shared mobility offerings in these cities primarily consists of car sharing, provided by one (or two) sole operators, predominantly using a station-based model (92.6%), with limited free-floating schemes (7.4%). The share between private and public schemes is 87.2% and 12.8% respectively. Geographically, 62.5% of these cities are situated in the United Kingdom, where Enterprise Car Club is prominent. There are no significant differences in covariates between this cluster and others, except for higher average precipitation and lower temperature levels compared to three other clusters.

4.2.2. Minor scooter sharing, minimal competition

The second cluster consists of 32 cities, depicting a share of 10.3%, that exclusively offer a scooter-sharing scheme operated by one (or two) operators. As scooter sharing is almost solely provided in a free-floating, private model, this cluster only includes private schemes. The majority of these cities are situated in Eastern and Southern Europe, where Bolt and Lime are dominant, together being present in 53.2% of the cities in this cluster. The cities in this cluster have significantly lower GDP per capita compared to five other clusters and fewer tourists compared to three other clusters.

4.2.3. Minor bike sharing (SB), minimal competition

The 22 cities belonging to this cluster (7.1% of the sample) primarily offer one station-based bike-sharing scheme, with a small share of cities also encountering moped sharing. In the case of bike sharing, there is, on average, one public operator. Mainly French cities are part of this cluster, but unlike the two previous clusters, there are no providers prevailing in this cluster. Nextbike is the largest operater, covering 18.5% fo the cities. The cities are characterised by a high number of cars and a high temperature, as these covariates are significantly higher compared to five other clusters.

4.2.4. Minor bike and car sharing, minimal competition

This is the first segment of cities to have a multimodal offer, mainly bike- and car-sharing schemes. It contains 40 cities, representing a 12.9% share. The bike-sharing schemes are almost exclusively operated by a public operator, with a share of 77.5% station-based and 22.5% free-floating. This is similar to car sharing, where the share between station-based and free-floating is 80.4% and 19.6% respectively. However, almost all car-sharing schemes are operated by a private entity. The municipalities are mainly located across three countries, the Netherlands, the UK and France. There are no dominant players in this cluster; however, for the aforementioned countries, there are prominent national actors. Comparable with the cluster 'minor CS, minimal competition', these cities do not display a significant difference in terms of their covariates, except for higher average precipitation levels compared to five other clusters.

4.2.5. Minor bike and scooter sharing, average competition

Comparable with the previous cluster, this cluster includes 24 cities (a sample share of 7.7%) having two modalities, namely bike- and scooter-sharing schemes. In this cluster, there is a considerably high share of free-floating bike sharing (46.9%), but the majority of bike-sharing schemes are still station-based (53.1%). These shares are also

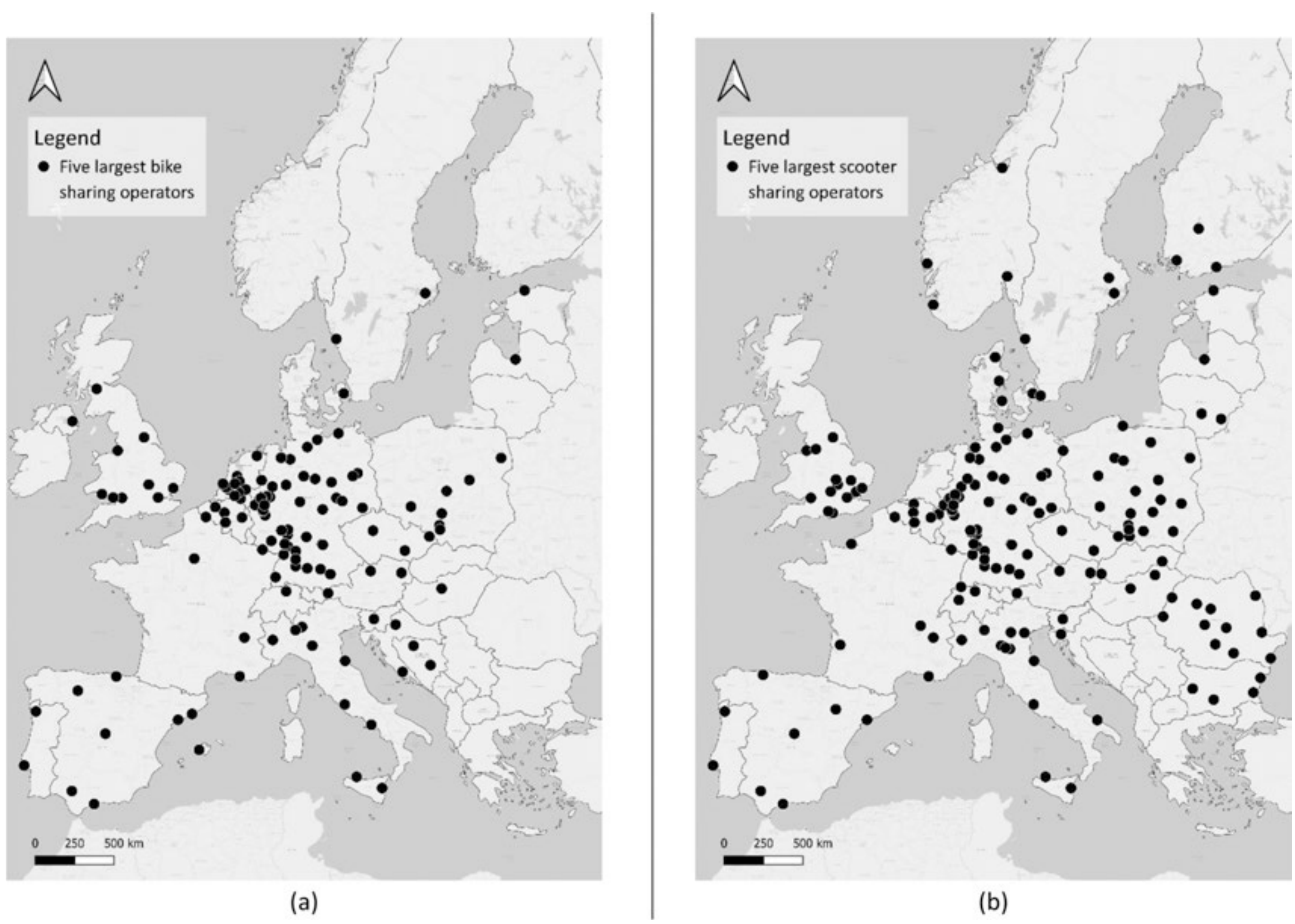


Fig. 2. Maps of the five largest operators for (a) bike sharing, (b) scooter sharing, (c) car sharing and (d) moped and cargo bike sharing.

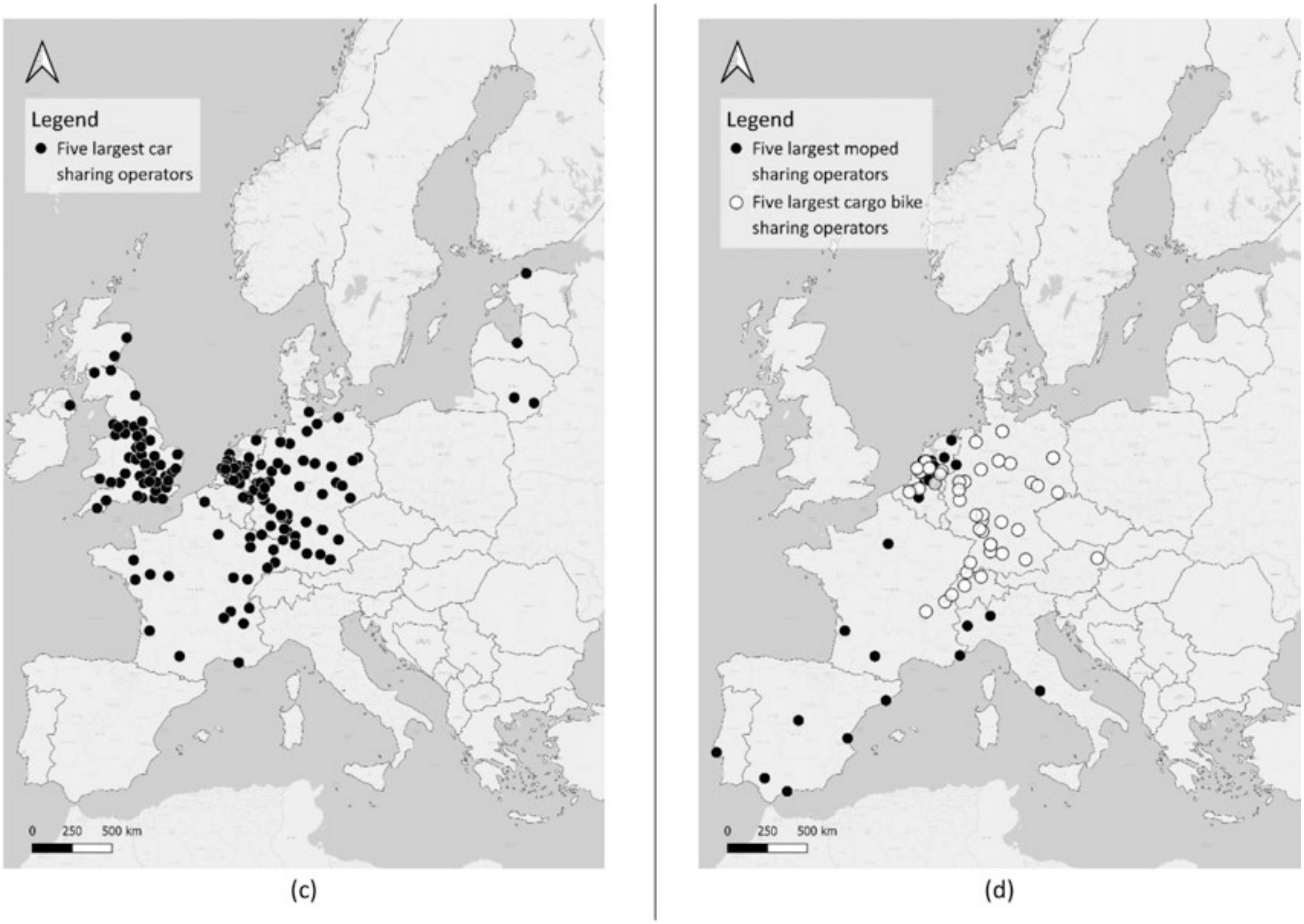


Fig. 2. (*continued*).

Table 3
LCCA and K-Means Model Fit.

No. of classes/ clusters	Bayesian Information Criterion (BIC)	Integrated Completed Likelihood (ICL)	Calinski and Harabasz index
1	709.79	709.79	/
2	702.14	702.82	161.36
3	239.68	240.01	193.13
4	−249.21	−249.10	252.70
5	−536.24	−536.234	220.43
6	−978.75	−978.75	271.97
7	−1081.51	−1067.86	247.91
8	−984.95	−951.72	320.46
9	**−1476.70**	**−1471.92**	**496.78**
10	−1384.84	−1364.80	460.09

reflected in the division between private and public bike-sharing operators, being 43.7% and 56.3%, respectively. As previously mentioned, scooter sharing almost exclusively consists of privately operated free-floating schemes. Contrasting the previous clusters, there are several operators for one (or both) of the modalities, introducing some competition. Geographically, this cluster includes mainly Southern and Eastern-European cities, with a high concentration of Italian cities (29.2%). The cluster does not encounter dominant actors, however the largest operators are multimodal, providing both free-floating scooter and bike sharing. This cluster is not characterised by a significant indicator, except for the share of families, as this is significantly higher compared to four other clusters.

4.2.6. *Minor car and scooter sharing, average competition*

This cluster consists of 19 cities having both car- and scooter-sharing schemes, representing 6.1% of the sample. Remarkably, the share of free-floating car sharing is considerably higher (44.4%) compared to the previous clusters. As expected from a free-floating focused cluster, the share of privately operated schemes (both scooter and car sharing) is high (91.3%). Similar to the previous cluster, there are several operators per modality, but competition is less expected between the modalities. The cities belonging to this cluster are mainly situated in Poland, Germany or the UK. The car-sharing operators tend to focus on one specific country, while the scooter-sharing operators are active in multiple countries. This cluster contains cities having lower temperature levels compared to four other clusters.

4.2.7. *Encompassing multimodal, average competition*

This is the first cluster that includes the three main shared modalities, namely bike, car and scooter sharing. It is the largest cluster, containing 73 cities, which indicates a share of 23.5%. The weight of schemes in this cluster indicates that scooter and car sharing represent a larger share (35.8% and 34.1%, respectively) compared to bike sharing (25.6%). Unlike the previous clusters, the share of free-floating bike and car sharing decreases again (33% and 32% respectively). This is also reflected in the ratio between public and private schemes, where public bike-sharing schemes represent a share of 70.1% (private 29.9%) and public car-sharing schemes 22.4% (private 77.6%). For certain cases, there are several operators per modality, but there can also be competition on one modality and only one operator for the other modalities. In this regard, there are no dominant providers in this cluster, but the

Table 4
Within-cluster market-indicators' and covariates' median values.

Cluster / Market Indicators	Dataset	Cl1: Minor CS, min. comp.	Cl2: Minor SS, min. comp.	Cl3: Minor BS, min. comp.	Cl4: Minor CS + BS, min. comp.	Cl5: Minor BS + SS, avg. comp.	Cl6: Minor CS + SS, avg. comp.	Cl7: Multimodal, avg. comp.	Cl8: Multimodal, excl. SS, large comp.	Cl9: Comprehensive multimodal, large comp.
Number of cities (share %)	311	40 (12.9%)	32 (10.3%)	22 (7.1%)	40 (12.9%)	24 (7.7%)	19 (6.1%)	73 (23.5%)	18 (5.8%)	43 (13.8%)
Prevalent countries		UK (62.5%)	Romania (31.3%)	France (40.9%), Spain (22.7%)	France (27.5%), UK (22.5%), Netherlands (15%)	Italy (29.2%), Spain (20.8%)	Germany (26.3%), UK (26.3%), Poland (21.1%)	Germany (32.9%), UK (16.4%)	Netherlands (77.8%)	Germany (48.8%)
Largest operators		Enterprise Car Club (43.6%)	Bolt (31.9%), Lime (21.3%)	Nextbike (18.5%), JcDecaux (11.1%)	Enterprise (9.1%), Citiz (8.1%), Nextbike (7.1%)	Bolt (12.3%), TIER (9.9%), Lime (8.6%)	TIER (13.4%), Bolt (10.4%), Enterprise Car Club (7.5%)	TIER (11%), Bolt (8%), Nextbike (8%)	GreenWheels, MyWheels (both 10.5%)	Lime, TIER, Bolt (all 8%)
Avg. no. dist. shared modalities	2.39	1.05	1.06	1.14	2.15	2.25	2.21	3.26	3.28	3.81
Avg. no. dist. operators	4.05	1.38	1.47	1.23	2.48	3.38	3.53	4.49	7.39	9.81
Av. of at least one scheme										
BS (%)	70.7%	0%	0%	100%	100%	100%	0%	100%	100%	100%
CS (%)	74.9%	100%	0%	0%	100%	0%	100%	100%	100%	100%
SS (%)	61.4%	0%	100%	0%	0%	100%	100%	100%	0%	100%
MS (%)	16.4%	2.5%	6.3%	13.6%	10%	16.7%	10.5%	9.5%	83.3%	30.2%
CBS (%)	15.8%	2.5%	0%	0%	5%	8.3%	10.5%	16.4%	44.4%	51.1%
Share BS (%)	25.8%	0.0%	0.0%	92.0%	41.3%	38.8%	0.0%	25.6%	36%	20.5%
SB (%)	53.4%	/	/	95.5%	77.5%	53.1%	/	56.2%	34%	42.3%
FF (%)	40.7%	/	/	4.5%	17.5%	46.9%	/	33.7%	66%	49.0%
Hybrid (%)	5.9%	/	/	0.0%	5.0%	0.0%	/	10.1%	0.0%	8.7%
Share CS (%)	37.5%	97.8%	0.0%	0.0%	53.5%	0.0%	52.3%	34.1%	33.3%	35.6%
SB (%)	65.4%	92.6%	/	/	80.4%	/	55.6%	68.0%	71.1%	50.6%
FF (%)	34.6%	7.4%	/	/	19.6%	/	44.4%	32.0%	28.9%	49.4%
Share SS (%)	30.1%	0.0%	97.4%	0.0%	0.0%	54.6%	44.1%	35.8%	0.0%	34.7%
Share MS (%)	4.1%	1.3%	2.6%	8.0%	3.5%	4.9%	1.5%	1.7%	23.0%	3.1%
Share CBS (%)	2.5%	1.0%	0.0%	0.0%	1.7%	1.7%	2.1%	2.8%	7.7%	6.0%
Share private schemes (%)	74.1%	87.2%	100.0%	12.5%	56.8%	74.4%	91.9%	72.4%	85.5%	80.1%
Share public schemes (%)	25.9%	12.8%	0.0%	87.5%	43.2%	25.6%	8.1%	27.6%	14.5%	19.9%
Covariates										
Population	214,435	157,946	192,122	183,749	210,306	166,755	168,020	222,868	220,353	703,529
Land area (km^2)	75	59	52	67.5	69.5	60.5	57	84	87.5	232
Pop. density (Inh./km^2)	3033	3080	3638	2921	3082	3070	3129	2936	3194	2927
GDP P/C (€/Inh.)	18,052	16,333	12,492	17,057	18,079	15,350	14,929	19,267	24,163	22,760
Househ. w. children (%)	24%	28.5%	26%	23%	22%	29%	24%	23%	22%	20%
Higher education (%)	38%	35%	34.5%	38%	38%	28.5%	39%	40.5%	42%	41%

(*continued on next page*)

Table 4 (*continued*)

Cluster **Market Indicators**	Dataset	Cl1: Minor CS, min. comp.	Cl2: Minor SS, min. comp.	Cl3: Minor BS, min. comp.	Cl4: Minor CS + BS, min. comp.	Cl5: Minor BS + SS, avg. comp.	Cl6: Minor CS + SS, avg. comp.	Cl7: Multimodal, avg. comp.	Cl8: Multimodal, excl. SS, large comp.	Cl9: Comprehensive multimodal, large comp.
Students (per 1000 inh.)	95.5	114	81	95	94	81	138	120	63	95
Tourists (nights/inh.)	4.0	4.5	2.0	4.0	4.5	4.0	4.0	4.0	6.0	5.0
Cars (per 1000 inh.)	429	431	482	485	450	464	411	415	366	400
Cycling infra. (meters/km^2)	480	657	350	174	503	350	682	532	3056	303
Temp. (°C)	10.7	10.2	12.3	12.4	10.7	13.8	9.9	10.1	10.7	10.7
Precip. (mm)	757	819	660	757	893	763	681	730	799	665
Elevation (m)	68.4	67.7	118.4	63.5	55.2	68.1	78.6	86.4	10.8	97.4

largest operators are free-floating bike- and scooter-sharing organisations. This cluster has a large geographical spread, covering many European countries, but the focal point is in Germany (34.3% of the cities are German). This cluster is not characterised by a particular covariate.

4.2.8. *Encompassing multimodal excluding scooter sharing, large competition*

The 18 cities belonging to this cluster (5.8% of the sample) are providing a range of modalities, but excluding scooter sharing. Instead, there is a large share of moped-sharing schemes (23%) and free-floating bike-sharing schemes (66% compared to 34% station-based bike sharing). There is also a small, not negligible, share of cargo bike-sharing schemes (7.7%). The average number of operators per city is quite high, indicating competition between and within modalities. When considering the location of the cities, they are practically all situated in the Netherlands, with the exception of large cities such as Paris, Barcelona and Dublin. The dominant operators are the local Dutch moped, car and bicycle providers. This cluster has significantly higher GDP per capita, more bicycle infrastructure, higher car ownership, and lower elevation levels.

4.2.9. *Comprehensive multimodal, large competition*

The last cluster contains 43 cities, representing a share of 13.8%, with the most comprehensive provision of shared mobility, averaging four different sharing modality types offered by many operators. Free-floating bike and car sharing have increased shares (both 49%). Car- and scooter-sharing schemes dominate (35.6% and 34.7% respectively), while moped-sharing schemes are less present (3.1%). Similar to the previous cluster, there is high competition between and within modalities. In this regard, the largest operators are free-floating scooter- and bike-sharing operators. This cluster is geographically spread across Europe, with a concentration in Germany. The other cities are capitals or major cities within a country. This is also confirmed in the characterisation of this cluster, which represents cities having a significantly higher GDP per capita, a lower share of families and a lower car ownership.

The analysis reveals a scattered European shared mobility landscape structured in nine distinct clusters (see **Appendix C** for the cluster allocations). Each cluster represents a certain shared mobility offer, ranging from minimal provision provided by a single operator to comprehensive shared mobility services provided by multiple operators. The comparative analysis indicates that certain variables are distinctive for specific clusters, providing insights into the factors influencing shared mobility provision in different cities. The next section will discuss these results and present possible explanations for this geographic and market structure.

5. Discussion

This paper discovered that the current market for shared mobility in larger European cities can be structured according to nine segments based on the results of two clustering approaches. The objective was better to understand the distribution of various types of sharing schemes to provide a reference dataset that can be used to assess the market's future development and to identify the opportunities and risks of the current market structure. Furthermore, this dataset helps to understand the usage patterns that can be expected from these compositions of local shared mobility supply and to learn which cities' characteristics are indicators for a city's attractiveness towards certain types of shared mobility providers.

As anticipated, the market is evolving at varying speeds. A significant number of municipalities have only one sharing scheme available. This pattern is visible in numerous UK cities, where there is typically one local station-based car-sharing provider; in many French, Spanish and Italian cities, where typically the public authority has invested in a bike-sharing scheme; and in less economically developed Eastern and

Southern European cities, where international scooter-sharing operators are active. Nonetheless, shared mobility is well-established in Europe, with 80.4% of cities over 100,000 inhabitants having at least one sharing scheme, and 69.7% of these 311 cities belong to clusters where there is more than one modality type available. A multimodal mix is beneficial, as different modalities and schemes can strengthen each other through increased awareness about shared mobility, which positively affects the usage intention and provides complementary use cases.

Considering the potential mobility patterns induced by the various provisions of shared mobility services established within the different clusters, there are certain aspects that need consideration. Scooter sharing dominates as a micro-mobility scheme across clusters, generating the risk of substitution mainly for walking, cycling, and public transport trips. However, the widespread availability of these services also initiates awareness regarding the lack of infrastructure for active mobility (International transport Forum, 2023). On the other hand, bike sharing is available in more cities, often with local authority involvement in station-based schemes. This generates opportunities to complement public transport, provided there is sufficient bike-sharing station density. However, this requires high investments, posing a risk of suboptimal service if local authorities lack financial resources. Car sharing's widespread availability across clusters offers numerous citizens an alternative to private car use, a role cargo bike sharing could also play, but it is underrepresented in most clusters. Therefore, this should be a focal point for local authorities when considering the further development of (public) shared mobility services.

Subsequently, the clusters' contextual characteristics contribute to a better understanding of the factors considered by the various types of both public and private providers. Private organisations drive the rapid development of shared mobility across Europe, except for station-based bike sharing, which is predominantly public due to high upfront infrastructure investment costs. It is assumed that primarily larger and richer municipalities would invest in such a system. Surprisingly, certain smaller municipalities, particularly in France, also invest in such systems. These municipalities, which only have the public bike-sharing scheme available as shared mobility, belonging to cluster 3, are seemingly looking for initiatives to stimulate sustainable mobility, as car ownership is particularly high in these areas. However, public bike-sharing schemes are often initiated to show dedication towards sustainable urban mobility so that other, more complex and resisting transport policy measures can be disregarded (Médard De Chardon, 2019). Contrastingly, the other two clusters with one single modality (i.e. CS or SS) include primarily privately operated schemes. Interestingly, the cluster with small scooter-sharing schemes comprises mainly less economically developed Eastern and Southern European municipalities, contrary to expectations that international scooter-sharing operators would target tourist-rich, affluent, and dense cities. As stated before, these major cities impose more and stricter regulations on particularly scooter schemes, which reduces the attractiveness and access to such cities. Certain scooter-sharing operators seem to be shifting or expanding to smaller, less economically developed municipalities, which have put less restrictive measures in place. In this regard, scooter-sharing operators are also diversifying their offer. While the number of multimodal operators is still relatively low, more and more larger operators

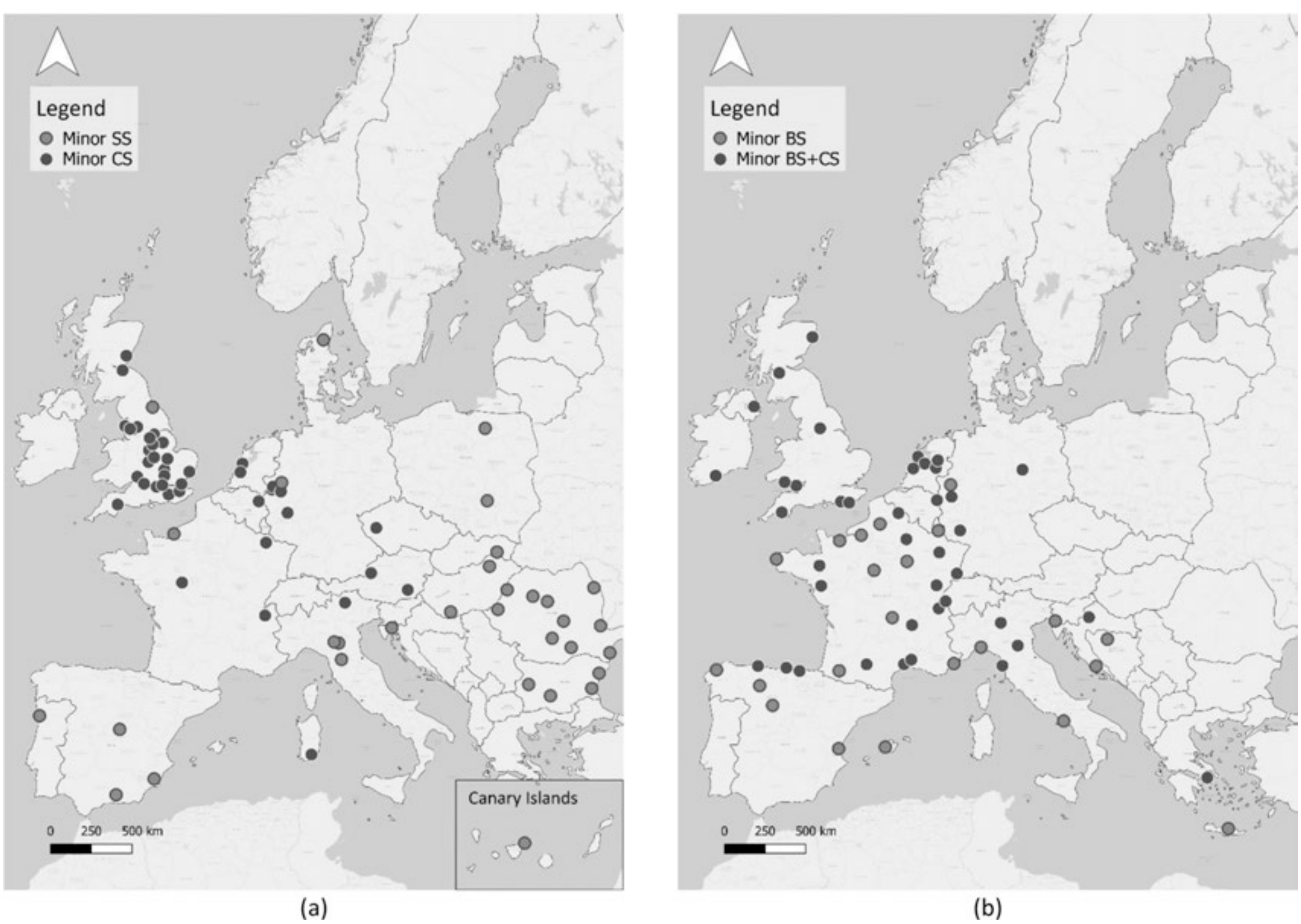
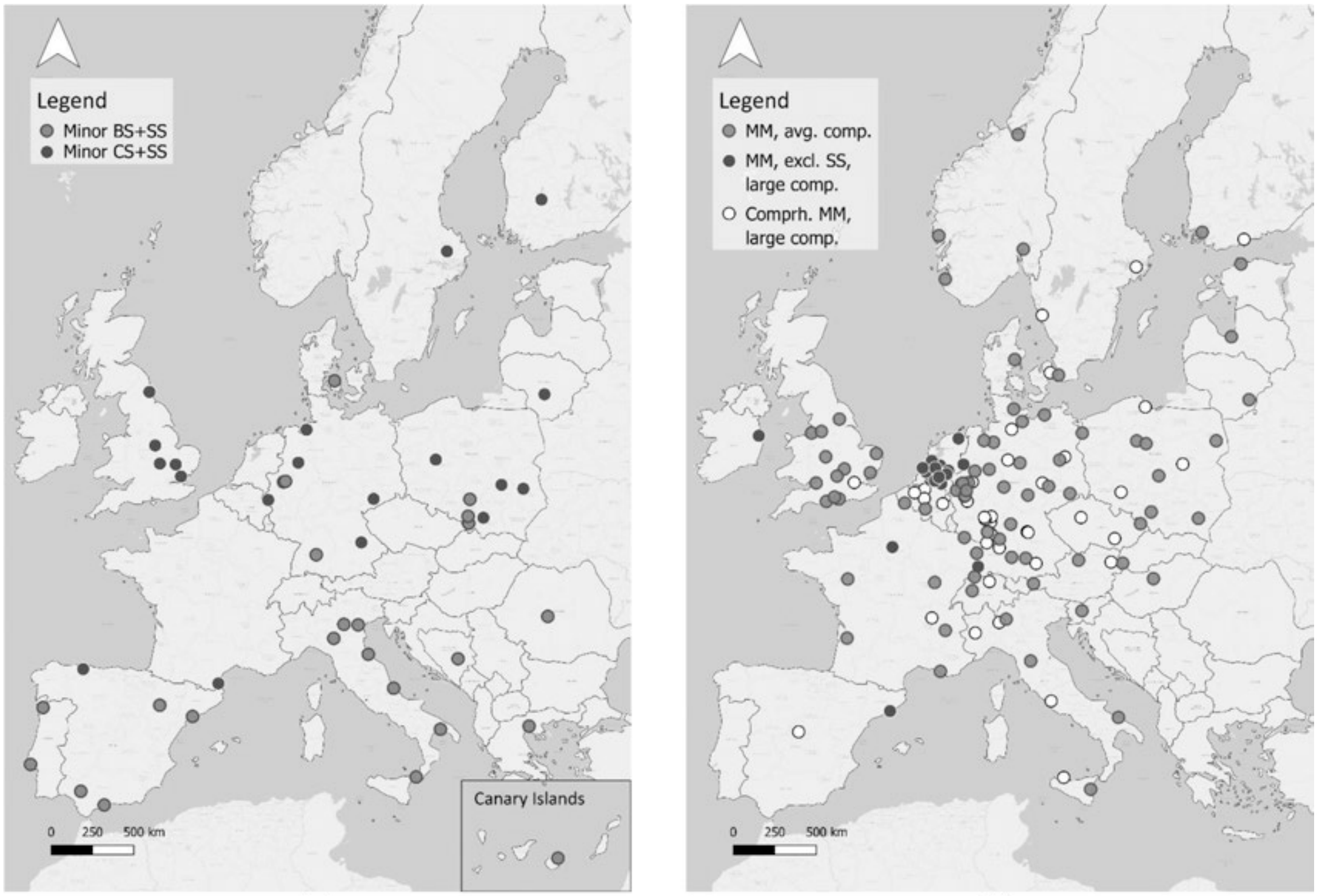


Fig. 3. Maps of distribution of (a) cluster 1 and 2, (b) clusters 3 and 4, (c) clusters 5 and 6, and (d) clusters 7, 8 and 9.



(c) (d)

Fig. 3. (*continued*).

are expanding their types of modalities to provide vehicles for different use cases and convince public authorities of their added value. However, as free-floating schemes are particularly confronted with problems related to cluttering and vandalism, the hybrid model is being tested (or imposed by local authorities). This either requires the user to park the shared vehicle in a virtual designated drop-off zone or attach it to existing infrastructure (such as bike racks). The dataset shows that this model is already established within bike sharing, possibly because this mode, in the past, had encountered many problems with its free-floating model. Furthermore, the presence of a free-floating scheme seems to attract other free-floating schemes, as indicated in clusters 5 and 6, where free-floating scooter sharing is available. In these clusters, the share of free-floating bike sharing and car sharing, respectively, increases compared to cluster 4 in which scooter sharing is not present. When regulations forbid scooter sharing, e.g., in the Netherlands and Paris, other free-floating modalities, such as mopeds and bicycles, enter the market and act as surrogates for scooters, supported by favourable conditions for shared mobility such as strong economic development, active mobility infrastructure and less established car culture. This enables a broad offer of shared mobility, even if these cities do not have a particularly high population. However, the most comprehensive provision of shared mobility is found in the largest cities across Europe, where Germany is a frontrunner. These cities, belonging to cluster 9, have a very favourable market in terms of GDP per capita, population, and target groups and thus have access to several types of modalities and operators per modality. They are typically confronted with major mobility problems (such as congestion, noise pollution and traffic accidents), so it can be imagined that they intensively look for and pilot innovative mobility services and remain open to numerous operators. Furthermore, all cities in the largest market segment have invested in a public bike- and/or car-sharing scheme, mitigating the risk of losing certain types of shared mobility if private operators retract from the local market.

As previously mentioned, scooter- and free-floating bike-sharing segments are dominated by a few actors. Their exit could leave many municipalities without shared mobility options or with a monopolistic single operator. In 2023, there have been several large international operators of scooters and bicycles simultaneously exiting a significant number of markets due to unprofitable circumstances, such as Bird (Bellan, 2022), Superpedestrian (Korosec and O'Kane, 2023) and TIER (Partington and Billing, 2023).

Regarding moped, car and cargo bike sharing, the large operators seem to be local champions, mainly providing services in their country. This could possibly be attributed to the aspect of scalability, as the asset costs (i.e. vehicles) are higher compared to bicycles and scooters (Heineke et al., 2020), which adds to the economic risk of extending to other cities with a different national context. Especially for car sharing, local champions also seem willing to provide their service in smaller cities with less favourable conditions. The impact when such a national operator stops is limited to a number of local markets, compared to the case of an international operator halting its operations.

Nonetheless, shared mobility is still a difficult market in which to operate a profitable service. There are many complexities, such as the variety of regulatory frameworks that have to be complied with. Despite these market challenges, the sector is maturing; private operators are slowing expansion, consolidation is occuring within and between types of operators (e.g. the merger between Nextbike, a station-based bike-sharing operator, and TIER, a free-floating scooter- and bike-sharing operator) in search for synergies and economies of scale, and public authorities are actively considering how they can participate or steer the local shared mobility market. Our results indicate that there are still considerable opportunities for certain municipalities to broaden their shared mobility provision, especially with regard to cargo bike sharing, which could induce travel behaviour replacing private car trips. Furthermore, the large number of clusters having a multimodal provision indicates that synergies between services should be further explored, potentially through technological advancements such as mobility platforms (e.g. MaaS) and physical infrastructure such as mobility hubs and infrastructure for active mobility.

6. Conclusion

This study offers a comprehensive overview of the shared mobility market in Europe, providing an explorative analysis regarding the different shared mobility service providers, their shared mobility modes, their business models and their operational areas. An underlying structure of this market was discovered, indicating that there are nine different clusters of shared mobility systems in European cities, ranging from a minor to an extensive, all-encompassing shared mobility offer, served by a very limited to a very large number of service providers. The comparison between the clusters' characteristics suggests that the city's market potential, indicated by demographics such as population, population density and income, gives an indication of how extensive its shared mobility ecosystem is.

These results are particularly interesting in light of the evolving landscape that shared mobility is. For operators, the results are particularly interesting to see where opportunities (i.e. in which areas/regions/cities) arise to start a shared mobility service. This is valid for operators of all modes and models, as this research created a unique database that contains, to the knowledge of the authors, all operators, their modes, their models and their operational areas.

Furthermore, it is of interest for policymakers to see how the current landscape of shared mobility in Europe is formed, and how it will further develop itself. This could support them in adopting regulations that either reinforce or restrict certain developments in the market. Furthermore, city officials could look at the characteristics of their city and compare them to the characteristics of the clusters. If their market potential is unfavourable, they can further investigate approaches that could improve their shared mobility ecosystem and study similar cities and their approaches that are part of a different cluster. Also, differences between cities from the same country can alert national policymakers to develop national regulations or communicate with cities in order to reduce this apparent divergence and thus support cities that are falling behind.

The limitations of our study need to be acknowledged. This study did not consider small municipalities (having a population below 100,000) and was not able to take into account the actual extent of the shared mobility provision in terms of the number of vehicles. Furthermore, the lack of information on the institutional context and the public transport system hinders a deeper understanding of why certain cities have a more extensive shared mobility system. National and local legislation significantly determine the attractiveness and openness of a city for shared mobility services (e.g. the Netherlands currently does not allow shared e-scooters to be deployed or used (ANWB, 2024). This does not account only for regulation directly aimed at shared mobility services, but also for regulation impacting on the attractiveness of other non-shared transportation modes (e.g. parking policies, dedicated infrastructure) (Cohen and Shaheen, 2018). This research suggests that large metropolitan areas are taking a forerunner role in developing regulations aimed at exploiting the opportunities shared mobility services offer. Additionally, the quality and extent of the public transport network can influence shared mobility offerings, as public transport and shared mobility have a complex, sometimes complementary and sometimes substitutive, relationship. However, it was not possible to examine on a city-per-city basis the institutional context and current transportation system's performance that could impact the presence of shared mobility services. Therefore, it remains to be seen how including the institutional and public transport context impacts the results of this study. Future research could follow up on the development of the market to see how the various segments will evolve and more thoroughly examine the role of various policy frameworks in that.

Furthermore, the perspective of the operator and its motivation for selecting a city could be studied. This improves the understanding of which tools policy-makers could use in order to attract, exploit the opportunities and optimise the effectiveness of shared mobility services.

Funding

This research is supported by the project “Smart Public Transport Initiatives for Climate-Neutral Cities in Europe” (SPINE).” This project has received funding from the European Union's Horizon research and innovation program under grant agreement ID 101096664.

Author statement

We confirm that this manuscript is original and has not been published elsewhere, nor is it under consideration by another journal.

All authors have approved the manuscript and agree with its submission to Journal of Transport Geography.

We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at elnert.coenegrachts@uantwerpen.be

CRediT authorship contribution statement

Elnert Coenegrachts: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Thierry Vanelslander:** Writing – review & editing, Supervision, Funding acquisition. **Ann Verhetsel:** Writing – review & editing, Supervision, Funding acquisition. **Joris Beckers:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

None.

Data availability

Shared mobility provision in European cities (Original data) (Zenodo)

Appendix A. Five largest operators per modality

Bike sharing operators		Scooter sharing operators		Moped sharing operators		Cargo bike sharing operators		Car sharing operators	
Nextbike (by TIER)	19.9%	**TIER**	22.2%	**Felyx**	15.1%	**Sigo**	27.4%	**Flinkster (Deutsche Bahn)**	10.7%
SB, public		FF, Private		FF, private		SB, private		SB, public	
Call-a-bike (Deutsche Bahn)	8.0%	**Bolt**	21.5%	**Check**	12.8%	**Nextbike (by TIER)**	17.7%	**Enterprise Car Club**	10.2%
SB, public		FF, Private		FF, private		SB, public		SB, private	
TIER	7.4%	**Lime**	16.3%	**Cooltra**	10.5%	**Cargoroo**	14.5%	**Citiz**	5.1%
FF, private		FF, Private		FF, private		SB, private		Mainly SB, mainly private	
Lime	6.5%	**VOI**	13.2%	**Go Sharing**	9.3%	**Baqme**	8.1%	**GreenWheels**	4.5%
FF, private		FF, Private		FF, private		FF, private		SB, private	
Bolt	5.9%	**Dott**	4.7%	**Yego**	9.3%	**Carvelo2go**	8.1%	**Stadtmobil**	4.3%
FF, private		FF, Private		FF, private		SB, private		Mainly SB, private	
Total	**47.8%**	**Total**	**77.8%**	**Total**	**57%**	**Total**	**75.8%**	**Total**	**34.8%**

Appendix B. Covariates Dunn test

Population

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	*p*-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			−0.89	1.00	−1.22	1.00	−2.00	1.00	−0.93	1.00	−0.53	1.00	**−3.16**	**0.05**	−2.50	0.34	**−6.73**	**0.00**
Cl2					−0.40	1.00	−1.00	1.00	−0.11	0.91	0.23	1.00	−1.93	1.00	−1.69	1.00	**−5.43**	**0.00**
Cl3							−0.47	1.00	0.28	1.00	0.56	1.00	−1.23	1.00	−1.21	1.00	**−4.41**	**0.00**
Cl4									0.80	1.00	1.08	1.00	−0.88	1.00	−0.92	1.00	**−4.69**	**0.00**
Cl5											0.31	1.00	−1.61	1.00	−1.50	1.00	**−4.86**	**0.00**
Cl6													−1.84	1.00	−1.71	1.00	**−4.84**	**0.00**
Cl7															−0.33	1.00	**−4.46**	**0.00**
Cl8																	−2.74	0.17

Land Area

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			0.18	1.00	−1.24	1.00	−1.81	1.00	−0.77	1.00	−0.54	1.00	**−3.68**	**0.01**	−2.27	0.59	**−7.26**	**0.00**
Cl2					−1.34	1.00	−1.89	1.00	−0.90	1.00	−0.67	1.00	**−3.62**	**0.01**	−2.33	0.52	**−7.01**	**0.00**
Cl3							−0.29	1.00	0.43	1.00	0.56	1.00	−1.63	1.00	−0.99	1.00	**−4.83**	**0.00**
Cl4									0.79	1.00	0.91	1.00	−1.62	1.00	−0.84	1.00	**−5.41**	**0.00**
Cl5											0.16	0.87	−2.23	0.62	−1.42	1.00	**−5.47**	**0.00**
Cl6													−2.22	0.60	−1.50	1.00	**−5.24**	**0.00**
Cl7															0.31	1.00	**−4.53**	**0.00**
Cl8																	**−3.39**	**0.02**

GDP per capita

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			2.92	0.08	0.19	0.85	−1.04	1.00	0.72	1.00	1.06	1.00	−1.81	0.98	**−3.95**	**0.00**	**−4.06**	**0.00**
Cl2					−2.32	0.37	**−3.91**	**0.00**	−1.88	0.90	−1.37	1.00	**−4.95**	**0.00**	**−6.15**	**0.00**	**−6.79**	**0.00**
Cl3							−1.07	1.00	0.45	1.00	0.78	1.00	−1.68	1.00	**−3.68**	**0.01**	**−3.60**	**0.01**
Cl4									1.62	1.00	1.90	0.93	−0.63	1.00	**−3.12**	**0.04**	−3.00	0.06
Cl5											0.36	1.00	−2.30	0.36	**−4.19**	**0.00**	**−4.23**	**0.00**
Cl6													−2.53	0.22	**−4.30**	**0.00**	**−4.31**	**0.00**
Cl7															−2.90	0.08	−2.78	0.11
Cl8																	0.81	1.00

Population density

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			−2.07	1.00	−0.08	1.00	−0.24	1.00	−0.85	1.00	0.19	1.00	1.12	1.00	−0.75	1.00	−0.04	1.00
Cl2					1.70	1.00	1.85	1.00	1.01	1.00	1.88	1.00	**3.36**	**0.03**	0.95	1.00	2.07	1.00
Cl3							−0.12	1.00	−0.67	1.00	0.24	1.00	0.99	1.00	−0.60	1.00	0.05	1.00
Cl4									−0.64	1.00	0.38	1.00	1.39	1.00	−0.56	1.00	0.21	1.00
Cl5											0.89	1.00	1.87	1.00	0.02	0.98	0.83	1.00
Cl6													0.65	1.00	−0.81	1.00	−0.22	1.00
Cl7															−1.65	1.00	−1.19	1.00
Cl8																	0.73	1.00

Families

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			0.26	1.00	1.54	1.00	2.50	0.33	−0.98	1.00	2.21	0.62	**3.51**	**0.01**	2.76	0.16	**4.19**	**0.00**
Cl2					1.20	1.00	1.98	1.00	−1.14	1.00	1.84	1.00	2.78	0.15	2.37	0.45	**3.49**	**0.02**
Cl3							0.55	1.00	−2.22	0.63	0.64	1.00	1.12	1.00	1.18	1.00	1.91	1.00
Cl4									**−3.12**	**0.05**	0.19	0.85	0.65	1.00	0.81	1.00	1.62	1.00
Cl5											2.82	0.14	**3.97**	**0.00**	**3.30**	**0.03**	**4.56**	**0.00**
Cl6													0.29	1.00	0.55	1.00	1.11	1.00
Cl7															0.40	1.00	1.20	1.00
Cl8																	0.43	1.00

Share of higher educated people

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			0.94	1.00	−0.23	1.00	−1.33	1.00	1.99	1.00	−1.42	1.00	−1.24	1.00	−2.67	0.23	−1.59	1.00
Cl2					−1.02	1.00	−2.05	1.00	0.92	1.00	−2.06	1.00	−2.03	1.00	**−3.17**	**0.05**	−2.28	0.66
Cl3							−0.88	1.00	1.93	1.00	−1.05	1.00	−0.74	1.00	−2.18	0.81	−1.09	1.00
Cl4									3.09	0.06	−0.33	1.00	0.28	1.00	−1.62	1.00	−0.24	1.00
Cl5											−2.94	0.10	**−3.17**	**0.05**	−4.03	0.00	**−3.32**	**0.03**
Cl6													0.58	1.00	−1.14	1.00	0.14	0.89
Cl7															−1.96	1.00	−0.56	1.00
Cl8																	1.45	1.00

Students

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	*p*-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			0.91	1.00	−0.15	1.00	0.46	1.00	1.42	1.00	−1.39	1.00	−1.27	1.00	1.83	1.00	−0.14	1.00
Cl2					−1.02	1.00	−0.53	1.00	0.61	1.00	−2.31	0.66	−2.53	0.37	1.11	1.00	−1.20	1.00
Cl3							0.60	1.00	1.49	1.00	−1.18	1.00	−0.98	1.00	1.88	1.00	0.04	0.97
Cl4									1.12	1.00	−1.94	1.00	−2.07	1.00	1.58	1.00	−0.69	1.00
Cl5											−2.69	0.23	−2.94	0.11	0.51	1.00	−1.73	1.00
Cl6													0.50	1.00	3.00	0.10	1.41	1.00
Cl7															**3.22**	**0.05**	1.34	1.00
Cl8																	−2.14	0.98

Tourists

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			2.83	0.15	−0.03	0.97	0.09	1.00	1.13	1.00	1.30	1.00	0.55	1.00	−0.19	1.00	−0.58	1.00
Cl2					−3.12	0.06	**−3.17**	**0.05**	−1.83	1.00	−1.28	1.00	**−3.31**	**0.03**	−2.29	0.68	**−4.40**	**0.00**
Cl3							0.13	1.00	1.26	1.00	1.42	1.00	0.66	1.00	−0.17	1.00	−0.60	1.00
Cl4									1.19	1.00	1.36	1.00	0.54	1.00	−0.27	1.00	−0.80	1.00
Cl5											0.30	1.00	−0.89	1.00	−1.05	1.00	−2.08	1.00
Cl6													−1.10	1.00	−1.21	1.00	−2.12	1.00
Cl7															−0.60	1.00	−1.64	1.00
Cl8																	−0.20	1.00

Car ownership

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	*p*-value
Cl1			−1.74	1.00	**−3.22**	**0.03**	−0.23	1.00	−2.55	0.23	0.74	1.00	1.04	1.00	2.79	0.12	1.84	1.00
Cl2					−1.33	1.00	1.56	1.00	−0.77	1.00	2.16	0.56	2.75	0.13	**3.95**	**0.00**	**3.32**	**0.03**
Cl3							3.05	0.06	0.54	1.00	**3.43**	**0.02**	**4.34**	**0.00**	**5.17**	**0.00**	**4.80**	**0.00**
Cl4									−2.38	0.35	0.93	1.00	1.30	1.00	2.98	0.07	2.09	0.63
Cl5											2.85	0.10	**3.58**	**0.01**	**4.58**	**0.00**	**4.09**	**0.00**
Cl6													0.00	1.00	1.81	1.00	0.73	1.00
Cl7															2.24	0.47	1.04	1.00
Cl8																	−1.41	1.00

Cycle network density

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			1.13	1.00	2.82	0.14	0.92	1.00	1.21	1.00	−0.07	1.00	0.57	1.00	−1.85	1.00	2.03	1.00
Cl2					1.86	1.00	−0.37	1.00	0.02	0.99	−1.24	1.00	−0.88	1.00	−3.09	0.06	0.74	1.00
Cl3							−2.37	0.48	−1.93	1.00	−2.96	0.09	−2.95	0.09	**−4.61**	**0.00**	−1.49	1.00
Cl4									0.42	1.00	−1.05	1.00	−0.60	1.00	**−3.18**	**0.05**	1.37	1.00
Cl5											−1.33	1.00	−1.00	1.00	**−3.31**	**0.03**	0.79	1.00
Cl6													0.69	1.00	−1.84	1.00	2.21	0.68
Cl7															−3.06	0.07	2.29	0.57
Cl8																	**4.45**	**0.00**

Temperature

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			**−4.08**	**0.00**	**−5.44**	**0.00**	−2.75	0.14	**−4.18**	**0.00**	1.02	1.00	−0.63	1.00	−2.18	0.49	−1.89	0.93
Cl2					−1.72	1.00	1.48	1.00	−0.41	1.00	**4.32**	**0.00**	**3.97**	**0.00**	1.18	1.00	2.36	0.33
Cl3							**3.13**	**0.04**	1.24	1.00	**5.52**	**0.00**	**5.43**	**0.00**	2.59	0.20	**3.92**	**0.00**
Cl4									−1.80	1.00	**3.23**	**0.03**	2.49	0.24	−0.02	0.99	0.90	1.00
Cl5											**4.44**	**0.00**	**4.06**	**0.00**	1.47	1.00	2.60	0.21
Cl6													−1.59	1.00	−2.75	0.14	−2.54	0.22
Cl7															−1.88	0.89	−1.52	1.00
Cl8																	0.73	1.00

Precipitation

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			**4.60**	**0.00**	1.27	1.00	−1.18	1.00	2.31	0.48	**3.65**	**0.01**	2.78	0.15	0.90	1.00	**3.80**	**0.00**
Cl2					−2.73	0.17	**−5.72**	**0.00**	−1.83	1.00	−0.26	1.00	−2.57	0.26	−2.84	0.13	−1.11	1.00
Cl3							−2.26	0.52	0.88	1.00	2.17	0.63	0.87	1.00	−0.26	1.00	1.90	1.00
Cl4									**3.33**	**0.02**	**4.59**	**0.00**	**4.12**	**0.00**	**5.00**	**0.00**	**3.33**	**0.02**
Cl5											1.37	1.00	−0.21	0.83	−1.10	1.00	0.93	1.00
Cl6													−1.82	1.00	−2.31	0.50	−0.66	1.00
Cl7															−1.11	1.00	1.49	1.00
Cl8																	2.06	0.79

Elevation

	CL1-minor CS		Cl2-minor SS		Cl3-minor BS		Cl4-BS + CS		Cl5-BS + SS		Cl6- CS + SS		Cl7-multimodal		Cl8-multimodal excl. SS		Cl9-Large multimodal	
	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	*p*-value	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Cl1			−1.76	1.00	−0.73	1.00	0.54	1.00	−0.37	1.00	−0.71	1.00	−0.79	1.00	**3.46**	**0.02**	−1.36	1.00
Cl2					0.81	1.00	2.27	0.65	1.19	1.00	0.76	1.00	1.24	1.00	**4.75**	**0.00**	0.51	1.00
Cl3							1.19	1.00	0.33	1.00	−0.01	0.99	0.16	1.00	**3.70**	**0.01**	−0.40	1.00
Cl4									−0.84	1.00	−1.14	1.00	−1.40	1.00	3.03	0.07	−1.91	1.00
Cl5											−0.33	1.00	−0.25	1.00	**3.46**	**0.02**	−0.80	1.00
Cl6													0.16	1.00	**3.59**	**0.01**	−0.37	1.00
Cl7															**4.32**	**0.00**	−0.75	1.00
Cl8																	**−4.57**	**0.00**

Appendix C. Cluster allocation

Cluster 1: 'Minor car sharing (SB), minimal competition'

Annecy; Bedford; Blackburn; Blackpool; Bolzano; Burnley; Cagliari; Coventry; Crawley; Derby; Doncaster; Dundee; Edinburgh; Exeter; Gloucester; Graz; Haarlem; Ipswich; Koblenz; Krefeld; Leicester; Lincoln; Luton; Maastricht; Maidstone; Mansfield; Metz; Moers; Peterborough; Pilsen; Preston; Reading; Salzburg; Sheffield; Slough; Southend-on-Sea; Swindon; Tours; Wuppertal; Zoetermeer

Cluster 2: 'Minor scootersharing, minimal competition'

Aalborg; Alcala de Henares; Arad; Brasov; Bucharest; Burgas; Cluj; Constanta; Galati; Granada; Iasi; Kielce; Kosice; Le Havre; Middlesbrough; Miskolc; Modena; Murcia; Olsztyn; Oradea; Pecs; Pitesti; Plovdiv; Porto; Prato; Recklinghausen; Reggio Emilia; Rijeka; Santa Cruz de Tenerife; Sofia; Targu Mures; Varna

Cluster 3: 'Minor bikesharing (SB), minimal competition'

A Coruna; Amiens; Banja Luka; Bottrop; Brest; Caen; Clermont-Ferrand; Genoa; Heraklion; Leon; Luxembourg; Naples; Nice; Orléans; Palma de Mallorca; Pau; Rouen; Split; Trieste; Troyes; Valencia; Valladolid

Cluster 4: 'Minor bike and car sharing, minimal competition'

Aberdeen; Alkmaar; Almere; Apeldoorn; Athens; Belfast; Besancon; Bilbao; Bologna; Brescia; Brighton; Cardiff; Cork; Eastbourne; Geneva; Gijon; Glasgow; Heerlen; Lausanne; Leeds; Leiden; Leverkusen; Livorno; Magdeburg; Montpellier; Mulhouse; Nancy; Nantes; Nimes; Offenbach; Plymouth; Reims; Rennes; Saint-Etienne; Santander; Swansea; Toulouse; Valenciennes; Zagreb; Zwolle

Cluster 5: 'Minor bike and scooter sharing, average competition'

Bielsko-Biala; Braga; Czestochowa; Gelsenkirchen; Herne; Las Palmas de Gran Canaria; Lisbon; Malaga; Odense; Padua; Parma; Pescara; Reggio di Calabria; Reutlingen; Rimini; Saragossa; Sarajevo; Seville; Sibiu; Taranto; Tarragona; Thessaloniki; Tychy; Verona

Cluster 6: Minor car and scooter sharing, average competition

Aachen; Bremerhaven; Cambridge; Chelmsford; Chemnitz; Kaunas; Krakow; Lublin; Newcastle; Northampton; Nottingham; Osnabruck; Oviedo; Perpignan; Poznan; Radom; Regensburg; Tampere; Uppsala

Cluster 7: 'Encompassing multimodal, average competition'

Aarhus; Angers; Augsburg; Bari; Basel; Bergamo; Bergen; Bern; Bialystok; Bielefeld; Birmingham; Bochum; Bordeaux; Bournemouth; Bratislava; Braunschweig; Bremen; Bristol; Budapest; Bydgoszcz; Catania; Charleroi; Colchester; Dijon; Dresden; Erfurt; Florence; Grenoble; Heilbronn; Innsbruck; Kassel; Katowice; Kiel; Leipzig; Lille; Linz; Liverpool; Ljubljana; Lodz; Lubeck; Ludwigshafen; Malmo; Manchester; Marseille; Milton Keynes; Monchengladbach; Mulheim; Munster; Norwich; Oberhausen; Oldenburg; Oslo; Ostrava; Oxford; Portsmouth; Potsdam; Riga; Rostock; Rzeszow; Saarbrucken; Solingen; Southampton; Stavanger; Strasbourg; Szczecin; Tallinn; Torun; Trondheim; Turku; Ulm; Vilnius; Wurzburg; York

Cluster 8: 'Encompassing multimodal including moped sharing, large competition'

Amersfoort; Amsterdam; Arnhem; Barcelona; Breda; Dordrecht; Dublin; Eindhoven; Enschede; Freiburg; Groningen; Nijmegen; Paris; Rotterdam; The Hague; Tilburg; Utrecht; s-Hertogenbosch

Cluster 9: 'Comprehensive multimodal, large competition'

Antwerp; Berlin; Bonn; Brno; Brussels; Cologne; Copenhagen; Darmstadt; Dortmund; Duisburg; Dusseldorf; Essen; Frankfurt; Furth; Gdansk; Ghent; Gothenburg; Halle an der Saale; Hamburg; Hannover; Heidelberg; Helsinki; Karlsruhe; Liege; London; Lyon; Madrid; Mainz; Mannheim; Milan; Munich; Nuremberg; Palermo; Prague; Rome; Stockholm; Stuttgart; Turin; Vienna; Warsaw; Wiesbaden; Wroclaw; Zurich

References

Aguilera-García, Á., Gomez, J., Sobrino, N., 2020. Exploring the adoption of moped scooter-sharing systems in Spanish urban areas. Cities 96, 102424. https://doi.org/10.1016/j.cities.2019.102424.

ANWB, 2024. Elektrische step - hoe zit dat? Retrieved 10/09/2023 from https://www.anwb.nl/belangenbehartiging/mobiliteit/elektrische-step.

Arias-Molinares, D., Romanillos, G., García-Palomares, J.C., Gutiérrez, J., 2021. Exploring the spatio-temporal dynamics of moped-style scooter sharing services in urban areas. J. Transp. Geogr. 96, 103193 https://doi.org/10.1016/j.jtrangeo.2021.103193.

Badia, H., Jenelius, E., 2023. Shared e-scooter micromobility: review of use patterns, perceptions and environmental impacts. Transp. Rev. 43 (5), 811–837. https://doi.org/10.1080/01441647.2023.2171500.

Bai, S., Jiao, J., 2020. Dockless E-scooter usage patterns and urban built Environments: A comparison study of, 20. Travel Behaviour and Society, Austin, TX, and Minneapolis, MN, pp. 264–272. https://doi.org/10.1016/j.tbs.2020.04.005.

Bean, R., Pojani, D., Corcoran, J., 2021. How does weather affect bikeshare use? A comparative analysis of forty cities across climate zones. J. Transp. Geogr. 95, 103155 https://doi.org/10.1016/j.jtrangeo.2021.103155.

Becker, S., Rudolf, C., 2018. Exploring the potential of free cargo-bikesharing for sustainable mobility. GAIA - Ecol. Perspect. Sci. Soc. 27 (1), 156–164. https://doi.org/10.14512/gaia.27.1.11.

Bellan, R., 2022. Bird exits Germany, Sweden, Norway and 'several dozen' US, EMEA markets. Techcrunch. Retrieved 10/01/2024 from https://techcrunch.com/2022/10/18/bird-exits-germany-sweden-norway-and-several-dozen-us-emea-markets/#:~:text=Bird%20said%20it%20will%20%E2%80%9Cfully,Africa%2C%20according%20to%20the%20company.

Caliński, T., Harabasz, J., 1974. A dendrite method for cluster analysis. Commun. Stat. 3 (1), 1–27. https://doi.org/10.1080/03610927408827101.

Caspi, O., Smart, M.J., Noland, R.B., 2020. Spatial associations of dockless shared e-scooter usage. Transportation Research Part D: Transport and Environment 86, 102396. https://doi.org/10.1016/j.trd.2020.102396.

Celsor, C., Millard-Ball, A., 2007. Where Does Carsharing Work? Using Geographic Information Systems to Assess Market Potential. Transportation Research Record: Journal of the Transportation Research Board 1992 (1), 61–69. https://doi.org/10.3141/1992-08.

Chen, Z., Van Lierop, D., Ettema, D., 2020. Dockless bike-sharing systems: what are the implications? Transp. Rev. 1-21 https://doi.org/10.1080/01441647.2019.1710306.

Christoforou, Z., Gioldasis, C., De Bortoli, A., Seidowsky, R., 2021. Who is using e-scooters and how? Evidence from Paris. Transp. Res. Part D: Transp. Environ. 92, 102708 https://doi.org/10.1016/j.trd.2021.102708.

Coenegrachts, E., Beckers, J., Vanelslander, T., Verhetsel, A., 2021. Business model blueprints for the shared mobility hub network. Sustainability 13 (12), 6939. https://doi.org/10.3390/su13126939.

Cohen, A., Shaheen, S., 2018. Planning for shared mobility. UC Berkeley Transp. Sustain. Res. Center. https://doi.org/10.7922/G2NV9GDD.

Coll, M.-H., Vandersmissen, M.-H., Thériault, M., 2014. Modeling spatio-temporal diffusion of carsharing membership in Québec City. J. Transp. Geogr. 38, 22–37. https://doi.org/10.1016/j.jtrangeo.2014.04.017.

Dempster, A.P., Laird, N.M., Rubin, D.B., 1977. Maximum likelihood from incomplete data via the EM algorithm. J. R. Stat. Soc. B. Methodol. 39 (1), 1–22. https://doi.org/10.1111/j.2517-6161.1977.tb01600.x.

Dunn, O.J., 1964. Multiple comparisons using rank sums. Technometrics 6 (3), 241–252. https://doi.org/10.1080/00401706.1964.10490181.

El-Assi, W., Salah Mahmoud, M., Nurul Habib, K., 2017. Effects of built environment and weather on bike sharing demand: a station level analysis of commercial bike sharing in Toronto. Transportation 44 (3), 589–613. https://doi.org/10.1007/s11116-015-9669-z.

Esztergár-Kiss, D., Lopez Lizarraga, J.C., 2021. Exploring user requirements and service features of e-micromobility in five European cities. Case Stud. Transp. Policy 9 (4), 1531–1541. https://doi.org/10.1016/j.cstp.2021.08.003.

European Commission, 2019. The European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN.

European Commission, 2020. Sustainable and Smart Mobility Strategy - putting European transport on track for the future. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789.

European Commission, 2021. Fit for 55: Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0550.

European Commission, 2024. EU missions – 100 climate-neutral and smart cities. Publications Office of the European Union. https://doi.org/10.2777/85010.

Everitt, B.S., Landau, S., Leese, M., Stahl, D., 2011. Cluster Analysis, 5th ed. Wiley.

Faghih-Imani, A., Eluru, N., 2016. Incorporating the impact of spatio-temporal interactions on bicycle sharing system demand: A case study of New York CitiBike system. Journal of Transport Geography 54, 218–227. https://doi.org/10.1016/j.jtrangeo.2016.06.008.

Ferrero, F., Perboli, G., Rosano, M., Vesco, A., 2018. Car-sharing services: an annotated review. Sustain. Cities Soc. 37, 501–518. https://doi.org/10.1016/j.scs.2017.09.020.

Fishman, E., 2016. Bikeshare: a review of recent literature. Transp. Rev. 36 (1), 92–113. https://doi.org/10.1080/01441647.2015.1033036.

Florczyk, A.J., Corbane, C., Schiavina, M., Pesaresi, M., Maffenini, L., Melchiorri, M., Politis, P., Sabo, F., Freire, S., Ehrlich, D., Kemper, T., Tommasi, P., Airaghi, D., Zanchetta, L., 2019. GHS Urban Centre Database 2015, multitemporal and multidimensional attributes, R2019A. In: European Commission. Joint Research Centre (JRC). http://data.europa.eu/89h/53473144-b88c-44bc-b4a3-4583ed1f547e.

Fluctuo, 2021a. City Dive. https://dive.fluctuo.com/#?dateRange=1631484000000&dateRange=1632088799999.

Fluctuo, 2021b. European Shared Mobility Index July 2021. https://european-index.fluctuo.com/.

Fraley, C., Raftery, A.E., 1998. How many clusters? Which clustering method? Answers via model-based cluster analysis. Comput. J. 41 (8), 578–588. https://doi.org/10.1093/comjnl/41.8.578.

Friedel, A., 2021. Free Floating Micro Mobility Map Europe. https://maphub.net/Augustin/micro.

Golalikhani, M., Oliveira, B.B., Carravilla, M.A., Oliveira, J.F., Antunes, A.P., 2021. Carsharing: a review of academic literature and business practices toward an integrated decision-support framework. Transp. Res. Part E: Log. Transp. Rev. 149, 102280 https://doi.org/10.1016/j.tre.2021.102280.

Gössling, S., 2020. Integrating e-scooters in urban transportation: problems, policies, and the prospect of system change. Transp. Res. Part D: Transp. Environ. 79, 102230 https://doi.org/10.1016/j.trd.2020.102230.

Han, S.S., 2020. The spatial spread of dockless bike-sharing programs among Chinese cities. J. Transp. Geogr. 86, 102782 https://doi.org/10.1016/j.jtrangeo.2020.102782.

Heineke, K., Kloss, B., Scurtu, D., Weig, F., 2019. Micromobility's 15000-Mile Checkup. McKinsey. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/micromobilitys-15000-mile-checkup.

Heineke, K., Kloss, B., Scurtu, D., 2020. The Future of Micromobility: Ridership and Revenue after a Crisis. McKinsey. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-micromobility-ridership-and-revenue-after-a-crisis.

Hess, A.-K., Schubert, I., 2019. Functional perceptions, barriers, and demographics concerning e-cargo bike sharing in Switzerland. Transp. Res. Part D: Transp. Environ. 71, 153–168. https://doi.org/10.1016/j.trd.2018.12.013.

Hosseinzadeh, A., Algomaiah, M., Kluger, R., Li, Z., 2021. Spatial analysis of shared e-scooter trips. J. Transp. Geogr. 92, 103016 https://doi.org/10.1016/j.jtrangeo.2021.103016.

Howe, E., 2021. Global Moped Sharing Map. https://mopedsharing.com/moped-sharing-map.

Huo, J., Yang, H., Li, C., Zheng, R., Yang, L., Wen, Y., 2021. Influence of the built environment on E-scooter sharing ridership: A tale of five cities. Journal of Transport Geography 93, 103084. https://doi.org/10.1016/j.jtrangeo.2021.103084.

International transport Forum, 2023. Towards the Light - Effective Light Mobility Policies in Cities. OECD Publishing Paris.

Jain, A.K., 2010. Data clustering: 50 years beyond K-means. Pattern Recogn. Lett. 31 (8), 651–666. https://doi.org/10.1016/j.patrec.2009.09.011.

Korosec, K., O'Kane, S., 2023. Scooter startup Superpedestrian shutting down US operations, exploring sale of Europe business. Techcrunch. Retrieved 15/01/2024 from https://techcrunch.com/2023/12/15/scooter-startup-superpedestrian-shutting-down-us-operations-explores-sale-of-europe-business/.

Magidson, J., Vermunt, J.K., 2004. Latent class models. In: Kaplan, D. (Ed.), The Sage Handbook of Quantitative Methodology for the Social Sciences. Sage, pp. 175–198.

Mateo-Babiano, I., Bean, R., Corcoran, J., Pojani, D., 2016. How does our natural and built environment affect the use of bicycle sharing? Transp. Res. A Policy Pract. 94, 295–307. https://doi.org/10.1016/j.tra.2016.09.015.

Médard De Chardon, C., 2019. The contradictions of bike-share benefits, purposes and outcomes. Transp. Res. A Policy Pract. 121, 401–419. https://doi.org/10.1016/j.tra.2019.01.031.

Médard De Chardon, C., Caruso, G., Thomas, I., 2017. Bicycle sharing system 'success' determinants. Transportation Research Part A: Policy and Practice 100, 202–214. https://doi.org/10.1016/j.tra.2017.04.020.

Meddin, R., DeMaio, P., O'Brien, O., Rabello, R., Yu, C., Seamon, J., Benicchio, T., 2021. The Meddin Bike-Sharing World Map. https://bikesharingworldmap.com/index.php#/all/2/0/51.5/.

Mehta, V., Bawa, S., Singh, J., 2020. Analytical review of clustering techniques and proximity measures. Artif. Intell. Rev. 53 (8), 5995–6023. https://doi.org/10.1007/s10462-020-09840-7.

Milligan, G.W., Cooper, M.C., 1985. An examination of procedures for determining the number of clusters in a data set. Psychometrika 50 (2), 159–179. https://doi.org/10.1007/BF02294245.

Mitra, R., Hess, P.M., 2021. Who are the potential users of shared e-scooters? An examination of socio-demographic, attitudinal and environmental factors. Travel Behav. Soc. 23, 100–107. https://doi.org/10.1016/j.tbs.2020.12.004.

Müller, J., Correia, G., Bogenberger, K., 2017. An Explanatory Model Approach for the Spatial Distribution of Free-Floating Carsharing Bookings: A Case-Study of German Cities. Sustainability 9 (7), 1290. https://doi.org/10.3390/su9071290.

Münzel, K., Boon, W., Frenken, K., Blomme, J., Van Der Linden, D., 2019. Explaining carsharing supply across Western European cities. Int. J. Sustain. Transp. 14 (4), 1–12. https://doi.org/10.1080/15568318.2018.1542756.

Numo, 2021. New Mobility Atlas. https://www.numo.global/new-mobility-atlas#7.6/50.28/5.697.

Nylund, K.L., Asparouhov, T., Muthén, B.O., 2007. Deciding on the number of classes in latent class analysis and growth mixture modeling: a Monte Carlo simulation study. Struct. Equ. Model. Multidiscip. J. 14 (4), 535–569. https://doi.org/10.1080/10705510701575396.

Parkes, S.D., Marsden, G., Shaheen, S.A., Cohen, A.P., 2013. Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. J. Transp. Geogr. 31, 94–103. https://doi.org/10.1016/j.jtrangeo.2013.06.003.

Partington, M., Billing, M., 2023. Micromobility giant tier lays off 22% of its workforce in push for profitability. Sifted. Retrieved 10/01/2024 from https://sifted.eu/articles/micromobility-giant-tier-layoffs.

Reck, D.J., Axhausen, K.W., 2021. Who uses shared micro-mobility services? Empirical evidence from Zurich, Switzerland. Transp. Res. Part D: Transp. Environ. 94, 102803 https://doi.org/10.1016/j.trd.2021.102803.

Reck, D.J., Haitao, H., Guidon, S., Axhausen, K.W., 2021. Explaining shared micromobility usage, competition and mode choice by modelling empirical data from Zurich, Switzerland. Transp. Res. Part C: Emerg. Technol. 124, 102947 https://doi.org/10.1016/j.trc.2020.102947.

Schönberg, T., 2018. Bike Sharing 5.0 - Market Insights and Outlook. Roland Berger. https://www.rolandberger.com/en/Publications/Bike-Sharing-Cornerstone-of-future-urban-mobility.html.

Scrucca, L., Fraley, C., Murphy, T.B., Raftery, A.E., 2023. Model-Based Clustering, Classification, and Density Estimation Using Mclust in R, 1st ed. ed. Chapman and Hall/CRC. https://doi.org/10.1201/9781003277965.

Shaheen, S.A., Cohen, A.P., Martin, E., 2010. Carsharing Parking Policy. Transportation Research Record: Journal of the Transportation Research Board 2187 (1), 146–156. https://doi.org/10.3141/2187-19.

Shen, Y., Zhang, X., Zhao, J., 2018. Understanding the usage of dockless bike sharing in Singapore. Int. J. Sustain. Transp. 12 (9), 686–700. https://doi.org/10.1080/15568318.2018.1429696.

Stillwater, T., Mokhtarian, P.L., Shaheen, S.A., 2009. Carsharing and the Built Environment. Transportation Research Record: Journal of the Transportation Research Board 2110 (1), 27–34. https://doi.org/10.3141/2110-04.

Teixeira, J.F., Silva, C., Moura, E., Sá, F., 2020. Empirical evidence on the impacts of bikesharing: a literature review. Transp. Rev. 41 (3), 1–23. https://doi.org/10.1080/01441647.2020.1841328.

Thanataveerat, A., 2020. Clustering Algorithm for Zero-Inflated Data.

Todd, J., O'Brien, O., Cheshire, J., 2021. A global comparison of bicycle sharing systems. J. Transp. Geogr. 94, 103119 https://doi.org/10.1016/j.jtrangeo.2021.103119.

Vermunt, J.K., Magidson, J., 2002. Latent class cluster analysis. In: Hagenaars, J., McCutcheon, A. (Eds.), Applied Latent Class Analysis. Cambride University Press, pp. 89–106.

Vermunt, J.K., Magidson, J., 2003. Latent class models for classification. Comp. Stat. Data Anal. 41 (3), 531–537. https://doi.org/10.1016/S0167-9473(02)00179-2.

Wang, K., Qian, X., Fitch, D.T., Lee, Y., Malik, J., Circella, G., 2023. What travel modes do shared e-scooters displace? A review of recent research findings. Transp. Rev. 43 (1), 5–31. https://doi.org/10.1080/01441647.2021.2015639.

Ye, J., Wang, D., Zhang, H., Yang, H., 2019. What Kind of People Use Carsharing for Commuting? Case Study in Shanghai. Transportation Research Record: Journal of the Transportation Research Board 2673 (5), 770–778. https://doi.org/10.1177/0361198119841045.

Zhang, Y., Kamargianni, M., 2023. A review on the factors influencing the adoption of new mobility technologies and services: autonomous vehicle, drone, micromobility and mobility as a service. Transp. Rev. 43 (3), 407–429. https://doi.org/10.1080/01441647.2022.2119297.

Zhu, R., Zhang, X., Kondor, D., Santi, P., Ratti, C., 2020. Understanding spatio-temporal heterogeneity of bike-sharing and scooter-sharing mobility. Comput. Environ. Urban. Syst. 81, 101483 https://doi.org/10.1016/j.compenvurbsys.2020.101483.