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MaaS: Which resources are enablers, and who is being excluded?☆

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ABSTRACT

Access to MaaS services is restricted for some population segments due to the spatial availability and to resources like mobile data, digital literacy, or vehicle-riding skills. Moreover, these services are frequently more expensive than traditional modes of transportation, which may contribute to social exclusion. This study aims to identify the resources that enable or hinder access to MaaS. These resources were identified from the literature and then included in a survey (n = 2000) conducted in Lisbon. Our results indicate that 20 to 30 % of respondents lack the necessary resources to use MaaS. However, the extent of access to MaaS is contingent upon the service or services within a MaaS bundle that a particular user is enabled to use, which is significantly influenced by their profile. We identified the main resources that provide access to MaaS and addressed the importance of providing flexibility for different enablers to increase accessibility. We conclude that public authorities should play a role in deciding where and how to provide new mobility services and that operators should consider the range of resources identified in this study to ensure broader access to the various modes of transport for a wider population segment and avoid exclusion.

1. Introduction

Mobility as a Service (MaaS) — "A mobility distribution model in which a customer's transportation needs are met over one interface and offered by a service provider" (Hietanen, 2014) — has been a hot topic in the last decade, with many transportation researchers and companies conducting studies. Much of the existing discussion is about its impacts on urban transport dynamics and socio-territorial inequalities. In her research about Transport-Related Social Exclusion (TRSE) and mobility innovations, Lucas (2019) concluded that the social and equity implications of new mobility technologies are underinvestigated, and we still lack an understanding of their effects on disadvantaged groups. In the case of MaaS, there needs to be more evidence on whether people can use it or if its requirements may generate social exclusion. Most studies on social exclusion commonly focus on car users (Orozco-Fontalvo & Moura, 2023), ignoring other population segments (e.g., economically disadvantaged, digitally unskilled, etc.). Since most car users already have the resources to use MaaS, ignoring other social and demographic groups indicates a gap in the topic of transport justice.

Lopes et al. (2023) conducted a literature review about MaaS and identified that most papers addressing MaaS are not based on real-world applications. The authors used the ROOW (Resources, Opportunities, Outcomes, and Well-being) approach to determine which characteristics and requirements benefit or exacerbate social goals. In the ROOW approach, resources are not limited to

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economic factors but encompass all attributes of an individual or household, whether owned or provided by the environment. Examples include car ownership, the availability of cycling infrastructure, or residing in a pollution-free environment (Martens et al., 2019). In the context of Mobility as a Service (MaaS), an additional layer of attributes should also be considered: the digital dimension.

On a globally aging population – more than 12 % of the worldwide population is over 60 years old and higher in most developed countries (Ritchie & Roser, 2019) – an increased life expectancy and significant pressure on technological capabilities or digital skills (Iancu & Iancu, 2020) highlights a growing issue of digital exclusion because of its technological design demanding a certain level of digital literacy (Durand et al., 2023). However, the elderly are not the only ones affected by the digital aspect. In poorer countries, the scarcity of digital skills of the "bottom billion" (as referred to by some) has been noted, revealing a potential barrier to MaaS access. In less affluent countries, the limited digital skills of the so-called "bottom billion" (James, 2021) represent a recognized challenge, potentially restricting access to MaaS. Moreover, within such contexts, transportation costs have been identified as a significant barrier to accessing public mobility systems (Silver et al., 2023), with these barriers expected to be even more pronounced in multimodal systems.

More than assessing MaaS systems outcomes and feasibility, it is important to understand what resources are required to enable access to the proposed systems by distinct population segments or individual profiles. In this sense, and based on the already acquired knowledge about transport inequality and MaaS functionality, we pose the question: ***to what extent do the requirements for using MaaS contribute to transportation exclusion?*** Still, the social impact is unclear, aside from governance and stakeholders' agreement issues. This paper focuses on the "Resources" variable from the ROOW framework, to identify possible barriers that would inhibit access to MaaS, analysing the main enablers, and identifying which population segments may be excluded. We conducted a survey in Lisbon to address this question, where, as in many cities worldwide, transport authorities are interested in the benefits of a MaaS system. The survey inquired about travel patterns and users' experience with new mobility services, namely shared mobility and ride-hailing, using it as a proxy for MaaS use (Arias-Molinares & Carlos García-Palomares, 2020).

After this introductory section, section 2 presents the literature overview on MaaS enablers. Section 3 describes the Lisbon case study, the survey methodology, sample characteristics, and the modelling approach. Section 4 presents the results of our analysis and the estimated model, highlighting the requirements for different transportation services, followed by the discussion in Section 5. Finally, Section 6 presents this study's conclusion and possible implications.

2. Literature overview

While the potential benefits and implementation barriers of MaaS are well-known (Arias-Molinares & García-Palomares, 2020; Butler et al., 2021), literature on what users need to be able to use the service is scarce. This has been likely overlooked in MaaS due to the premise that MaaS inherently improves equity, and because most implementations have occurred in high-income systems with

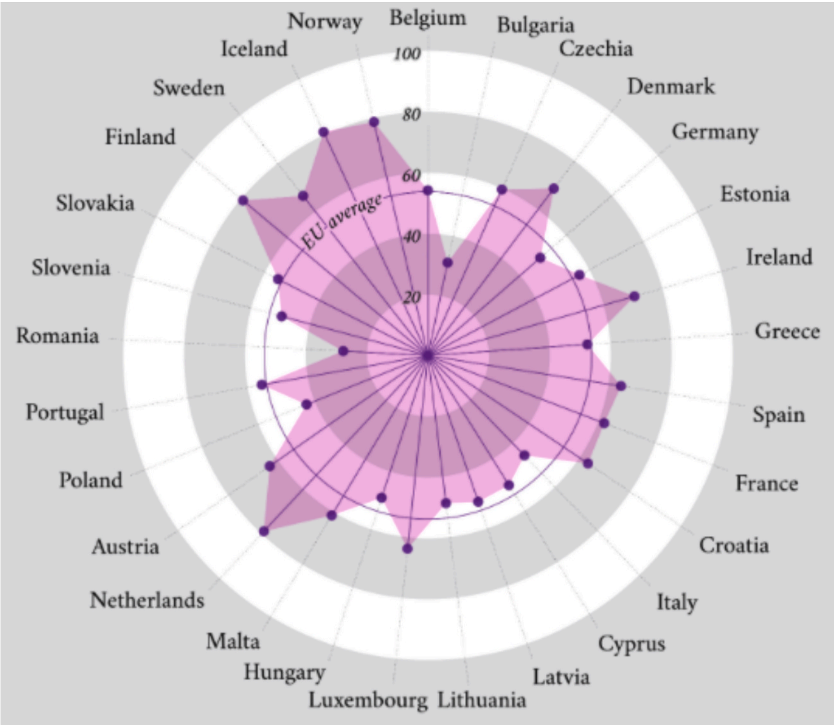

Fig. 1. Individuals with basic digital skills or above in Europe.

mature transport systems (Caballini et al., 2022; Dadashzadeh et al., 2022), where access to resources is generally not a major barrier. However, several authors have already expressed possible equity issues of MaaS (Kloeke, 2020; Li et al., 2020; Lopes et al., 2023; Storme et al., 2021).Given the lack of resources of some population groups, and its potential expansion to the Global South, it is essential to identify the main prerequisites to use MaaS. Moreover, even within the European Union, the conditions vary, for instance, digital literacy (an important skill to use MaaS) is below 60 % (EU average) in 10 of the 27 members (Fig. 1)(EU, 2023).

In this context, Martens et al. (2019) proposed the ROOW framework to assess transport justice, organizing benefits and burdens into four interrelated dimensions: Resources, Opportunities and Risks, Outcomes and wellbeing.

- **Resources** refer to individual or household attributes that can enable or constrain mobility (e.g., access to digital tools, income, physical ability or infrastructure availability)
- **Opportunities and risks** relate to the implications of holding certain resources, as it is possible to hold a resource but lack opportunities (e.g., a car owner who is banned from driving), while other conditions may pose a risk (cyclists who use unsafe infrastructure).
- **Outcomes** are objectively measurable benefits or burdens, (e.g., the number of trips, the time spent, expenses, and the number of car crashes).
- **Wellbeing** refers to people's subjective perception of their situation, which results from the interplay of resources, risks and opportunities, outcomes, and context.

This paper explicitly focuses on the **Resources** dimension, aiming to identify whether individuals possess the necessary means to use MaaS services in the first place, as understanding whether MaaS is even accessible is a necessary precursor to assessing preferences, benefits and other **Outcomes**.

For over three decades, the Capability Approach (Sen, 1974, 1979b; Sen, 1979a) has emphasized individuals' freedom to achieve well-being as a matter of what people can do and be. Moreover, from a distributive perspective, resources are vital to understanding justice and access (Palmateer & Levinson, 2017). Both the Capability Approach and the "Resourcist" Approach (which prioritizes the distribution of material resources) offer distinct frameworks for assessing well-being and social justice. This study adopts a more generalist approach, drawing from both perspectives, not limited to one framework, but considers both capabilities and resources as critical factors.

To our knowledge, only Dadashzadeh et al. (2022), Li et al. (2020), and Lopes et al. (2023) specifically analysed MaaS resources from the perspective of social exclusion. Other authors, such as Durand et al. (2022) and Turoń (2022), have explored the relationship between resources and social exclusion from the perspective of digital technologies and shared mobility services. These studies highlight several key factors that affect the use of new mobility services, from which we could identify digital skills, age, income, physical disabilities, and attitudes. Those more associated with modern mobility services are smartphone possession, spatial access, digital literacy, gender, age, income, and physical (dis)abilities.

From this broad view, we identify four classes of factors, encompassing distinct dimensions related to both material resources and capabilities, both understood as crucial from a justice perspective (Rosano et al., 2009). The material resources are (1) possession of **items** (e.g., smartphone) and (2) **spatial** access (e.g., relative location to MaaS supplied infrastructure). The capabilities are (3) specific **abilities** (e.g., digital literacy, bicycle riding skills) and (4) **individual characteristics**, such as age, income, gender, and physical

Table 1
Factor groups of all identified capabilities and resources that may hinder or improve MaaS adoption.

Category	Resource	Description
Items	Smartphone	Is the cornerstone for mobility digitalization and seen as the primary item that serves as a hindering resource.(Durand et al., 2023; Li & Voege, 2017).
	Electronic Payment Services	Necessary to acquire online services (Durand et al., 2023; Li & Voege, 2017).
	Driver License	Is essential for car-sharing and is known to affect exclusion and accessibility levels (Casas, 2007).
	Data Plan	For online services outside the home (Sieck et al., 2021).
Location	Spatial Access	And proximity (Vale, 2020) to and between MaaS options (scooters, bikes, PT, cars, etc.) is vital its usability. Long distances work as a hindrance.
Abilities	Digital Literacy	Required to use new technologies in general terms (Iancu & Iancu, 2020; James, 2021) and specifically within MaaS (Durand et al., 2022, 2023).
	Riding ability	Necessary capacity to use certain modes included in MaaS solutions, such as shared cars, motorbikes and bicycles.
Individual characteristics	Income	Works as an enabler and is highlighted as a critical transport-related social exclusion factor related to MaaS (Silver et al., 2023; Lopes et al., 2023).
	Age	Age groups tend to behave differently regarding travel behaviour (Li et al. (2020), Durand et al. (2022), Iancu & Iancu (2020)).
	Gender	Affects the modal choice and MaaS due to safety, riding ability (McIlroy), (2023) and the sexual division of labour (Siqueira et al., 2022).
	Physical (dis)abilities	May hinder the usability of specific modes (bicycle, scooter, etc.). (Dadashzadeh et al., 2022; Goralzik et al., 2022)
	Foreigners	Endure distinct mobility, social and economic conditions if compared to nationals (García-Palomares et al., 2013), (Chung et al., 2014).

disability. Considering the transport-related nature of the human activity encompassed in MaaS, the list of factors should contain two additional elements: driving ability plus a driver's license (since MaaS frequently includes rental and shared cars transport mode as an option) and mobile data plan (because MaaS platforms require data to work, and they must be accessed from various locations).

This study incorporates an additional resource consideration: foreign nationality. Foreigners often exhibit distinct travel patterns, demonstrating a higher willingness to walk and reliance on public transport (García-Palomares et al., 2013). Evidence shows that social exclusion and spatial isolation (Chung et al., 2014) hinder access to urban services, particularly for low-income or unskilled foreigners. Many countries restrict the validity of foreign driver's licenses, especially those issued in developing nations, limiting access to some MaaS options such as car or motorcycle sharing. As a first result, the identified primary resources are presented in Table 1, serving as a starting point for us to answer the research question.

Unlike previous studies that treat MaaS as a uniform system, our research is novel in disaggregating MaaS into its individual services to examine the distinct resource-based enablers and barriers, thereby offering fresh insights into the digital and material requirements that influence equitable access and contribute to transport-related social exclusion.

3. Methodology

To assess *to what extent the requirements for using MaaS contribute to transportation exclusion*, we conducted three main methodological procedures: (1) a behavior and resources survey, (2) an exploratory analysis of the collected data, and (3) a structured analysis to explain the impacts of resources on MaaS adoption.

First, we elaborated a questionnaire to capture the necessary data regarding individuals' surrounding conditions, resources, abilities, and mobility decisions concerning available shared modes that typically participate in MaaS solutions. This survey was derived from the literature review and was conducted in Lisbon, which will be presented in section 3.1. Then, we elaborated an exploratory analysis based on the classification of MaaS access levels as a first attempt to answer the posed question. Next, we proceeded with a more structured analysis to estimate the role of each identified factor in the level of app-based shared mobility solutions. This analysis tried to overcome the limitations of the exploratory study and was based on the answers collected from the survey applied to a generalized linear model.

3.1. Overview of Lisbon and its multimodal transport system

Lisbon, the capital of Portugal, has a metropolitan population of approximately 2.8 million people, with 500,000 residing in the city itself. Despite being a popular European destination attracting thousands of young tourists, the city is characterized by a significant demographic trend, with more than 21 % of its population aged 65 or older (INE, 2021) and a topography dominated by steep hills in several areas. These factors pose substantial challenges to the adoption of shared mobility solutions. The aging population may be unable or willing to engage with such systems. Moreover, digital literacy is estimated around 60 %, matching the EU average.

Nonetheless, electric shared mobility witnessed a noticeable improvement in 2022 (Fluctuo, 2022). Evidence of this condition is that, besides the 19PT operators (among trains, metros, busses, and boats), Lisbon currently holds several ride-hailing (Uber, Bolt, Freenow), shared modes (Gira, Ecooltra, etc.), and micro-mobility operators (Lime, Link, Bird, Whoosh). Gira (Lisbon's shared bike system) is the only public bike-sharing system based on fixed stations scattered over the city. The Gira system counted 161 stations (by July 2024) unevenly distributed over 100 km2 of Lisbon city (Fig. 2). The service areas for dockless mobility services are shown in Fig. 1 (right). It is a non-exhaustive list, as we've only mapped the major operators illustrating the coverage of these services, as many overlap.

These two maps show the dock-based bike-sharing system (Fig. 1 to the left) and the dockless active-mode services (bikes and

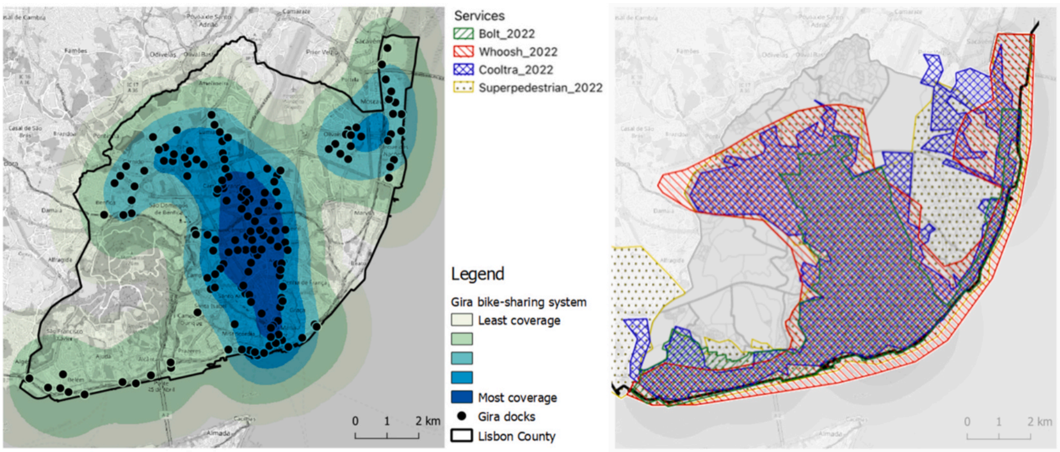

Fig. 2. Bike-sharing system coverage (left) and dockless shared mobility services coverage (right).

scooters) (Fig. 1 to the right). By combining both maps, we can understand how the supply of shared transport modes is distributed on the territory. Most are located in the city centre (closer to the Targus River, where most tourists are concentrated) and middle- to high-income neighbourhoods. Meanwhile, areas at the periphery or predominantly low-income neighborhoods remain underserved. Notably, the dockless services in the eastern zone include some low-income and social housing neighbourhoods like Olaias and Chelas (to the East). However, these areas are only served by one operator (Superpedestrian).

3.2. Survey design

The survey was conducted both in person and online between May and July 2022 to collect detailed data on demographics, travel patterns, Resources (see Section 2), transportation costs, shared mode usage, and satisfaction levels. Using the LimeSurvey platform, we designed the survey to achieve high-resolution data. To ensure representativeness across key-socio-demographic groups and neighborhoods, we employed a non-probabilistic mixed sampling approach, combing quota and convenience sampling, using both social media and trained pollsters. Pollsters intercepted individuals and conducted face-to-face interviews in public spaces until quotas based on census distributions for age, gender and neighborhood ("Freguesia") were met.

The survey targeted three municipalities in the Lisbon Metropolitan Area to reflect varying income levels and urban contexts: Lisbon (the capital), Cascais (a high-income, touristic area, with free public transport), and Vila Franca de Xira (a middle-to-low-income, non-touristic area with more peripheral characteristics). This selection was purposedly intended to capture variability in access to MaaS.

A total of 2144 responses were collected, with 1856 valid after data cleaning. Table 2 provides an overview of the sample's characteristics and representativeness, highlighting variables such as smartphone ownership, digital literacy, and spatial access to MaaS.

We effectively obtained a sample that follows the general trend of census data regarding most demographic characteristics, and the results aligned with existing literature. For example, only 1 % of elderly respondents reported using shared mobility services, reaffirming that age is a significant barrier to adoption.

3.3. Exploratory analysis

Before advancing to a more robust analysis, we conducted an exploratory study to categorize access to MaaS. Since MaaS integrates various services into one, we hypothesize that more distinct resources would be needed for an adequate MaaS experience rather than assuming that a set of uniform resources would suffice for a user to benefit from all services. To conduct the exploratory analysis, we considered three categories of access levels to MaaS:

1. **No access**: This applies to users who lack a smartphone, which is indispensable to use MaaS.
2. **Restricted access**: This applies to users who own a smartphone but meet one or more exclusion conditions (e.g., income, lack of riding skills, etc).
3. **Full access**: Users with all necessary resources and abilities to use the full potential of MaaS.

Certain conditions apply to each mode of transport. If a user does not meet these criteria, access to that mode might be restricted. Table 3 outlines the services considered part of the MaaS solutions and the exclusion conditions (resources and abilities) that limit access to each service.

Following these levels, we measured the number of respondents with access to each type of service typically included in a MaaS bundle. The services range from the least to the most restrictive, as described by the exclusion conditions in Table 3). Fig. 3 illustrates these percentages. It is important to note that multimodal MaaS systems rely on users accessing multiple modes per journey.

In our empirical application, 40 % of respondents had full access to MaaS, meaning they passed all exclusion conditions. These have all the necessary resources/capabilities to take advantage of the available shared modes. It is important to note that this approach may be unrealistic as many users do not require or want to use all indicated transport modes. We assume that shared-mobility access levels are stacked over each other as a hierarchical system. Such hierarchical conditions make it difficult to tell which modes are accessible or not to individuals with distinct conditions.

Table 2
Sample characteristics.

Resource	Survey	Survey %	Population %	Use Shared	Use %
Physical (dis)ability	132	7 %	17 %*	7	5 %
Mobile Data plan	1560	84 %	–	256	16 %
Trip planner (digital literacy) users	1262	68 %	60 %	238	19 %
Elderly > 65	478	26 %	22 %	4	1 %
Low income	316	17 %	29 %	27	9 %
Smartphone owners	1593	86 %	–	259	16 %
Spatial access	1466	79 %	73 %	199	14 %

Table 3
Exclusion conditions per service within a MaaS environment[1].

MaaS Services/ Resources	Lack of smartphone	Age > 65 years	Low Income	Physical (dis) ability	No Driver licence	No driving skills	Digital illiteracy
Public transport	x						
Ride-hailing/Taxi	x		x				x
Car-sharing / Motorcycle-sharing	x	x	x	x	x	x	x
Bike-sharing*	x	x		x		x	x
E-scooters	x	x	x	x			x

[a] A cell with an 'X' indicates that the specific transport mode (rows) might not be accessible if the criteria (columns) are unmet.

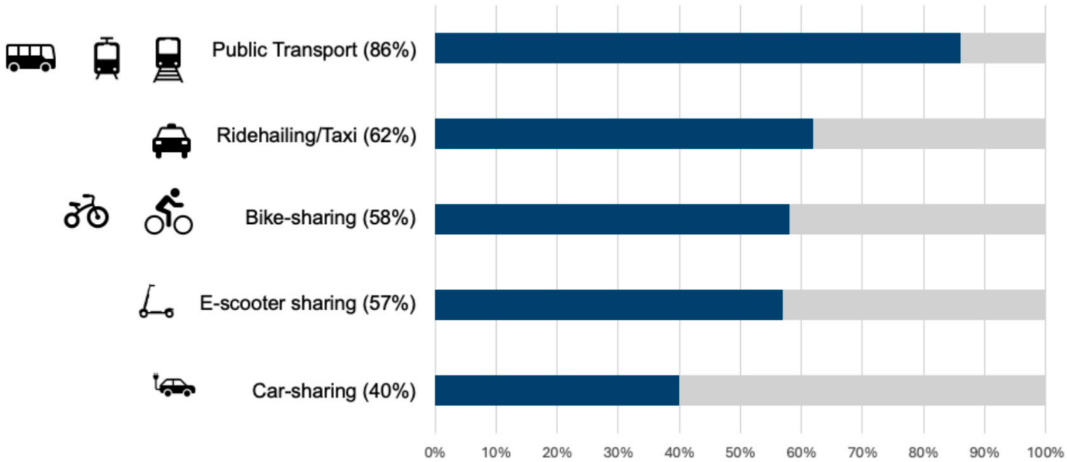

Fig. 3. Respondents (%) with access to each service.

3.4. Modelling approach

The model aligns each respondent's resource availability with their reported use of shared mobility and new technologies. This allowed us to measure the impact of all considered resources on access to multiple modes typically included in MaaS bundles. We decided to compute and sum the number of modes each respondent could access based on the classification and resource/ability associations indicated in Table 3. In other words, each resource works as an exclusion condition for each transport mode offered in MaaS bundles. The exclusion conditions (e.g., lack of smartphone, digital literacy, insufficient income, etc.) were encoded as binary variables, being "1″ if the respondent met the condition (had the resource/ability) or "0" the other way. Each respondent's access to different MaaS services was interpreted as the dependent variable (number of services being able to use).

To analyse the influence of each resource on access to MaaS, we estimated a Generalized Linear Model (GLM) with a binomial distribution. This specification was adopted because the dependent variable represents bounded count data (number of accessible modes out of a maximum total of six), making the binomial model appropriate and theoretically grounded. The binomial distribution accommodates the fact that the number of accessible modes cannot exceed six and allows us to model the probability of "success" (i.e., access to a number of modes) as a function of the available resources.

To model the number of transport modes accessible to each individual (ranging from 0 to 6), we employed a binomial generalized linear model (GLM) with a logit link function. In this framework, the number of accessible modes per respondent is considered a "success" in a sequence of six independent Bernoulli trials (for example "success" could be to have access to 2 modes and "failures" not having access to 4 modes). The model structure is:

$$Y_i \ Binomial\,(n = 6, p_i)$$

where Y_i is the number of accessible modes for individual i, and p_i represents the underlying probability of being able to access a given number of modes. The logit link function relates this probability to a linear predictor:

$$\eta_i = \log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 X_{i1} + . + ..\beta_k X_{ik},$$

where X_{ij} are the explanatory variables (e.g., individual resources or sociodemographic characteristics), and β_j are their estimated coefficients.

We used R statistical software and its built-in function "GLM" (Generalized Linear Model) to run the model. Section 4 will present the results indicating which resources significantly impacted MaaS access.

4. Model results

The results show that not all the resources identified in the literature were critical, the dependant variable was defined as *"number of services able to use"* within a MaaS environment. All significant variables were included in the model. "Lack of smartphone" was left out because 98 % of the respondents already owned one, leaving no room for heterogeneity. "Gender" (coded as Woman = 1) was included despite not being statistically significant ($p = 0{,}09$) given its theoretical relevance in MaaS and equity research. Moreover, its inclusion slightly improved model fit. Although the literature suggests women may face specific barriers to accessing MaaS (McIlroy, 2023), our data did not reveal statistically significant differences in access between genders. The model results are presented in Table 4.

"Digital literacy" showed the strongest effect on MaaS access (OR = 13.96, $p < 0.001$), followed by "possession of a driver's license" (OR = 2.20, $p < 0.001$), "high income" (OR = 1.65, $p < 0.001$), "riding ability" (OR = 1.41, $p < 0.001$), and "data plan availability" (OR = 1.40, $p < 0.001$). In contrast, "Physical (Dis)ability" was associated with reduced odds of access (OR = 0.50, $p < 0.001$), indicating that individuals with self-reported physical disabilities are less likely to access multiple services. Gender (Woman) had a marginal, non-significant effect (OR = 1.10, $p = 0.096$). Variables such as "spatial access," "age," and "foreign nationality" did not show statistically significant effects and were excluded from the final model.

To assess model fit, we report McFadden's pseudo-R2, which evaluates the improvement in model likelihood compared to an intercept-only (null) model. In the context of logistic and binomial models, values between 0.2 and 0.4 are typically interpreted as indicative of a model with good explanatory power (McFadden, 1974). In our model, the pseudo-R^2 is 0.562, suggesting a strong improvement over the null model. Additionally, the Likelihood Ratio test was highly significant ($\chi^2 = 5015.83$, df = 8, $p < 0.001$), indicating that the predictors jointly contribute meaningfully to the model. The lower AIC (3921.5) and BIC (3965) further supports the adequacy of the model fit, when compared to alternative specifications (like Poisson or Quasi-Poisson) and the inclusion of other predictors. Finally, we verified that the dispersion parameter is close to 1 (dispersion = 1.03), indicating that the binomial model is well-calibrated in terms of residual variance and provides a suitable specification for our outcome variable. Together, these fit indices support the appropriateness of the chosen model structure.

For a more comprehensive interpretation of our results, we report odds ratios (ORs) for each variable, as presented in Table 4. Individuals with "Digital literacy" had nearly 14 times higher odds of accessing more MaaS services compared to those without this skill (holding all other factors constant). Followed by having a driver's license with 2.2 times and being "high income" with 65 % higher odds. Those with "Data plan availability" or "riding ability" had approximately 40 % higher odds. In contrast, "Physical (dis) ability" reduced the odds of access by half, although the type of disability will indicate which specific services are excluded for the user; offering alternatives that require minimal user actions could still make MaaS an appealing option for these individuals.

In summary, "Digital literacy" stands out as the most critical resource/ability required for MaaS access. This finding highlights the necessity of addressing digital inclusion and skill development to enhance the adoption of MaaS platforms. The results show how specific resources significantly increase the likelihood of having access to multiple mobility services, while some could sharply constrain access.

5. Discussion

Our study contributes to the literature by breaking down MaaS into separate services and investigating resource-specific enablers and barriers to access. This detailed method not only closes the gap identified in the literature but also offers policymakers with practical insights. Our findings challenge the assumption that access to MaaS means being able to use more than one mobility service, a common issue in MaaS bundle studies where pre-defined choice set scenarios are presenting without controlling if the individual can actually use all the modes being presented. We conclude that we should not generalize *access to MaaS* but rather assess it in terms of the *degree of access*, which depends on the type and number of services available to the user based on their individual resources. This is a

Table 4
Summary of GLM results and Odds ratios.

Variable	Estimate	Std. Error	z value	OR	2.5 %	97.5 %
(Intercept)	−1.883	0.089	−21.069	0.152	0.128	0.181
Digital Literacy	2.636	0.063	41.530	13.96	12.33	15.82
Physical Disability	−0.699	0.112	−6.267	0.50	0.399	0.62
Riding ability	0.347	0.076	4.580	1.41	1.22	1.64
Data Plan availability	0.334	0.084	3.985	1.40	1.19	1.65
High Income	0.502	0.068	7.337	1.65	1.45	1.89
Gender (Woman)	0.095	0.057	1.663	1.10	0.98	1.23
Driver's License	0.787	0.057	13.730	2.20	1.96	2.46
AIC	3921					
BIC	3965					
Log. Ratio test	5016					
Pseudo R^2 (McFadden)	0.56					

previous step that should be considered before assessing outcomes and preferences.

Moreover, as users may have different needs depending on the trip purpose, time of the day, day of the week, etc., the resources and capabilities they possess will determine which services will be included in their mobility package. On the other hand, public authorities and operators can use this information to mitigate those that become a barrier.

The results of the binomial model support our premise that MaaS services involve varying degrees of accessibility depending on the resources available to users. The main findings, directly derived from the model's result, are summarized in Table 5.

In Lisbon, our survey, in association with a literature review, identified the resources/capacities needed to use the different services included in a MaaS. Hence, personalized MaaS bundles are required if we want users to be able to use them fully. Since "Riding ability" emerged as a significant barrier to access. In our view, basic cycling skills should be taught at the elementary school level, as is already the case in some European countries. This, combined with the expansion of safe cycling infrastructure, could greatly reduce this barrier (Félix et al., 2020). In Lisbon, such measures are particularly feasible given the city's flat areas and the growing supply of public electric bikes (Gira) which effectively support mobility in hilly areas.

Our results show that how new mobility services are supplied (and, therefore, adopted by the population) tends to benefit specific population segments. These services are commonly concentrated in wealthy or tourist places and only sometimes solve the low or middle-income population's travel needs. This could result from a market-driven approach in which for-profit operators may ignore urban mobility's societal goals, which is in line with Lucas' (2019) premise that "many companies will not currently rent cars to people living in social housing.".

Following Lucas (2019), we discuss if, in our empirical application, the current setting of shared mobility services could increase accessibility (optimists) or if, on the contrary, it increases the concentration of transport wealth amongst the already privileged and excludes marginalized groups (pessimists). The results show that if the public authority does not intervene in providing these services, the pessimistic scenario will become a reality in Lisbon, given that only 39 % of potential users can use MaaS fully. The results on "Income" are essential for transport justice and indicate that stakeholders should regulate it to avoid possible transport gentrification.

Regarding other factors, "digital payment" was not considered in the analysis, given that it is no longer a barrier in the global North (if you have a smartphone, you can access this service). "Spatial access" was not directly associated with any service, given that our survey shows people who do not have it (people living in areas not served by shared mobility operators) still use it. The motivation behind this use is not clear. In the same tone, "Smartphone ownership" may not be a problem in Europe, but this may not be true for some global southern cities. From a policy perspective, and assuming that this factor may be an important barrier in certain situations, alternatives to smartphones, such as internet-enabled kiosks in public locations, train or bus stations, and free Wi-Fi in stations, stops, and dock locations, may mitigate the risk of exclusion.

We acknowledge some limitations to this study. The main limitation lies in the fact that, although the resources were derived from an extensive literature review, they represent a general framework that may not fully account for context-specific variations. Moreover, the defined dependent variable, "number of services able to use", was a self-defined construct based on exclusion assumptions. Therefore, our results are valid while the exclusion conditions of the resources identified hold true.

Another area for improvement is that some resources, more related to attitudes or preferences, could have been considered in this work, such as safety perception or tech savviness (Astroza et al., 2017; Hauslbauer et al., 2022; Orozco-Fontalvo et al., 2024; Useche et al., 2023). Depending on the case, these could become barriers or motivators to use MaaS adoption at the individual level. Future research should examine whether the Resources identified in this study across cities with different levels of transport maturity and socio-economic contexts. Additionally, incorporating users' attitudes and exploring the effect of subjective resources (latent variables) through hybrid choice modelling could reveal further access barriers or enablers. Finally, given that no official MaaS platform operates in Lisbon, benchmarking against cities with established MaaS systems (e.g. Berlin, Vienna, Taipei) could provide meaningful insights into real-world access conditions. This comparative approach may also highlight additional variables not found in the literature such as language, race, or network awareness which remain unexplored in the literature.

6. Conclusions

Based on a literature review, this study identified the resources needed to access MaaS. It assessed how each impacts access to the services typically offered within a MaaS bundle through an empirical survey in Lisbon and a generalized linear model with a binomial distribution. The findings revealed that lacking specific resources can limit access to one or more services within a MaaS framework. In

Table 5
List of findings.

Finding	Description
Digital Literacy as a Key Factor	Digital literacy is crucial for MaaS access. Initiatives are needed to improve skills in vulnerable groups.
Economic Barriers and Transport Gentrification	High-income individuals enjoy better MaaS access. Policies must ensure affordable access for all users.
Role of Public Authorities	Public authorities must intervene to prevent MaaS from reinforcing socio-territorial inequalities, as well as prohibitive prices and selective operation areas.
Personalized MaaS Bundles (Mobility packages)	MaaS services should be tailored to individual or profile groups needs to ensure wider accessibility. MaaS offerings need to consider potential users resources/capabilities.
Spatial Inequality in Service Availability	Shared mobility services are concentrated in wealthier areas, creating spatial exclusion. Service distribution must be equitable.

line with previous research, we found that elderly individuals and people with disabilities may be at a higher risk of being excluded from some MaaS services. However, the analysis also highlighted that factors beyond sociodemographic characteristics can enable or hinder access, with digital literacy emerging as the resource with the highest odds ratio.

Our main conclusion is that "access to MaaS" should not be treated as a binary condition. Instead, it depends on whether users can access each of the individual services included in a MaaS package. In this sense, we argue for a shift in how MaaS access is conceptualized, proposing the view of "degree of access to MaaS" based on the combination of services that users can realistically utilize. Additionally, we provide insights on the importance of each of the resources identified, allowing for a direct comparison or ranking among them.

In policy terms, this has several implications: First, digital inclusion should become one of the pillars of any MaaS strategy. Improving digital literacy and ensuring affordable services and mobile data access will directly increase access to multiple modes. Second, vehicle design and mobility hubs infrastructure should account for the needs of users with physical impairments as in our analysis they had approximately half the odds of accessing services compared to those without such impairments. Third, riding ability remains a significant barrier. Therefore, we recommend that MaaS initiatives incorporate educational programs that help users acquire or improve riding skills, particularly for e-scooters and bicycles.

Based on these insights, we recommend that public authorities play a role in deciding where and how to provide new mobility services and that operators consider the range of resources identified in this study to ensure broader access to the various modes of transport for a wider population segment. This layered, hierarchical structure of access levels suggests that MaaS solutions must consider each user's individual limitations to avoid excluding large portions of the population. To guarantee that MaaS does not contribute to social exclusion, it is important to consider the necessary resources that potential users must possess to access the system.

Finally, this work contributes to shared mobility research by highlighting the complex, resource-dependent character of MaaS access. Our disaggregated study supports that enabling equal access to MaaS involves more than just increasing service availability; it also necessitates tailored measures that address the digital and material resources required for adoption. We have identified key areas where policy interventions can have a major impact, such as digital literacy and inclusive service design, using empirical evidence from the Lisbon case study. Additionally, our analysis not only addresses a key gap in the existing literature but also establishes a platform for future research on subjective and contextual barriers to MaaS, thus leading to better informed and successful transport justice initiatives.

CRediT authorship contribution statement

Mauricio Orozco-Fontalvo: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **André Soares Lopes:** Writing – review & editing. **David Vale:** Writing – review & editing, Supervision, Funding acquisition. **Filipe Moura:** Writing – review & editing, Supervision, Project administration, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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