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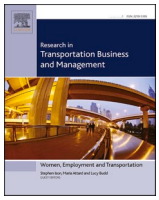

A Mobility Justice Framework to prioritize areas for mobility interventions

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ABSTRACT

Understanding, visualizing, and quantifying how resources are allocated and the fairness of distributions and access is significant for supporting decision-makers in incentivizing development and ensuring that future changes are widely beneficial and fair. By pointing out the need for mobility justice research to shift from state-centric to more society-centric frameworks and metrics, this study proposed a Mobility Justice Framework that integrated two important theories of justice: distribution and recognition justice. The proposed framework highlights the distribution of amenities and burdens in providing transport infrastructure. It also aims to identify those disadvantaged socio-economic groups more exposed to mobility inequalities. To make the framework applicable within the city context and guide decision-making, several metrics (variables) were identified to make principles of distributive and recognition justice operationalizable. Variables such as 1) accessibility by walking, 2) exposure to traffic negative effects, 3) frequency of use of transport modes, and 4) availability of transport infrastructure were used to identify neighborhoods and the different types of mobility resources/burdens that disadvantaged socio-economic groups are exposed to. To showcase its usability, the framework and methodology have been applied to the city of Munich to highlight neighborhoods with a higher proportion of older people and the transport disadvantages associated with these target groups. A higher negative correlation between older people and mobility resources/burdens can be observed for the following variables: accessibility by walking to activities, availability of walking and cycling infrastructure, and availability of car-sharing services. When measured against exposure to negative transport effects, a higher positive correlation was observed. The paper ends with a discussion section on the relevance and usability of the proposed framework for transport planning and policy and its limitations.

1. Introduction

Pressing issues for our cities, like climate change, population growth, urban renaissance and the fear of future pandemics, are affecting the distribution of resources and burdens (Logan et al., 2021). Regrettably, the equitable distribution of these resources and burdens in transport-related infrastructures and services remains far from optimal, directly affecting the quality of life for residents residing in underserved areas. Over the years, transportation scholars have examined issues of unequal access to locations and the unjust distribution of resources, utilizing a multitude of justice-related theories to inform their research (Lucas et al., 2016; Iglesias et al., 2019; Martens, 2012). The importance of studying these issues lies in preventing social exclusion and disadvantages that might come from unequal distributions of mobility resources.

State-centred research on mobility justice has produced a variety of methodologies and philosophical frameworks that aim to highlight unequal patterns of mobility resource distribution. While distributive principles have been instrumental in addressing disparities in the allocation of benefits and costs within transportation systems (Hay, 1993; Hodge, 1988; Murray and Davis, 2001), scholars are recognizing the limitations of this approach in capturing the complex social dynamics intertwined with mobility (Foth et al., 2013; Pereira et al., 2019). Therefore, research on mobility justice has seen a shift from a state-centred to a more society-centred view of these issues.

Simultaneously, sustainable territorial transformations have become a global and time-critical imperative, causing our built environments to change rapidly. But can our built environments change and attract investment in a way that promotes justice even for the most disadvantaged social groups? In this article, we aim to develop a framework for incorporating justice principles into decision-making by highlighting and spatially visualizing the distribution of resources and burdens associated with the transport system, and disadvantaged socio-economic

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groups that are more exposed to mobility inequalities. By combining distributive and recognition principles in the provision of transport infrastructure, the framework can be used by policymakers, mobility advocates, and transport planners to identify disadvantaged socio-economic groups who are more prone to suffer from inequalities in the spatial distribution of transport infrastructure and services. By understanding the spatial distribution of the most disadvantaged socio-economic groups and identifying groups that have fewer access to mobility opportunities, we want to shift the attention from distributive principles toward a society-centric understanding of transport justice using recognition justice principles.

For the sake of brevity and because this article aims to present the application of the methodology behind the Mobility Justice Framework, this study applied the Mobility Justice Framework to the case of older people as an example in order to highlight and spatially visualize their mobility disadvantages at the neighborhood scale in Munich. Four main variables composing the mobility justice framework have been derived from the justice theories discussed in this study, such as distributive justice and recognition justice. The variables used for the analysis are 1) accessibility by walking to amenities such as health services, food providers, education, community center, and sports facilities, 2) availability of transport infrastructure and services, 3) frequency of using sustainable modes of transport such as walking, cycling, public transport, and car-sharing services, and, 4) exposure to traffic negative effects such as air pollution, noise pollution, and road crashes. All these variables have been compared with the neediest and most disadvantaged social groups, focusing on older people in order to show the application of the Mobility Justice Framework to highlight transport disadvantages for this specific socio-economic disadvantaged groups.

The remainder of the paper is organized as follows. The next section discusses transportation and justice considerations, focusing on distributive and social justice theories in mobility research. We then highlight the limited research aiming to operationalize recognition justice theories and provide a Mobility Justice Framework used for the analysis that can help to identify disadvantaged neighborhoods (Section 2). The methodology followed to operationalize the Mobility Justice Framework has been described in Section 3. Section 4 focuses on applying the Mobility Justice Framework and its methodology to the city of Munich. In addition, the results and findings from the analysis will be discussed. This is followed by a discussion on how policymakers and mobility advocates can use the framework to guide their decision-making processes and strive for a more equitable mobility system (Section 5). Section 6 concludes with the benefits and limitations of the proposed framework and the variables used to make it operationalizable to offer direct policy recommendations.

2. Mobility and justice considerations

Justice considerations focus on disadvantaged populations, intending to enhance equality regarding access and movement. This section analyses transportation and justice considerations from two converging principles, distributive and social justice principles (i.e. recognition). The latter aims to consider mobility justice issues from a more society-centered perspective and provide frameworks and methods used in mobility justice work. The next two subsections aim to analyze the focus of work and methods used to identify mobility justice issues using distributive and social justice theories. The final subsection proposes a framework to evaluate mobility justice based on the principles discussed, the focus of previous work on mobility justice, and the methods used.

2.1. Distributive principles in mobility justice

The discourse on distributive principles has been a persistent theme in mobility justice literature, with a number of scholars shaping the discussion over the years. Distributive justice theories can help to address the structural issues found in transport policy and planning by providing normative rules (i.e. what should and should not be done) to guide decision-making (Hananel and Berechman, 2016). This section discusses some of the indicators identified within the literature as useful for measuring different dimensions of distributive principles related to transport. A review of the existing literature concerning distribution principles in relation to mobility justice was conducted, utilizing the Scopus database to identify relevant studies up to the present date. The database search query used for the scanning of relevant articles was the following:

(distribution AND justice OR distributive AND justice)
AND
(transport OR mobility);

In addition, the search was limited to English-language articles and to the following areas: social sciences, environmental sciences, engineering, arts and humanities, energy, and decision sciences. A total of 159 articles were selected, and later on, a manual screening of titles and abstracts was performed to exclude irrelevant papers. The excluded papers generally discussed issues surrounding the decarbonization of the transport sector in general and energy justice in specific; distributive principles falling under the big umbrella of environmental justice; global justice and migration; and social mobility. A total of 43 papers were included in the final analysis. The aim of the analysis was to understand the focus that the distributive principles were being used for and the associated methodology. Table 1 shows the results of the final studies explored in-depth to understand the focus of the distributive principles being used to study mobility justice.

Most of the studies focused on the distribution of accessibility and aimed at providing metrics to guide policymaking on what can be considered as just accessibility. Martens (2012) adopts the perspective that equitable transport policy should center around the notion of accessibility. This stance is grounded in the utilization of Walzer's Spheres of Justice, a framework advocating that material goods that hold distinct social meanings need their own set of norms in order to establish a fair distribution. Studies on the fair distribution of main services and equitable access to services emphasized the inadequacy of conventional spatial approaches and highlighted the significance of spatiotemporal dynamics (Ryan, Pereira, & Andersson, 2023; Henckel and Thomaier, 2016). Other studies focused on the accessibility to basic services like health systems by offering metrics and frameworks to measure acceptable times and distances (Humberto, 2023; Hundt et al., 2012).

Research focusing on the distribution of mobility goods, does not only focus on accessibility issues, but also on ensuring that mobility options are available to all, regardless of socio-economic status. The distribution of transport infrastructure focused not only on public transport issues but also on providing adequate infrastructure for cycling and walking. A number of studies aimed at understanding and

Table 1
The focus of distributive principles in mobility justice research.

Distributive principles focused on…	No. of studies with a similar focus
Distribution of accessibility	9
Distribution of public investments	8
Distribution of public street space	7
Distribution of public transport infrastructure and services	7
Distribution of benefits and costs	7
Distribution of bike infrastructure	3
Distribution of air pollution	3
Distribution of social impacts	2
Distribution of waiting time for pedestrians	1
Distribution of motility	1
Distribution of temporal inequalities	1
Distribution of time and distance travelled	1

evaluating the fair allocation of cycling resources and benefits, shedding light on the need for equitable access and distribution across diverse communities and contexts (Cunha and Silva, 2023; Duran-Rodas et al., 2020; Ferenchak and Marshall, 2021).

A common theme throughout the studies related to mobility justice is that opportunities can improve, and benefit disadvantaged groups or, reinforce negative dynamics. Hence, the equitable and efficient allocation of public resources holds utmost significance, as it influences not only individuals' economic and social opportunities but also impacts their overall well-being (Fainstein, 2009). The question that has been addressed by researchers so far is related to how equitable the distribution of public resources is to fulfil the mobility demands of the population (Kloppenburg, 2020). A large number of studies focused on the interrelation between the distribution of public investments and public street space (Attard, 2020; Guzman et al., 2021), highlighting how an equitable allocation of street space and resources can impact residents' mobility options and overall quality of life.

Distributive principles of mobility justice encompass not only the equitable distribution of societal benefits but also the allocation of costs. The disparities in air and noise pollution exposure, as studied by Tonne et al. (2018) and Martens (2020), underscore the environmental justice and health considerations inherent in transportation planning.

It is important to note that theories of distributive justice in mobility focus on both the distribution of benefits (e.g., access to services, availability of transportation infrastructure and services) and the distribution of transportation-related costs (i.e., air pollution, noise pollution, transportation risks, etc.). However, despite their application in the area of mobility justice, distributional principles have significant limitations. For example, they do not recognize the importance of ensuring the fair participation of a wide range of stakeholders in policymaking, and they do not consider the influences of exogenous complex systems on how people move and interact with transportation systems (Verlinghieri & Schwanen, 2020).

2.2. Recognition justice as a proxy to social justice theories in mobility

The discussion on the definition of transport or mobility justice within an alternative framework is evolving rapidly. According to Karner et al. (2020), the transition from transport equity to transport justice, broadly encompassing all aspects of justice pertaining to people's daily mobilities, involves a broader scope that encompasses a more diverse set of stakeholders and considerations. This shift recognizes that achieving true equity goes beyond equal distribution, embracing the diverse needs and experiences of various communities, especially the most disadvantaged ones (i.e. low-income, people with disabilities, and minority populations).

One of the main limitations of distributive justice remains its reliance solely on numerical metrics without taking into account lived experiences, the way mobility intersects with other dimensions of life and the importance of ensuring the fair participation of a wide range of stakeholders in policymaking (Pereira, Schwanen and Banister, 2017; Randal et al., 2020). Most significant here is that a resource such as accessibility, or even mobility, understood as the ease of moving through physical space, cannot duly account for the diversity in needs, aspirations, and abilities (Pereira et al., 2017).

Many studies attempting to shift from the heavy state-centric perspective to a more society-centric perspective of mobility justice have employed new alternative methods to discuss mobility justice (Table 2). This approach aims to rectify not only material disparities but also the unequal power dynamics and perceptions that influence mobility access.

Participatory Action Research (PAR) is a very common method used in mobility justice research (Lucas, 2012; Verlinghieri, 2020; Barber, 2020: Sagaris, Berríos, & Tiznado-Aitken, 2020). By using PAR as a methodology to highlight mobility justice issues, research in this direction involves local communities, stakeholders, and marginalized groups in shaping transportation policies and solutions (Lucas, 2012). The studies underscore the importance of understanding and adapting to the specific contexts in which transportation issues arise. Acknowledging that one-size-fits-all solutions are insufficient and that interventions should be tailored to local circumstances becomes of paramount importance (Sagaris et al., 2020). Moreover, Verlinghieri (2020) introduces the concept of a "resourcefulness-based worldview", which emphasizes recognizing and leveraging existing community resources, knowledge, and practices when designing transportation interventions.

Table 2
Methods employed in society-centric mobility justice research.

Author(s)	Year	Method(s)
Beyazit	2011	Capability Approaches (CA) with existing methods (distributive)
Lucas	2013	Action research to address current social and environmental challenges posed by transport impacts
Pereira et al	2017	Accessibility as a human capability (distributive + CA)
Butz and Cook	2018	Use of visual methods - autophotography
Verlinghieri	2020	Participatory Action Research
Bantis and Haworth	2020	Linking accessibility with CA
Barber	2020	Participatory Action Research
Randal et al	2020	Distributive and capability approach
Sagaris et al	2020	Participatory Action Research
Vecchio	2020	Micro-stories
Sunio	2021	Multi-criteria mapping of stakeholders
Randal et al	2023	Distributive and capability approach

Other studies share a similar critical stance toward traditional transportation planning approaches, often pointing out their limitations in addressing real-world complexities and diverse needs (Beyazit, 2011; Pereira et al., 2017; Randal et al., 2020). Studies in this line of research argue the need and benefits of combining distributive principles with the Capability Approach theory developed by (Sen, 1993) to consider social justice norms in transport research. Adding to the toolkit of methods to analyze mobility justice, Butz & Cook (2017) reflect on the use of visual methods detailing the use of autophotography in a study of the everyday implications of a newly constructed road for a small community in mountainous northern Pakistan.

Another innovative approach is that of Vecchio (2020), who applied the Capability Approach framework to micro-stories of everyday mobility to draw on perceptions of mobility injustice. These studies and methodologies employ different lenses of justice theories when it comes to mobility justice, such as procedural justice and recognition justice. Both participatory action research and the Capability Approach highlight the individuals who are part of society, their needs, and their perspectives when it comes to perceiving mobility around them. In both cases, the value of experiential knowledge is prioritized in order to tackle problems caused by unequal systems. Studies focused on the Capability Approach highlighted the need to recognize different individual needs, experiences, and practices related to everyday mobility. Considering these, in order to go beyond simply addressing material inequalities in mobility, but also acknowledge the cultural and social dimension of injustice, recognition justice theory has been used, as a complementary theory to the distributive one. As introduced by theorists like Fraser (1995) and Honneth (1996), Recognition Justice asserts that individuals must be recognized as full members of society with their identities, experiences, and contributions acknowledged and respected. Within this study, it aims to bring a more social justice perspective to analyze mobility justice, guide decision-making processes based on local needs, and identify who is and who is not given access to mobility services.

2.3. A proposed mobility Justice framework

Understanding, visualizing, and quantifying how resources are

allocated and the fairness of distributions is a significant tool for supporting decision-makers to incentivize development to ensure that future changes are both widely beneficial and fair. From what was discussed above, a Mobility Justice Framework based on both, distributive and recognition justice has been developed. Distributive justice addresses objective mobility disparities, while recognition justice brings attention to social, economic and cultural dimensions of injustice. The integration of these approaches offers a nuanced understanding of mobility justice and supports the development of policies and interventions that holistically address the multi-dimensional challenges faced by diverse individuals and communities in accessing and navigating transportation systems. The purpose of the framework developed in this section is twofold:

- It aims to guide analysis and decision-making on mobility interventions based on two dimensions of mobility justice, social recognition, and distributive, by making spatially visible areas where disadvantaged socioeconomic groups suffer from a lack of mobility resources or negative externalities associated with mobility.
- Apart from its theoretical basis, the framework aims to be applied in a way that allows for spatial visualization of the data where inputs can be highly visible and easy to interpret.

Fig. 1 shows the interrelation between the two dimensions of justice that make up the Mobility Justice Framework and the variables used to interpret mobility justice.

Based on a dialogue between Rawlsian and Capability Approaches, Pereira et al. (2017) proposed that distributive justice concerns over transport disadvantage and social exclusion should focus primarily on accessibility as a human capability. The principle of distributive justice requires that basic services (i.e. health services) are accessible to individuals according to need and within the context of resource availability. When there are barriers preventing access and/or availability of resources to reach such services, distributive justice is compromised. Hence, accessibility to services is considered a crucial variable for assessing resource distribution within the proposed framework.

The analysis of studies focusing on distribution principles in transportation, shows that the distribution of accessibility goes hand in hand with distribution of transport infrastructure and services. The equitable distribution of a public transit network is of utmost significance, serving not only to provide access to services regardless of socio-economic factors but also to prevent the concentration of investments in particular neighborhoods, thereby averting the potential risk of gentrification (Priya Uteng, 2007; Revington, 2015; Adli et al., 2019). Therefore, the availability of transport infrastructures and services plays a vital role in the proposed Mobility Justice Framework. Aiming at making the results spatially visible and considering previous studies focused on mobility distribution, elements that compose the availability analysis for this study are: 1) car-sharing membership, 2) bike and e-bike ownership, 3) availability of public transport stops, 4) availability of cycling infrastructure, and 5) availability of walking infrastructure.

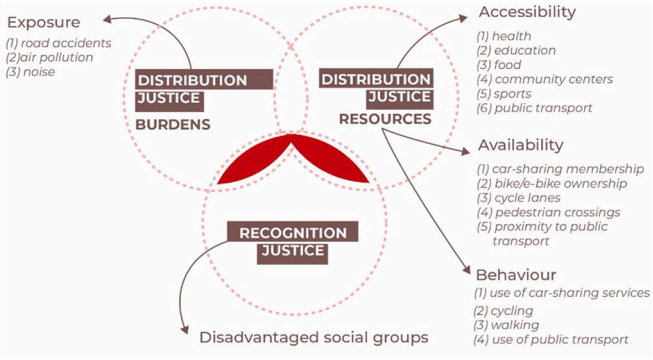

Fig. 1. Mobility justice framework.

As previously discussed in Section 2.1 the focus of the distributive principles associated with mobility, despite being closely linked to accessibility and availability of resources, also aims at analyzing the impacts of the resource distribution. Therefore, behavior (frequency of use of a transport mode) was extracted as a third variable, which can be viewed more as a proxy for accessibility and availability, to determine whether the frequency of using a transport mode more/less is due to the transport resource not being there in the first place.

On the other hand, distributive justice focuses not only on the distribution of resources but also on the distribution of costs/burdens. The exposure to negative impacts of transportation is a fourth variable used to analyze the distribution of costs in the community. Studies that focus on the distribution of costs have mentioned the negative impacts of transportation such as air pollution, noise pollution, and traffic accidents.

A more recent but well-developed notion of justice is recognition justice, which is based on the notion that there are many ways that certain individuals and social groups can be included or marginalized due to their identities, such as ethnicity, race, gender, and sexuality. Being able to counteract such systemic exclusion, generates recognition justice. Therefore, the final variable that is closely related to theories of recognition is that of disadvantaged socioeconomic groups. By identifying neighborhoods with a higher proportion of disadvantaged socioeconomic groups and revealing their mobility deficits, the study serves as a first attempt to identify the mobility disadvantages of specific disadvantaged socioeconomic groups. Hence, we can later offer recommendations on the neighborhoods where such mobility interventions are needed the most and which disadvantaged socioeconomic group the planning process should target.

3. Methodology

Having identified the main variables that compose the Mobility Justice Framework, a methodology has been proposed to make the framework applicable in cities. This methodology employs geospatial analytical tools, notably Geographic Information Systems (GIS), to dissect spatial patterns and dynamics. As previously discussed, the four main variables, that compose the analysis behind this study, namely, 1) accessibility, 2) availability, 3) behavior, and, 4) exposure, have been derived from distributive principles of mobility justice, by focusing on both, resources and burdens of transportation. All these variables have been measured against the most disadvantaged social groups and those who are not in an attempt to identify neighborhoods where a majority of disadvantaged socio-economic groups live. The neighborhood unit has been chosen as the right unit for the purpose of this research for the following reasons:

- Possibility to make the results from the quantitative analysis transferable and easily understandable for the population that will be recruited for the surveys and focus group interviews;
- To provide policy recommendations and cooperation with district administrators.

3.1. Socio-economic (dis)advantage score

The socio-economic groups considered for this analysis were: older people (over 65 years old), children and teenagers (under 18 years old), migrants, single-parent households, low-income and unemployed. These socio-economic disadvantaged groups were selected due to the availability of data at the scale of 100 × 100 census grid. This data was processed in GIS and by using the 'vector intersection tool' the census grid was intersected with the neighborhood layer, to obtain the percentage of each social group per neighborhood.

Each of these social groups was analyzed separately. In order to

compare neighborhoods to the city average, each indicator underwent a normalization process, rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage). The 75th quartile for each socio-economic group per neighborhood was calculated to qualify neighborhoods that exhibit either "High Disadvantage" or "Low Disadvantage". Considering these six socio-economic indicators, a "socio-economic disadvantage score" (SD) has been computed by summing up the indicators and comparing them to the city average.

$$SD_j = norm(\Sigma\ V_i)$$

Where

- SD_j is the social disadvantaged score for each j spatial zone analyzed, e.g. neighborhood level
- V_i is a boolean indicator (0,1) representing if the spatial zone j belongs to the highest quartile (1), or not (0) in terms of the percentage of residents belonging to a disadvantaged group i in comparison with the other zones
- norm(): minmax normalization

This analysis serves as a benchmark for facilitating inter-neighborhood comparisons, with the aim of understanding and recognizing neighborhoods that have a higher percentage of socio-economic categories that can be considered as disadvantaged. However, this "score" is just a reference for this study. It is essential to acknowledge that additional indicators should be taken into account when analyzing diverse socio-economic disadvantages or vulnerabilities, such as health, environment, education, crime, etc.

This socio-economic (Dis)advantage score is then contrasted with the Mobility (Dis)advantage score explained below.

3.2. Mobility (dis)advantage score

The mobility disadvantage variables considered for this study were: Accessibility, Availability, Behavior, and Exposure. Each variable has been analyzed separately and the final accumulative result per neighborhood has been standardized using values from 0 to 1, with 0 being the worst and 1 the best.

The 25th quartile for each mobility resource variable (accessibility, availability, behavior) per neighborhood was calculated to qualify the neighborhood as exhibiting either "High Disadvantage" or "Low Disadvantage" concerning these indicators relative to the city's entirety. On the other hand, calculations for the mobility burden variable (exposure) considered the 75th quartile per neighborhood to highlight neighborhoods exhibiting "High Disadvantage" or "Low Disadvantage". In order to summarize the results of the multiple variables, a final Mobility (Dis)advantage Score was estimated. The main goal of the score is to summarize per neighborhood, how often lower mobility resources and more mobility burdens are present in comparison with other neighborhoods. The standardized values per neighborhood for all four variables have been summed up, giving a score per neighborhood. The main limitation of this score is that it does not weigh the different variables; however, it gives an idea of where there are repetitive cases of disadvantage in terms of mobility resources and mobility burdens for one neighborhood in comparison to the rest of the city.

The four variables have been analyzed separately on GIS as follows:

3.2.1. Accessibility – geospatial data analysis

In this case, accessibility was considered as the ease of reaching the daily basic needs, defined as the percentage of people served in the neighborhood by each amenity. The accessibility analysis aimed at identifying the service distribution of five main amenities (POIs - points of interest): health services, food providers, sports centers, community centers, and education per neighborhood. Walking accessibility was chosen for the purpose of this paper since accessibility is seen from the prism of accessibility by proximity. The GIS assessment process was performed as follows:

- Using the road network (excluding highways) which was obtained by Open Street Maps, a 'network analysis' was performed for each amenity. In order to define the service area, the analysis considered a 700-m distance from each POI (the amenity) for a walking speed of 3.5 km/h.
- The service area was converted to a polygon (convex hull), dissolved, and intersected with the population grid (calculated by neighborhood as explained in Section 3.1) to calculate the total population served by each amenity, for each user group at the neighborhood level.

3.2.2. Availability – geospatial data analysis

The choice of mobility option can be a result of certain social or economic barriers related to population subgroups. However, some groups have concrete barriers related to their mobility choices. The availability analysis aims to identify areas more prone to specific population subgroups suffering from the lack of available opportunities. In this section, the following have been analyzed: 1) car-sharing membership, 2) bike and e-bike ownership, 3) availability of public transport stops, 4) availability of cycling infrastructure, and 5) availability of walking infrastructure. Car-sharing membership and bike and e-bike ownership data was extracted from the German National Mobility (Nobis & Kuhnimhof, 2019), while data for the other three indicators was extracted from Open Street Maps. After obtaining the data for the city of Munich, the following analysis was performed per each of these indicators to assess the availability of these indicators at the neighborhood level:

- Using GIS, data from each indicator at the city level was intersected with neighborhood boundaries to calculate the availability of such indicators per neighborhood and compare neighborhoods.
- Since all these indicators had different units, they underwent a normalization process rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage) to create the availability analysis.
- The five indicators were summed up to create the overall availability analysis per neighborhood. The summed-up values per neighborhood also underwent a normalization process (0 - indicating high disadvantage to 1 - indicating low disadvantage) in order to make it easier to compare and evaluate all four variables (accessibility, availability, behavior, exposure).

3.2.3. Behavior – geospatial data analysis

Behavioral analysis is deemed important for the purpose of this research to understand how certain population subgroups behave in different neighborhood units. The analysis has been done based on the frequency of use of different transport modes at least 1 to 3 times a week for walking, cycling, and public transport; or at least once a month for car-sharing. The analysis includes data from the German National Mobility Survey (Nobis & Kuhnimhof, 2019). After obtaining the data at the city level, the following analysis was performed per each indicator to assess the frequency of use at the neighborhood level:

- Using GIS, data from each indicator at the city level was intersected with neighborhood boundaries to calculate the frequency of the indicators per neighborhood and compare them with each other.
- They then underwent a normalization process rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage). to create the behavior analysis.
- The indicators were then summed up per neighborhood and normalized again (0 - indicating high disadvantage to 1 - indicating low disadvantage) in order to make it easier to compare and evaluate all four variables (accessibility, availability, behavior, exposure).

3.2.4. Exposure – geospatial data analysis

Exposure data determines the relative degree of risk or danger of various road traffic situations. The analysis aimed at identifying and measuring three main components: road crashes (overall), noise pollution, and air pollution. The exposure data analysis was performed per neighborhood and follows the following structure:

- Using GIS, road crashes have been spatially located, aggregated at a neighborhood level and finally, weighted by area unit to understand the distribution of road crashes per neighborhood in the city of Munich. Noise pollution was calculated per each neighborhood with an average LDEN dB (A) (Equivalent Continuous Noise Index) over 55 dB. Air pollution data has been processed based on particulate matter with a diameter of 2.5 μm or less (PM2.5). Since the data varies based on different week and weekend days, the mean of gram units per PM2.5 has been calculated as an average per neighborhood. Data has been estimated and extracted based on the road network of each neighborhood.
- To standardize comparisons, each indicator underwent a process of normalization; however, in this case, since mobility burdens are under investigation, the values ranged from 0 (indicating low disadvantage) to 1 (reflecting high disadvantage).
- The indicators were then summed up per neighborhood and normalized again (0 - indicating high disadvantage to 1 - indicating low disadvantage).

3.2.5. Mobility (Dis)Advantage Score

As an index to combine the different types of variables, we estimated the mobility (Dis)advantaged score (MD):

$$MD_j = w_{Acc}{*}Accessibility_j + w_{Av}{*}Availability_j + w_B{*}Behaivor_j + w_{Ex}{*}Exposure_j$$

$$| \, w_{Acc} + w_{Av} + w_B + w_{Ex} = 4$$

Where:

- w are the weights given for each type of variable' categories, given that $| \, w_{Acc} + w_{Av} + w_B + w_{Ex} = 4$
- $Accessibility_j$ is the Accessibility score for zone j, which is the sum of the minmax normalization of the variables included in the Accessibility categories. The same applies to the Availability, Behavior and Exposure scores. These scores should be such that, after normalization, the highest disadvantage should be 0, and the lowest disadvantage should be 1.

3.3. Correlation analysis

A correlation analysis has been conducted utilizing standardized values for socio-economic disadvantaged groups and mobility resources and burdens at the neighborhood level. A correlation matrix was used to show the association between the different variables. For example, areas with high migration are associated with high noise. This result would help to prioritize areas where, as a "coincidence", more migrants live and there is more noise. However, based on our approach, we do not explore causality. This means that we cannot state that because more migrants live there, there is more noise, or because there is a noisy area, more migrants live there. To understand and explore causality, we recommend going to the area of the study and developing surveys and interviews. This approach will help to understand what the priorities of the citizens are. The atlas aims to identify exclusively areas where the transport and social disadvantages intersect at a macro levels.

The numerical values within the matrix range from −1 to 0, denoting negative relationships. A value of −1 signifies the strongest negative correlation, signifying that as one value increases, the other decreases. On the other hand, positive values range from 0 to 1, indicating a positive correlation between the variables. A positive value suggests that as one variable increases, the other variable also increases. Finally, the results of the correlation matrix have been used to identify significant relationships between the variables under investigation.

4. Applying the proposed framework and methodology in Munich, Germany

The aim of the proposed Mobility Justice Framework is to be used to guide the analysis which can aid policymakers and other professionals working in the built environment, to identify disadvantaged areas in their cities. Due to data availability issues, the framework has been applied in Munich where it aimed to map out mobility inequalities based on the four main variables that have been previously discussed. However, a similar framework can also be used for analysis in other cities. This section will show step by step how the proposed methodology has been applied in Munich, as well as results and recommendations from our analysis of mobility inequalities for older people in Munich.

4.1. Case study – Mobility Justice Framework for older people in Munich

This research is part of the Mobility Justice in Metropolitan Regions project (MGEM), whose focus is the city of Munich, Germany. The project aims at laying the foundation for a mobility system in which the entire population of the metropolitan region can participate in the future of mobility. Based on the Mobility Justice Framework and methodology described in this paper, a Mobility Injustice Atlas has been produced as part of the project. It aims at highlighting neighborhoods where the allocation of transport infrastructure and mobility-related services do not meet the needs of the most disadvantaged population.

The city of Munich was selected for this project due to its existing relationship with the MGEM project and the availability of open data from official government sources, including the population census and mobility survey. These data sources are described in detail for each variable in Section 4.2. Munich is a city in southern Germany with a population of 1,558,395 as of 2020; it is the capital and most populous city of Bavaria as well as the third biggest and most densely populated city in Germany; it is divided into 108 neighborhoods ("Stadtbezirketeile") (Statistisches Amt der Landeshauptstadt München, Fischer, & Shewamal, 2020).

As one of the aims of this paper is to assess the applicability of the mobility justice framework, it is not feasible to present the full range of findings for the various socioeconomic disadvantaged groups. Consequently, this paper focuses on Munich as a case study and examines the mobility disadvantages experienced by older people (aged 65 and above). This group represents 17.5 % of Munich's total population (Landeshauptstadt München, 2020), and thus provides a representative sample of the broader disadvantaged population.

As shown in Section 2, the distributional concept of equity focuses on the accessibility and availability of primary goods (Aparicio, 2018). Stöckle (2020) found that mainly higher educated, younger, affluent, male full-time employed people use the bike sharing system in Munich. Car sharing is mainly used by males and young people in Berlin and Munich (Mueller, Schmoeller, & Giesel, 2015). As most new mobility innovations mainly benefit the privileged population (Kloppenburg, 2020), places need to be identified where these mobility interventions are needed the most. Therefore, it is necessary to assess in Munich who has access and will have access in the future and how we can plan for future mobility without leaving out the older population.

4.2. Datasets

This type of dataset has been used throughout the analysis of the 4 main variables, namely, accessibility, availability, behavior, and exposure. These variables have been measured against the disadvantaged socio- economic groups. Table 3 gives an overview of the datasets that

Table 3
Datasets and sources.

Variable	Type of data	Source
Accessibility	1 Road network	Open Street Map
	2 Points of interest (health, food, etc)	Open Street Map
	3 General Transit Feed Specifications	German National GTFS (https://gtfs.de/)
Availability and behavior	1 National Mobility Survey	Mobilität in Deutschland (MiD), 2017 (https://www.mobilitaet-in-deutschland.de/)
	2 Cycle lanes, road intersections, PT stops	Open Street Map
Exposure	1 Road accidents	'Unfallatlas', Statistischen Ämter des Bundes und der Länder (https://unfallatlas.statistikportal.de)
	2 Noise Pollution	Umwelt Atlas, Bayerisches Landesamt für Umwelt (https://www.umweltatlas.bayern.de/mapapps/resources/apps/umweltatlas/index.html?lang=de&dn=lfu_domain-laerm)
	3 Air Pollution	MATSim simulation tool
Socio-demographics	1 Social groups	Landeshauptstadt München (2018–2021) (https://www.mstatistik-muenchen.de/indikatorenatlas/atlas.html?indicator=i63&date=2018)
	2 Older people, young people and migrants	National Census 2011 (https://www.zensus2011.de/DE/Home/Aktuelles/DemografischeGrunddaten.html)

have been collected and where they come from.

4.2.1. Accessibility data preparation

Road network and points of interest (amenities) were downloaded from open sources like OSM. The selection of main amenities was based on a literature review about the importance of different users' daily mobility and surveys (Weng et al., 2019) like health services, food providers, sports centers, community centers, and education.

4.2.2. Availability and behavior data preparation

The data has been collected using a mobility survey, Mobility in *Deutschland* (MiD), which includes 14,410 households, 29,353 people surveyed, and 90,031 reported routes. It is a nationwide survey of households on their everyday traffic behavior on behalf of the Federal Ministry of Transport and Digital Infrastructure (BMVI). It was collected in 2002 and 2008. The current dataset was collected in 2017. Simultaneously, the public transport information dataset was obtained from the German national GTFS.

4.2.3. Exposure data preparation

Exposure data such as road accidents has been downloaded from the 'Unfallatlas' for Germany which is open-source data. The data has then been processed and aggregated at the neighborhood level. A similar approach has been followed for noise pollution data which has been imported into the QGIS project folder with WMS. The data has been made available as open source from Bayerisches Landesamt für Umwelt and has been made available online in the format of an Umwelt Atlas. The air pollution data has been collected using a multi-agent transport simulation model, MATSim, an open-source framework for implementing large-scale agent-based transport simulations.

4.3. Results of the analysis

The socio-demographic and economic data analysis of older people in Munich aimed at identifying those neighborhoods that have the highest concentration of this target group. To perform this analysis and subsequently render the outcomes in a spatially visual format, neighborhoods denoted as 'disadvantaged' based on the 'Socio-economic disadvantage score' explained in Section 3.2, were delineated. This categorization entailed identifying neighborhoods situated within the upper 75th quartile relative to the city's entirety. Fig. 2 shows the distribution of older people per neighborhood. The darker highlighted neighborhoods are those with the highest number of older residents, corresponding to neighborhoods located in more peripheral areas.

Accessibility analysis for older people focused on walking distances within a 700-m radius. This analysis encompassed five services: health facilities, food providers, community centers, sports centers and education. The resulting maps effectively portray the interplay between the overall population served, and the proportion of the older population served. This spatial visualization is executed at the level of neighborhoods. Notably, Fig. 3 serves to highlight the neighborhoods within Munich, necessitating heightened attention to address mobility challenges related to accessibility. To standardize comparisons, each indicator went through a process of normalization, rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage). In particular, areas in the outskirts, highlighted in light blue, show those areas where older people encounter obstacles while trying to access one or more of the essential services outlined.

The resultant map, Fig. 4, illustrates the correlation between the proportion of older people per neighborhood (classified as either high or low in comparison to the citywide average, based on the 75th quartile) and the mobility score for accessibility in that neighborhood (also classified as either high or low in comparison to the citywide average, based on the 25th quartile), as explained in Section 3.2. This approach allows us to derive a bivariate indicator at the neighborhood level, where we intersect the disadvantage of the social group (in this case, the high percentage of older people) with the disadvantage in transportation, in this case low accessibility. The resulting map identifies neighborhoods where the combination of a high percentage of older people and low accessibility represents a critical disadvantage, showed in dark pink (Fig. 4). Neighborhoods that are situated in the peripheries of the city are predisposed to conditions of disadvantage. It can be observed that those neighborhoods marked by a high presence of older population, simultaneously exhibit low accessibility to the five services assessed – namely health, food providers, community centers, sports centers, and education – by walking.

Availability analysis was performed by using the following indicators: 1) car-sharing membership, 2) bike and e-bike ownership, 3) availability of public transport stops, 4) availability of cycling infrastructure, and 5) availability of walking infrastructure. All these five indicators were initially analyzed separately and underwent a normalization process, rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage) to create the overall availability analysis. Notably, Fig. 5 shows the overall availability analysis for Munich, where neighborhoods on the city's outskirts face a greater disadvantage concerning transport infrastructure and services. Subsequently, the overall availability analysis map was cross-referenced and integrated with the preexisting population distribution map for older people (Fig. 2).

Similarly to the accessibility analysis, Fig. 6 aimed to gain insights into how transport infrastructure and services (availability) are spread across neighborhoods with a higher concentration of older people. A similar pattern to that of the accessibility analysis can be observed where, again, a higher percentage of older people living on the city's outskirts have fewer mobility options available to them.

Behavior analysis measured the frequency of use of the various sustainable modes of transportation. The analysis has been done based on using different transport modes at least 1 to 3 times a week for walking, cycling, and public transport; or at least once a month for car-sharing. Again, all indicators have been initially analyzed separately and have then undergone a process of normalization, rendering values ranging from 0 (indicating high disadvantage) to 1 (reflecting low disadvantage), in order to create the overall behavior analysis and classified as high or low compared to the city average, as explained in Section 3.2.

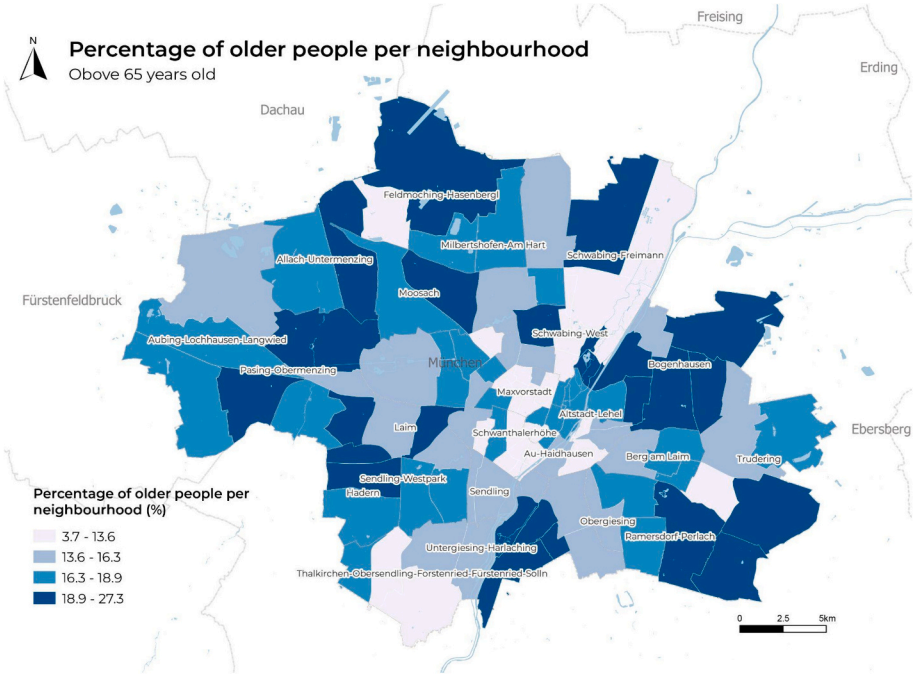

Fig. 2. Distribution of older people per neighborhood.

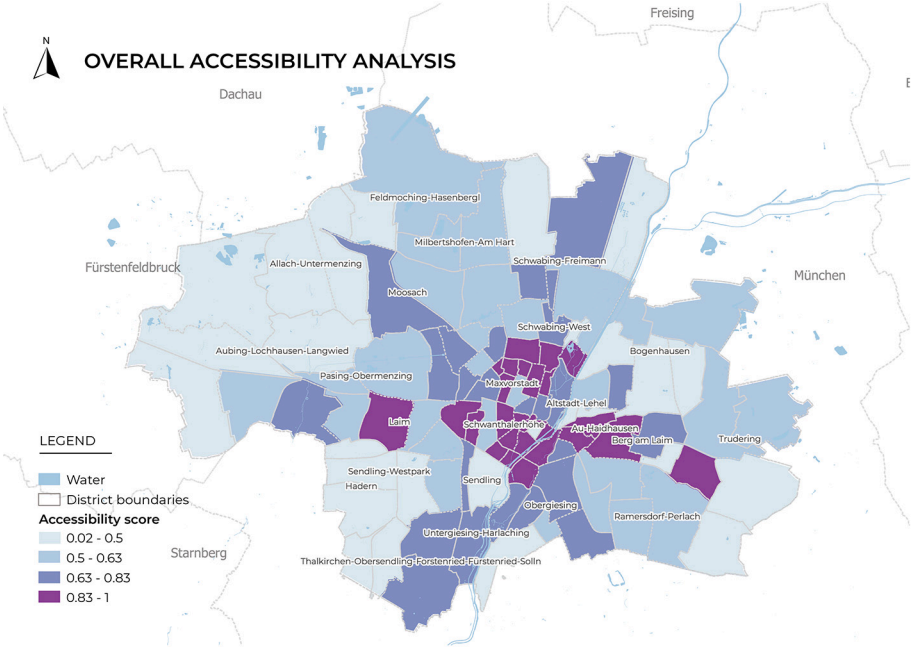

Fig. 3. Walking accessibility.

Fig. 7 shows that the neighborhoods that use less sustainable modes of transportation are mainly located in the northwest and southeast of the city.

Fig. 8 illustrates the correlation between the proportion of older people per neighborhood (classified as either high or low in comparison to the citywide average, based on the upper 75th quartile) and the mobility score for behavior (use of sustainable modes of transport) in that neighborhood (also classified as either high or low in comparison to the citywide average, based on the 25th quartile). The resulting map identifies in dark blue those neighborhoods where the combination of a high percentage of older people and low use of sustainable modes of transport represents a critical disadvantage, located mainly in the outskirts.

Exposure analysis for older people was performed using three main indicators and their distribution across various neighborhoods: road crashes (overall), noise pollution, and air pollution (PM2.5). Understanding which areas are more prone to traffic negative effects is important for policymakers and professionals working in the built environment so that they can think of possible interventions to counterbalance these negative externalities. To standardize comparisons, each indicator underwent a process of normalization, however, in this case, the values ranged from 0 (indicating low disadvantage) to 1

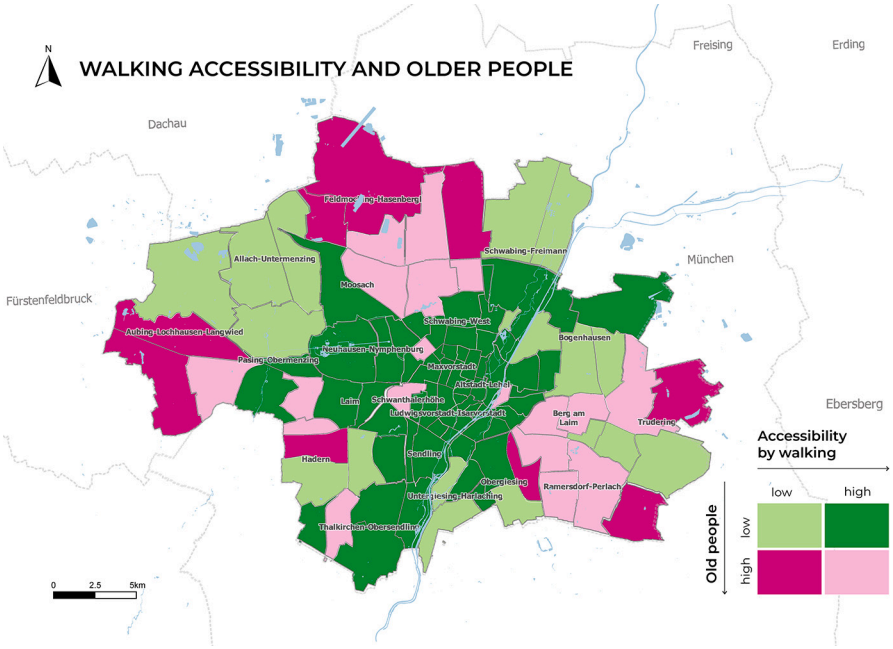

Fig. 4. Relation between older people and accessibility.

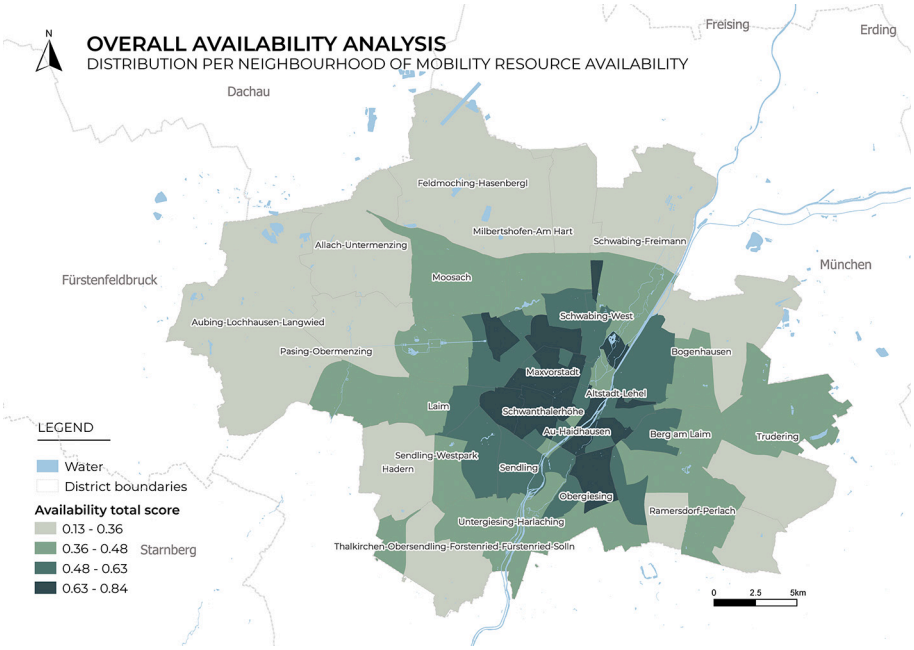

Fig. 5. Availability analysis.

(reflecting high disadvantage).

Fig. 9 shows the resultant map of all exposure analysis, highlighting areas where neighborhoods face elevated exposure to traffic negative effects. It is important to notice that in this case, central areas of the city are those that suffer more the burdens of traffic's negative effects. By juxtaposing this analysis with the previous assessment of resource distribution like accessibility, availability, and behavior, a noteworthy pattern emerges: neighborhoods that enjoyed ample provisions of transport infrastructure and services are the same neighborhoods that suffer from transport-related burdens. Consequently, when strategizing future transport infrastructure developments, it becomes imperative to account not only for the immediate benefits but also for the potential counterbalancing impacts that such infrastructural advancements might entail.

Similar to the previous analysis, Fig. 10 illustrates the correlation between the proportion of older people by neighborhood (classified as either high or low in comparison to the citywide average, based on the 75th quartile) and the mobility score for exposure in that neighborhood (also classified as either high or low in comparison to the citywide average, based on the 75th quartile, since we are measuring negative effects). This approach allows us to derive a bivariate indicator at the neighborhood level, where we intersect the disadvantage of the social group (in this case, the high percentage of older people) with the disadvantage in transportation, in this case high exposure to transport negative effects. The resulting map identifies in dark blue disadvantaged neighborhoods due to the combination of a high percentage of older

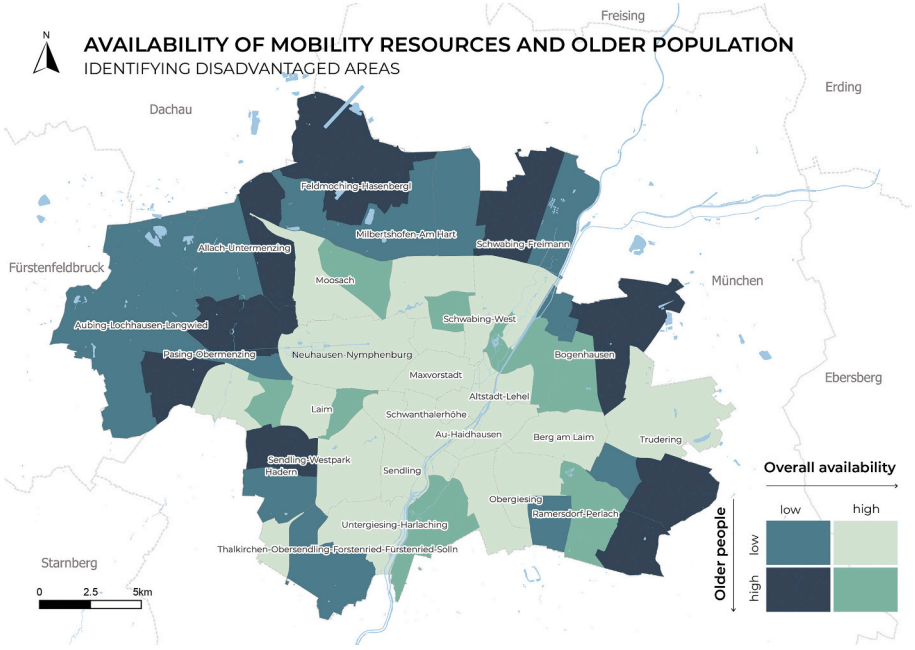

Fig. 6. Availability analysis for older people.

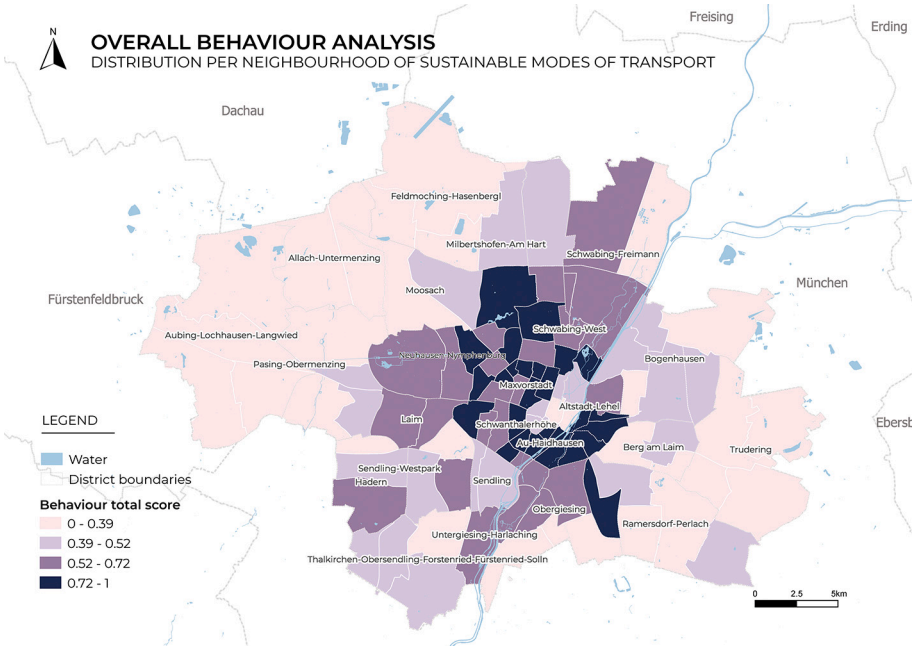

Fig. 7. Behavior analysis.

people and high exposure to traffic negative effects such accidents, noise and bad air quality.

4.4. *Findings – which neighborhoods require intervention?*

Based on the Mobility Justice Framework developed in Section 2, the analysis focused on highlighting those neighborhoods where a higher percentage of older people live and the distribution of mobility resources and burdens in these neighborhoods. Older people were mainly chosen as an example to show the applicability of the framework for one of the disadvantaged social groups. By doing so, this study aimed at combining and operationalizing, even though in a quantitative way, two important dimensions of transport justice, distributive and recognition justice. Initially, the process involved aggregating the standardized values of each indicator for every neighborhood, leading to the formulation of a Mobility Score (refer to Fig. 11). The Mobility Score included the following:

- Accessibility by walking to food providers, health services, and community centers;
- Availability of car-sharing membership, bike/e-bike, cycling infrastructure, walking infrastructure and public transport;
- Frequency of using walking, cycling, public transport, and car-sharing services;
- Exposure to road crashes, noise pollution, and air pollution.

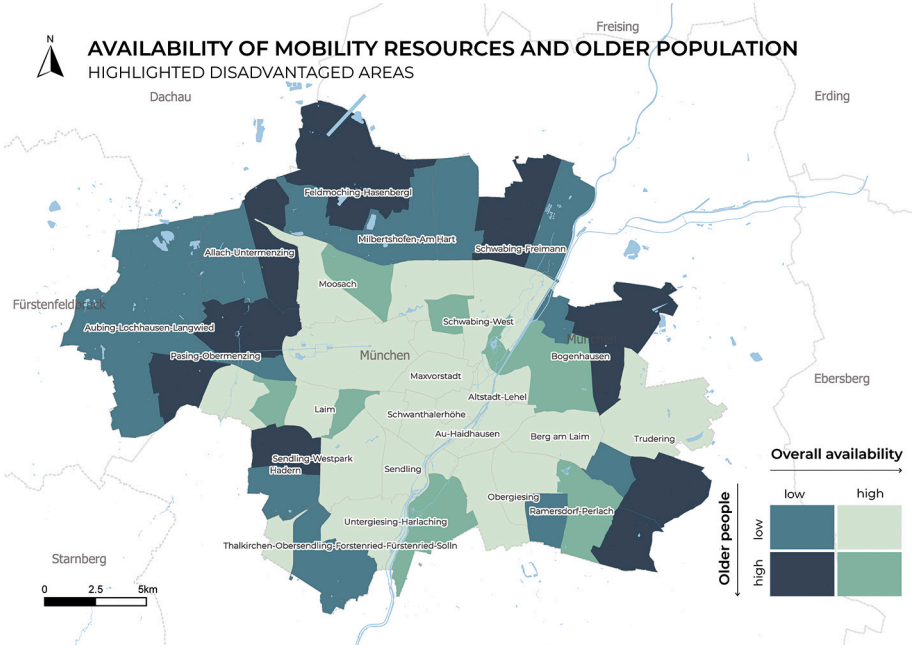

Fig. 8. Behavior analysis for older people.

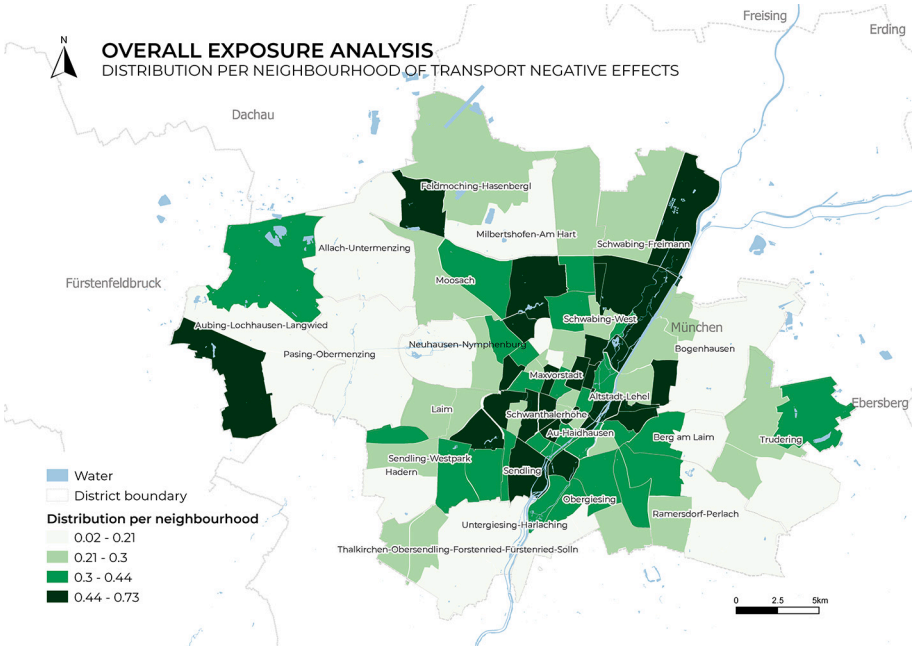

Fig. 9. Exposure analysis.

The mobility score analysis correlated with the older people analysis to identify those neighborhoods with a higher concentration of older people and that are more disadvantaged in terms of mobility resources and burdens. The resultant map (Fig. 12) highlights neighborhoods necessitating heightened policy attention for improved infrastructure and service provision to better serve the needs of older people living in these neighborhoods.

So far, the study has shown how the framework can be applied in Munich by considering older people to exemplify its applicability. A correlation analysis was performed to understand the type of mobility disadvantage that older people and other disadvantaged socio-economic groups are more likely to suffer from. The analysis was performed to ascertain whether a pattern exists of residing in areas with either more or fewer mobility resources and externalities.

A higher negative correlation between older people and mobility resources/ burdens can be observed for the following variables and neighborhoods:

- Accessibility generally to basic needs like food suppliers, health services, community centers, education, and sports centers. Neighborhoods where these disadvantages rank higher in Munich are: Biederstein, Daglfing, Freimann, Harlaching, Industriebezirk, Kleinhesselohe, Waldperlach, Waldtrudering.
- Regarding availability (and behavior as a proxy), a notable trend emerges: neighborhoods with a higher proportion of older people show limited access to sustainable transportation modes. This

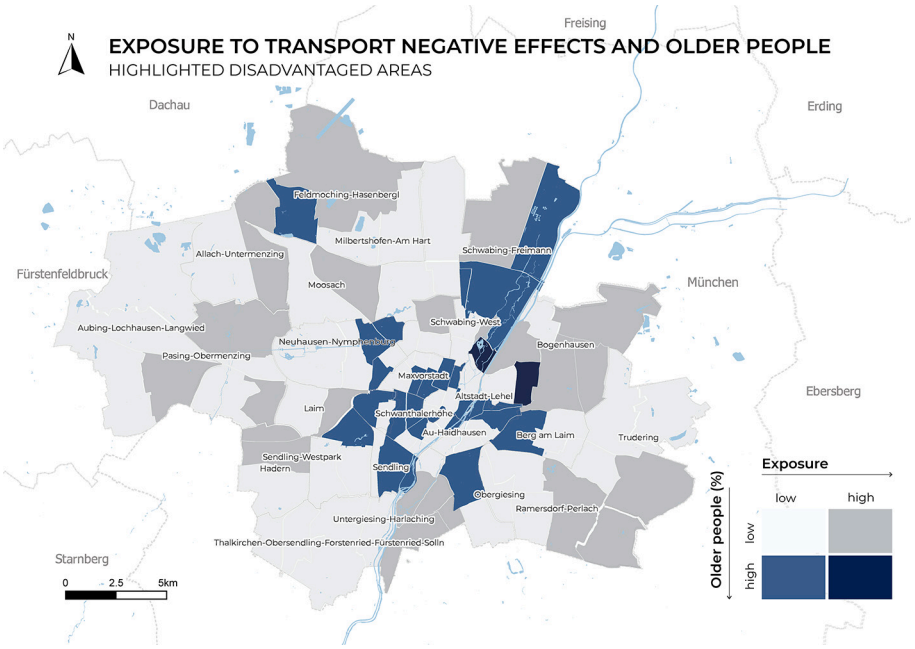

Fig. 10. Exposure analysis for older people.

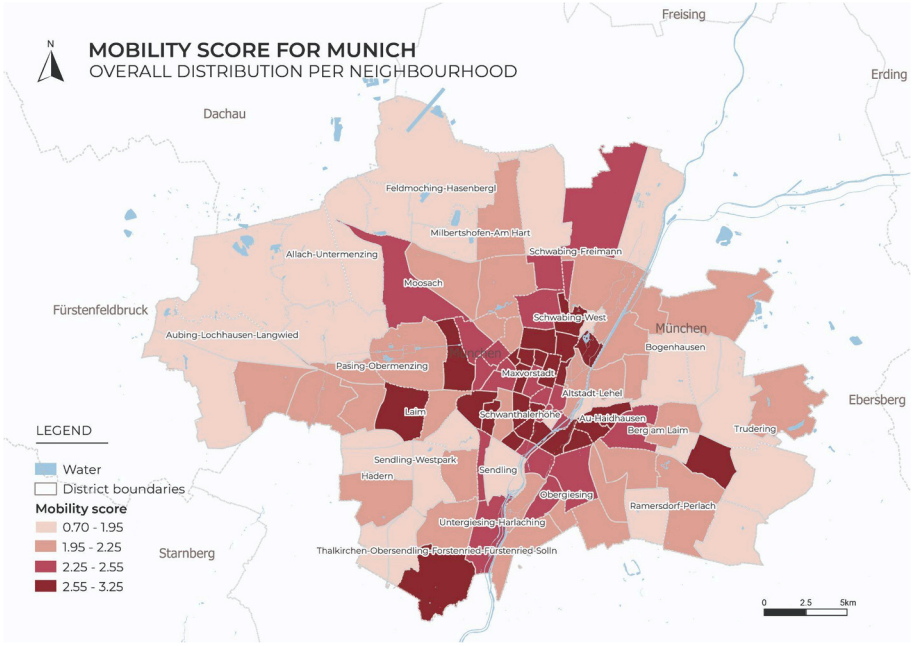

Fig. 11. Mobility (Dis)Advantage Score for Munich.

underscores the imperative to channel more investment into enhancing transport infrastructure and services, thereby giving the inhabitants of these neighborhoods a broader array of transport options. The neighborhoods that have priority in this context are Alt Moosach, Aubing-Süd, Blumenau, Daglfing, Feldmoching, Freimann, Neuhadern, Neuperlach, Waldtrudering.

- No negative correlation is observed regarding traffic negative effects in neighborhoods with a higher concentration of older people.

5. Discussion

Based on the analysis, neighborhoods with a higher share of older people in Munich suffer from mobility disadvantages when accessing services such as food, health, community centers, etc. Simultaneously, sustainable modes of transport such as car-sharing and public transport, as well as, active modes like walking and cycling, are not much present in neighborhoods with a higher proportion of older people compared to the rest of the city. These concerns extend beyond just the city's suburban areas, encompassing various neighborhoods. These findings align with prior research conducted within the German context, indicating that novel mobility solutions such as bike-sharing and car-sharing services are primarily accessible to young, affluent, and predominantly male adults (Stöckle, 2020; Müller et al., 2015). This highlights a critical call to action for policymakers. It underscores the imperative for strategic investments that prioritize inclusivity across all demographics, particularly, in this case, older people, ensuring that emerging mobility

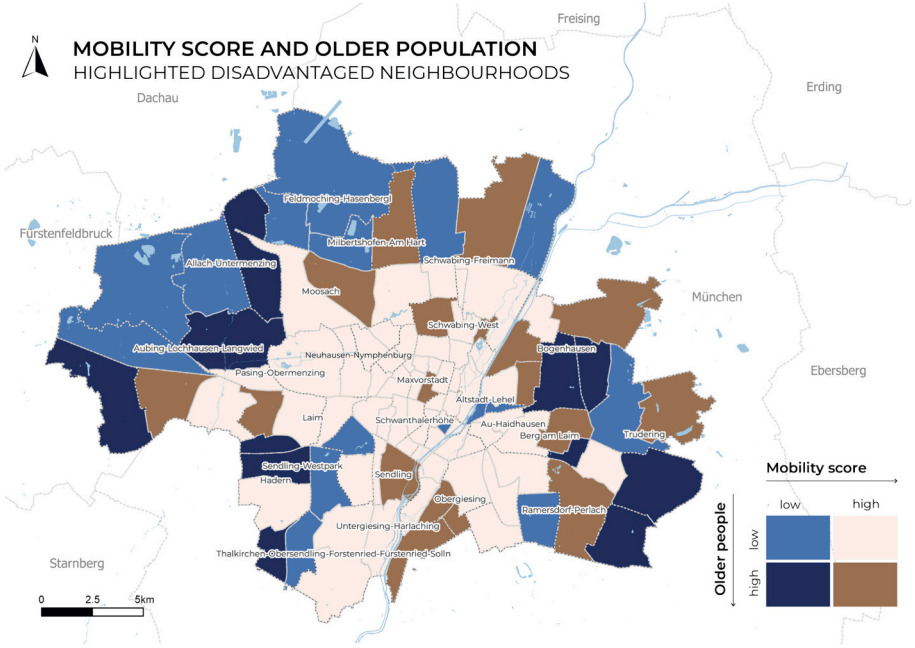

Fig. 12. Mobility (Dis)advantage Score and older people.

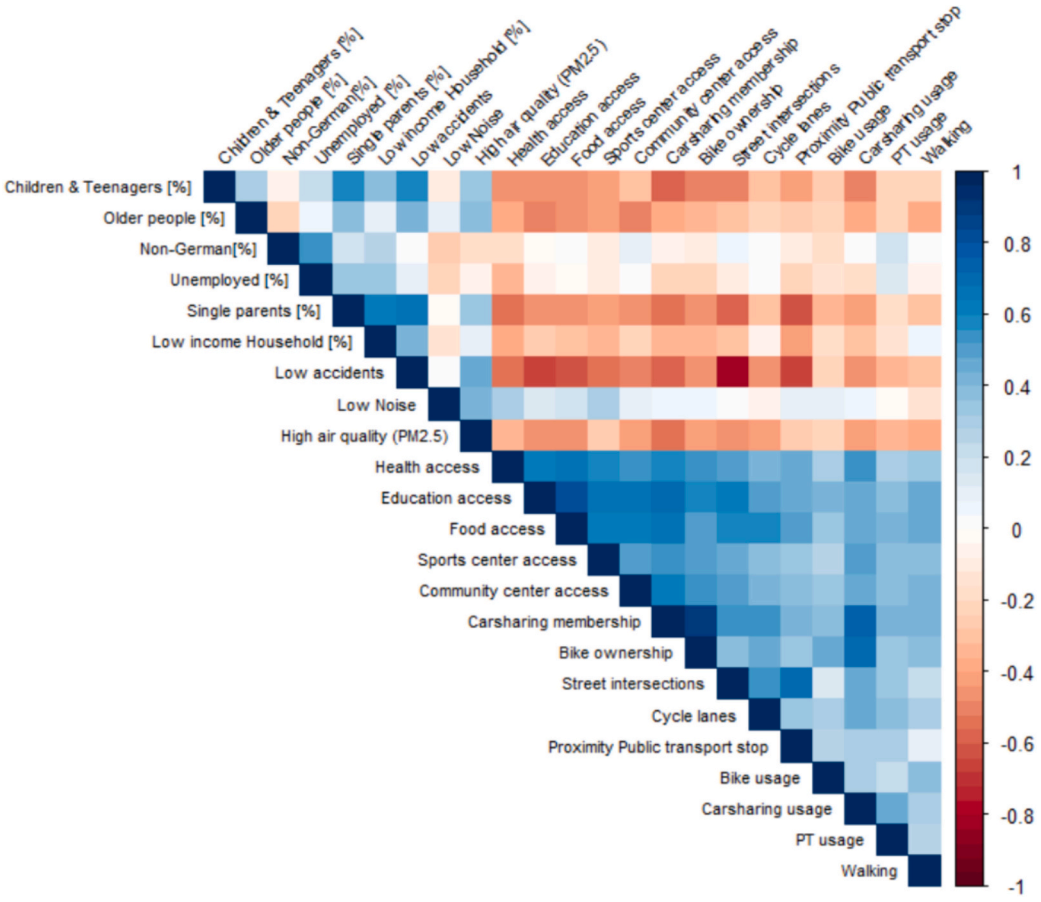

Fig. 13. Spearman correlation matrix.

innovations benefit everyone.

The correlation matrix (Fig. 13) highlights areas where multiple socio-economic disadvantages overlap with transport disadvantages. Other key observations regarding other disadvantaged socio-economic groups show that low-income households are:

- Positively correlated with poor air quality and higher noise levels, indicating environmental disadvantages.
- Negatively correlated with health access, education access, food access, sports center access, and community center access, suggesting limited access to essential services.
- Also negatively correlated with carsharing membership, bike ownership, and bike usage, indicating transport disadvantages.

On the other hand, people who are unemployed and those with a migration background show similar patterns to low-income households, indicating that these groups also face significant transport disadvantages and limited access to services. Interestingly, high air quality and low noise are positively correlated with higher access to health, education and food and negatively correlated with disadvantaged socio-economic groups. Positive correlations among different forms of transport can be observed (e.g., bike lanes, public transport stops, carsharing usage), suggesting that neighborhoods with better transport infrastructure have fewer socio-economic disadvantages. Accompanied by both, statistical and visual elements, the proposed framework to analyze mobility inequalities at the city scale can aid policy-makers, mobility advocates, and professionals in the built environment to make a first screening of the neighborhoods that require more attention when it comes to developing mobility strategies.

Understanding the composition of the neighborhoods is of paramount importance in order to prioritize the interventions based on the needs of the socio-demographic distribution of that neighborhood. The proposed Mobility Justice Framework aimed at offering an applicable framework for analysis at the city level, by integrating both, distributive and recognition justice principles. By doing so, it aimed to shift the attention in addressing mobility inequities from a state-centric to a more society-centric view. This is important for decision-makers and mobility advocates for the following reasons.

- It can mitigate the limitations that governmental bodies have to recognize and understand the diverse needs, experiences, and habits of all population groups, especially the most disadvantaged ones. Schwanen (2020) argues that even in London, known for its progressive stance on cycling and walking, there are limits to which the state apparatus is able to recognize the full extent of needs and daily practices associated with cycling and walking, especially when targeting disadvantaged groups such as people with disabilities.
- Acknowledging the needs, experiences, and habits of all groups related to certain mobility infrastructures and services, i.e. cycling, can play a vital role in promoting and encouraging the adoption of sustainable transportation modes. This holds significant importance in mitigating urban climate change impacts, a point which is very high in city planning agendas worldwide.
- Understanding the composition of the neighborhood is of paramount importance in order to prioritize the interventions based on the needs of the socio-demographic distribution of that neighborhood.

However, despite the integration of justice theories that focus on both quantitative and qualitative analysis of mobility justice, the nature of this study analysis remains quantitative. We are aware that with this framework and the proposed methodology, we cannot do justice to the lived experiences and subjective identification of the people subsumed under such categories in the underlying data. Furthermore, it is important to clarify that disadvantages are intersectional and that the categorized data does not allow for such an intersectional perspective (e.g. a person affected by several intersecting discriminations, such as classism and racism, which could increase the degrees of disadvantage). Further qualitative research is needed to understand the mobility perceptions of disadvantaged socio-demographic groups targeted by the study. A more qualitative analysis would complement and validate the quantitative work to allow for data triangulation on what people consider as unequal distribution of resources in their area and explore the stories behind these perceived mobility injustices.

6. Conclusions and future research directions

The study sought to introduce a framework for examining mobility justice that integrates distributive and recognition justice principles. While existing literature and methodologies predominantly center around distributive aspects of mobility justice, the Mobility Justice Framework analysis emphasizes the importance of accounting for the specific demographic affected by mobility interventions or their absence. The applicability of the conceptual framework and the methodology that has been developed for the purpose of this research are considered important and valid for practitioners and policymakers working with mobility issues. While this approach has been tested to work for Munich, the transferability of this framework and method should also be tested in other cities. Despite using open data sources and national mobility surveys and census, to ensure that similar data can be obtained for other cities, some elements used to feed into the mobility resources and mobility burdens variables would be different. The quantitative method needs to be complemented by more qualitative assessments; however, this spatial approach offers a possibility to test current mobility developments in our neighborhoods and highlight areas for improvement, considering the needs of the most disadvantaged socio-economic groups.

Through the results of this study, different strategies for the future of mobility in Munich can be recommended in the targeted neighborhoods, which also include the less privileged population. For instance, when assessing the distribution of mobility resources and burdens for neighborhoods with a higher share of older people, the analysis shows that this specific target group is at a higher risk of suffering from a lack of accessibility to services such as health, food, community centers, etc., as well as lack of available infrastructure and services. Giving priority to neighborhoods prone to these disparities should become a focal point for directing public investments. These investments should be precisely aimed at fulfilling the accessibility and transportation infrastructure requirements for the older population.

Work along these lines frames mobility justice as an ongoing process shaped by places, spatial configurations, and the diversity of the people living there. This study aimed to demonstrate the importance of effectively visualizing mobility challenges while proposing a comprehensive framework that seamlessly integrates distributive and recognition equity. This framework holds the potential to greatly enhance mobility justice decision-making processes. The variables used for this analysis, accessibility, availability, behavior, exposure, and disadvantaged socio-economic groups, have been drawn from prior studies within the same research domain, aiming at analyzing mobility justice based on distributive and recognition justice considerations. It is essential to note that this study's objective was not to provide a comprehensive overview of all potential variables. The chosen variables were strategically used to visualize and understand mobility injustices at the neighborhood level with a specific focus on identifying the target groups that are more disadvantaged.

However, it is acknowledged that other variables remain open for consideration. For instance, this study focused mainly on the accessibility to basic services without considering other services which are more related to leisure and recreational activities. Another important variable used in distributive justice studies is time and distance travelled. This variable can be very relevant to understanding the needs of those neighborhoods that have longer commuting times and distances and channel public investments in a way that can make it easier for

people residing in areas with higher travel demands to fulfil their daily needs and activities.

While this paper highlighted older people as the target disadvantaged socio-economic group, the broader study focused on the analysis of other disadvantaged socio-economic groups such as children and teenagers (under 18 years old), migrants, single-parent households, low-income and unemployed. Further research would be needed to analyze other disadvantaged groups, including people with disabilities and other minorities. Furthermore, a cross-sectional analysis of socio-demographic data is recommended to offer a clearer and more comprehensive depiction of socio-economic profiles.

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CRediT authorship contribution statement

Sindi Haxhija: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. **David Duran-Rodas:** Data curation, Investigation, Methodology, Writing – review & editing. **María Teresa Baquero Larriva:** Data curation, Formal analysis, Methodology, Writing – review & editing. **Gebhard Wulfhorst:** Funding acquisition, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Technical University of Munich team working on the Mobility Justice for Metropolitan Areas project reports financial support was provided by Federal Ministry of Education and Research Berlin Office. Maria Teresa Baquero Larriva reports a relationship with European Commission that includes: funding grants. If there are other authors, they 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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