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DOI
10.1016/j.jtrangeo.2025.104151

Publication date
2025

Document Version
Final published version

Published in
Journal of Transport Geography

Journal of Transport Geography 123 (2025) 104151

Contents lists available at ScienceDirect

Journal of Transport Geography

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

Exploring the interplay of transport, social, and geographical disadvantages and its effect on perceived inaccessibility

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ARTICLE INFO

Keywords:
Perceived accessibility
Transport poverty
Accessibility poverty framework
Transport-related social exclusion

ABSTRACT

To address transport injustice and social exclusion, the needs and perceptions of different groups of individuals seem indispensable. Consequently, perceived accessibility has received a growing interest in recent years. While it is well established that transport and social disadvantages cause transport poverty and perceived inaccessibility, only recently the relevance of geographical disadvantages has been addressed.

This paper explores the idea that an individual is more likely to experience inaccessibility if they face transport, social, or geographical disadvantages in at least two of these dimensions of transport poverty. For instance, while living in a rural area or lacking the ownership of a car may not translate into low perceived access on themselves, the combination of the two might lower perceived access. To empirically assess whether and which disadvantages indeed lower perceived accessibility further, the effect of combinations of disadvantages on perceived accessibility in rural and urban areas of the Netherlands are systematically explored using a regression analysis. Data is retrieved from the Dutch National Travel Survey. This survey includes a 1-day travel diary, measures both objective and subjective accessibility, and is administered among a representative sample of the Dutch population. In total, a large and representative sample of 22,742 participants is included in the analysis.

Results highlight that rural-living individuals only perceive inaccessibility if they indeed encounter one or more transport and/or social disadvantages as well. Also, not possessing a driver's license determines perceived inaccessibility to a larger extent than a lack of car ownership. Lastly, possessing an e-bike is beneficial for the elderly in both rural and urban Dutch areas. The research findings may support policymakers and practitioners in tailoring policy interventions towards the needs of individuals who suffer from multiple disadvantages.

1. Introduction

Approximately 2.4 billion individuals are estimated to be at risk of social exclusion in 2024, representing around 30 % of the global population (Cuesta et al., 2024). Here, social exclusion refers to the situation in which individuals are unable to participate fully in society (United Nations, 2016). Reducing social exclusion involves improving access to resources (e.g. income, employment, and housing) as well as services (education and healthcare) among disadvantaged people (United Nations, 2016).

The last two decades denoted a growing interest in the nexus between transport and social exclusion. Reducing social exclusion is mainly concerned with providing individuals with the possibilities to participate in society rather than providing the resources themselves (Jeekel and Martens, 2017) and, thus, social exclusion is inherently related to the transport system. The Social Exclusion Unit study, which helped in identifying the relationship between transport and areas of policy concern such as unemployment and poor education, is seen as one of the most influential studies on transport-related social exclusion (Lucas, 2012), leading to a rapidly increasing body of research.

To date, research on transport-related social exclusion has mainly been centred around identifying vulnerable groups in relation to the transport system. This approach studies travel behaviours as well as attitudes and perceptions of social groups that are seen as disadvantaged in the transport system (Church et al., 2000). Several studies have identified possible drivers behind lower levels of accessibility. Commonly, these drivers depict disadvantages in either the transport or social dimension of accessibility. Whereas a lack of car ownership, high cost of fares, and poor public transport services are examples of transport disadvantages, older age, lower income, and poor digital skills are examples of social disadvantages. In addition, Lucas (2012) stressed that the most socially disadvantaged within society are likely to perceive the

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https://doi.org/10.1016/j.jtrangeo.2025.104151
Received 27 August 2024; Received in revised form 20 January 2025; Accepted 7 February 2025
Available online 15 February 2025

lowest levels of accessibility if they also experience one or more transport disadvantages. Only recently, Pot et al. (2020) added disadvantages in the geographical dimension of accessibility to the set of drivers of lower perceived accessibility. Such disadvantages refer to the extent to which land-use enables individuals to reach and participate in activities (Pot et al., 2020). For instance, if individuals need to travel longer distances to participate in activities or encounter a lower density of amenities in proximity, this may translate into perceived inaccessibility (Pot et al., 2020).

However, adequately assessing who is left behind does not only involve the use of objective indicators, the perceptions of these individuals must also be considered (United Nations, 2016). After all, social exclusion depends on personal experiences (United Nations, 2010). Van Wee (2016) underlined that perceived accessibility was understudied at the time, urging to study subjective accessibility in more detail. Since then, studies have concluded that subjective accessibility systematically differs in outcomes compared to objective accessibility (e.g. Lättman et al., 2016, 2018). In other words, objectively calculated accessibility may not fully reflect the way how individuals actually experience accessibility.

In the past years, more studies have been centred around addressing perceived accessibility. The majority of these studies examined the effects of either social, transport, or geographical disadvantages on perceived accessibility, or examined general accessibility levels. Only limited studies included disadvantages within all dimensions (e.g. Olfindo, 2021; Liu et al., 2021; Chen et al., 2022; Pot et al., 2023; Fu et al., 2024). However, as early acknowledged by Church et al. (2000), studies often focus on a particular dimension of the problem, which may not fully acknowledge the interaction with other social, transport, and geographical factors.

Of these studies focussed on perceived accessibility, Pot et al. (2020) acknowledged that it is not the single effect of transport, social, and geographical disadvantages but the combined effect of two or more disadvantages that determines whether inaccessibility is experienced. For instance, living in rural areas may only be perceived as problematic if one lacks the ownership of a car as well. For urban areas, car dependency is far lower (e.g. Zijlstra et al., 2022; Jorritsma et al., 2023) and, thus, may be of less importance for perceived inaccessibility. Still, the subtle notion that combined effects of transport, social, and geographical disadvantages lower perceived accessibility is not yet extensively addressed.

This paper builds on this notion of Pot et al. (2020) that transport, social, and geographical disadvantages interact to cause perceived inaccessibility by systematically exploring the interactions between these disadvantages. In doing so, this paper aims to empirically explore whether and which combinations of disadvantages drive lower levels of perceived accessibility. This knowledge may aid policymakers and practitioners in developing informed policies to increase (perceived) accessibility.

The Dutch National Travel Survey is used to estimate the single and combined effect of various disadvantages on perceived accessibility. This survey provides information on travel patterns and behaviour of respondents on a particular day of the year (Statistics Netherlands, 2025). In addition, respondents were asked to indicate their perceived accessibility of various locations, such as the hospital, train station, and grocery market. In total, 22,742 respondents were included in the analysis.

The remainder of this paper is structured as follows. Section 2 discusses the background literature, whereas Section 3 presents the analytical framework. Section 4 proposes the methods used and Section 5 formulates the model findings and discusses the results in light of earlier findings. Lastly, Section 6 provides concluding remarks, policy implications, and recommendations for future research.

2. Background literature

2.1. Accessibility, accessibility poverty, and transport-related social exclusion

Following Geurs and Van Wee (2004), accessibility is defined as '*the extent to which land-use and transport systems enable [...] individuals to reach activities or destinations*'. In line with this, accessibility poverty and social exclusion lurk if it is *'systematically difficult to reach and participate in activities in a specific society at a reasonable time, ease, and cost'* (Moleman and Kroesen, 2024). Both objective as well as subjective accessibility measures can be used to address accessibility poverty and transport-related social exclusion.

While Morris et al. (1979) emphasised this distinction between objective and subjective accessibility measures several decades ago, objective measures are more often applied to study the effect of accessibility and accessibility poverty on social exclusion. Commonly, these measures reflect one of the four components of accessibility as distinguished by Geurs and Van Wee (2004). These are the land-use, transportation, temporal, and individual components. However, as Geurs and Van Wee (2004) emphasize, these components are not often studied simultaneously.

Yet, in light of transport-related social exclusion, Lucas (2012) underlined that it is the combination of disadvantages in the transportation and individual components that drive individuals' accessibility levels. Whereas transport disadvantages involve difficulties experienced in travelling when needed, social disadvantages are related to the socio-demographics of the individual itself. For the transport dimension, Currie et al. (2010) proposed the lack of car ownership as one disadvantage. Afterwards, Lucas (2012) extended the set of transport disadvantages with the high cost of fares and poor public transport services. For the social dimension, disadvantages are related to, for example, low education, income, digital skills. When an individual is unable to offset a transport or social disadvantage in the other dimension, activities or locations may become inaccessible (Lucas, 2012). This is often referred to as transport poverty.

Pot et al. (2020) extended the transport and social dimensions of transport poverty with the spatial dimension, aligned with the definition of accessibility by Geurs and Van Wee (2004). As stressed by Pot et al. (2020), adding this spatial layer to transport poverty is relevant to study transport-related social exclusion. In accordance, Miller (2018) argued that accessibility is the result of opportunities provided by the land-use and transportation component, while dependent on individual abilities. Examples of geographical disadvantages are longer distances and a lower number of amenities in proximity (Pot et al., 2020).

2.2. Perceived accessibility

The last decade denoted a growing interest in perceived accessibility and its measures. In recent studies, perceived inaccessibility is often linked with transport poverty. This link between transport poverty and perceived inaccessibility emphasises that transport, social, and geographical disadvantages may translate into perceived inaccessibility. In addition, as stressed by Moleman and Kroesen (2024) in the Accessibility Poverty Framework, accessibility poverty lurks if a small segment of society perceives low accessibility levels while the majority perceives high accessibility levels.

Van Wee (2016) argued that perceived accessibility was understudied at the time, urging to study the differences between objective and subjective accessibility measures. These studies showed that perceived accessibility consistently differed in outcomes compared to objective accessibility, which implies that individuals' level of accessibility inferred based on calculated data do not necessarily reflect the level of accessibility perceived by individuals (see, for instance, Pot et al., 2021).

The majority of both qualitative and quantitative studies in light of perceived accessibility focussed on either the social, transport, or geographical dimension of transport poverty, or examined general accessibility levels (e.g. Albacete et al., 2017; Lättman et al., 2018; Guimarães et al., 2019; Márquez et al., 2019; Tiznado-Aitken et al., 2020; Tiznado-Aitken et al., 2021; Van der Vlugt et al., 2022; Wang et al., 2022a; Wang et al., 2022b; Smale et al., 2022; Ward and Walsh, 2023; Guzman et al., 2023; Friman and Olsson, 2023; Lättman et al., 2023; Watthanaklang et al., 2024). Heterogeneity in accessibility levels is often mitigated since most studies do not explicitly evaluate differences in perceived accessibility across diverging groups of individuals. Combined effects of disadvantages on perceived accessibility are not commonly assessed as well.

Only limited studies integrate disadvantages in all three dimensions of transport poverty to study their effect on perceived accessibility scores (e.g. Olfindo, 2021; Liu et al., 2021; Chen et al., 2022; Pot et al., 2023; Fu et al., 2024). Olfindo (2021) examined satisfaction with bus stop accessibilities based on objective and subjective accessibility measures, whereas Liu et al. (2021) examined the role of smartphone-based activities on perceived accessibility. Chen et al. (2022) explored the effects of three perception-based disadvantages: high costs or efforts, limited physical abilities, and opportunity inaccessibility. Both Pot et al. (2023) and Fu et al. (2024) conducted a regression analysis to explore the effects of objective accessibility measures on perceived accessibility. Whereas Pot et al. (2023) narrowed down to rural areas only, Fu et al. (2024) focussed on multimodality.

Among those studies that integrate disadvantages in all three dimensions of transport poverty, Pot et al. (2023) studied the combined effect of geographical and transport disadvantages as well as geographical and social disadvantages for rural areas. For this, commonly used transport and social disadvantages are examined, among others older age, low income, and lack of car ownership. Nonetheless, the effect of other transport and social disadvantages remained unexplored. In addition, the sample size of 2227 respondents only include rural-living individuals, leaving out urban-living individuals. The perceived accessibility of respondents living in rural areas of the Netherlands is measured using the PAC-scale proposed by Lättman et al. (2018). Consequently, the notion that the combined effect of disadvantages may result in lower perceived accessibility compared to the single effect of disadvantages is not yet extensively addressed. As a result, a thorough understanding of which set of objective accessibility measures matters in estimating and predicting perceived accessibility is not yet established.

This paper aims to further explore the idea put forward by Pot et al. (2020) that individuals are likely to perceive inaccessibility if they face transport, social, or geographical disadvantages in at least two dimensions. To empirically assess whether and which disadvantages lower perceived accessibility further, the effect of combinations of disadvantages on perceived accessibility in rural as well as urban areas are systematically explored. To this end, a regression analysis is conducted. In doing so, this paper provides an understanding of which combinations of measures affect individuals' perceived accessibility by exploring the perceived accessibility to destinations for a large set of respondents in both rural and urban areas of the Netherlands.

3. Conceptual model

To further clarify the study's focus, a conceptual model is developed. Fig. 1 shows this model, which is based on earlier frameworks proposed by Lucas (2012), Pot et al. (2020), and Moleman and Kroesen (2024). Whereas Lucas (2012) underlines that transport and social disadvantages interact to cause transport poverty, both Pot et al. (2020) and Moleman and Kroesen (2024) state that it is rather the interplay between transport, social, and geographical disadvantages that causes transport poverty. The conceptual model in Fig. 1 combines both notions, by highlighting the subtle difference between two-way and three-way interactions between disadvantages. Here, we emphasize that two dimensions may interact to cause transport poverty, while it may be the case that transport poverty is the result of the interplay between all three dimensions, potentially decreasing a person's perceived level of accessibility further.

While it is not the focus of this study, an additional path from perceived inaccessibility to the various disadvantages is incorporated in the conceptual model to emphasize the possible role of learning within a specified context. Here, contextual factors may entail social norms and practices, economic and political structures, as well as governance and decision-making processes (Moleman and Kroesen, 2024).

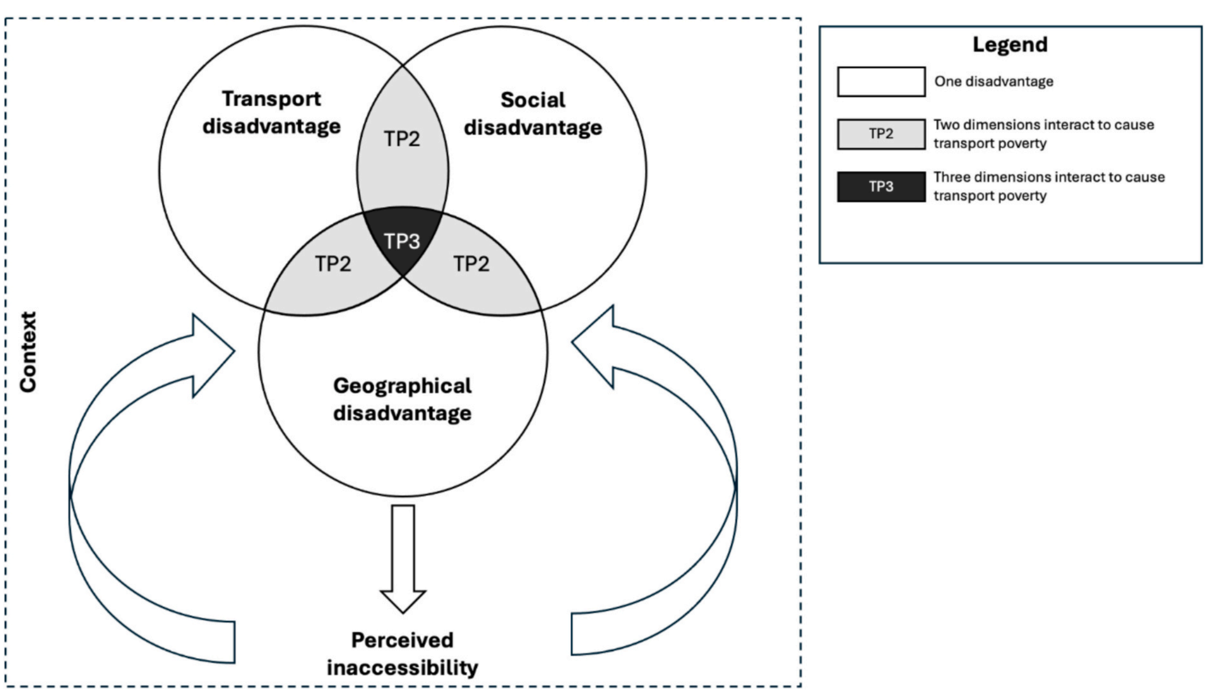

Fig. 1. Conceptualization (based on Lucas (2012), Pot et al. (2020), and Moleman and Kroesen (2024)).

4. Methods

4.1. Data

This paper uses the Dutch National Travel Survey to estimate the effects of objective accessibility measures on perceived accessibility levels. This survey provides information on travel patterns and behaviour of respondents on a particular day of the year. A representative sample of the population is obtained using stratified sampling in two steps. First, municipalities are randomly selected based on their number of residents. Second, random sampling is performed on these selected municipalities. (Statistics Netherlands, 2025)

In total, 22,742 respondents were included in the analysis. First, all respondents who were not asked to fill in their perceived accessibility were excluded from the sample. These respondents were either younger than 15 or did not travel to the given location. Second, missing values for perceived accessibility (7 % of values) and income (3 % of values) were imputed using a K-Nearest Neighbours algorithm. This imputation strategy is chosen in light of the potential bias imposed on the data when applying either listwise or pairwise deletion (see Schafer and Graham, 2002). While the percentage of missingness is relatively low, it remains difficult to judge the extent to which bias will be introduced when deleting cases based on missing values (Schafer and Graham, 2002). With regard to the algorithm used to do so, a K-Nearest Neighbours algorithm is applied. This algorithm allows to deal with ordinal measures. The optimal number of *k* nearest neighbours was obtained by assessing the root mean squared error, which resulted in an optimal value of 15 neighbours. The overall descriptive statistics of both the perceived accessibility indicators and income variables did not change significantly after imputing missing values using the K-Nearest Neighbours algorithm.

4.2. Measures

4.2.1. Objective measures

The objective measures are chosen in light of the research goal to examine the role of combinations of disadvantages on perceived accessibility. To do so, objective measures of the transport, social, and geographical dimensions of transport poverty are chosen. For the transport dimensions, car ownership, e-bike ownership, and driver's license are used. While Pot et al. (2023) suggested that both car and e-bike ownership may result in higher perceived accessibility scores in rural areas, it would be interesting to evaluate whether this is the case in urban areas as well. In addition, ownership of a driver's license is also assessed since including this type of ownership is far less common to include in empirical studies than car ownership, while it may provide the first barrier to perceived accessibility. For the social dimension, gender, age, migration background, education level, employment status, and spendable income are included based on the social drivers of perceived accessibility as reviewed by Jamai et al. (2022). Migration background is included in the analysis as well to gain an understanding whether a difference in background plays a role in shaping perceived accessibility as well. The level of urbanization is depicted as a measure of the geographical dimension.

Table 1 displays the sample distribution of objective measures compared to the distributions in the population. The population distribution is obtained from Statistics Netherlands. From comparing the sample with population distributions it can be concluded that the sample is representative for gender, migration background, and car ownership. However, the sample includes fewer elderly than the population. Also, the sample consists of a relatively high share of respondents who possess a university or college degree, are employed, have a high income, possess a driver's license, or live in urban areas. Lastly, e-bike ownership is less represented in the sample, when compared with the population.

Pot et al. (2023) suggested that car and e-bike ownership may have a significant beneficial effect on perceived accessibility scores in rural Dutch areas.

Table 1
Distribution of objective measures in the sample compared with population.

		Sample (# resp.)	Sample (%)	Population[a] (%)
Social dimension				
Gender	Male	12,037	53	50
	Female	10,705	47	50
Age	15–25 years	4975	22	14
	25–45 years	9021	40	30
	45–75 years	8004	35	45
	75 years and older	742	3	11
Background	Dutch background	16,503	73	75
	Western migration background	2562	11	11
	Non-Western	3677	16	14
Level of education	Not a university/ college degree	11,694	51	68
	University/college degree	11,048	49	32
Employment status	No	7205	32	46
	Yes	15,537	68	54
Standardised spendable income	First 50 % group	7657	35	50
	Second 50 % group	15,085	85	50
Transport dimension				
Car ownership	No	12,638	56	53
	Yes	10,104	44	47
Driver's license	No	4469	20	35
	Yes	18,273	80	65
E-bike ownership	No	14,889	66	57
	Yes	7853	34	43
Geographical dimension				
Urbanity	Very strongly urban	7494	33	25
	Moderately urban	13,987	61	58
	Rural	1261	6	17

[a] Data retrieved from Statistics Netherlands (http://statline.cbs.nl/Statweb/).

4.2.2. Subjective measures

The indicators used to measure perceived accessibility are shown in Table 2. Respondents are asked to rate accessibility levels of key activities or locations on a five-point Likert scale ranging from never accessible (1) to always accessible (5). Work, education, grocery stores, hospitals, general practitioners, train stations, local public transit, family and friends, and sports are included as activities or locations. The descriptive statistics of the perceived accessibility indicators show a high accessibility level perceived by the sample.

The exploratory factor analysis provided a single factor for perceived accessibility with an eigenvalue above 1 to estimate the effects of objective measures on these perceived accessibility scores. This single factor explains around 66 % of the variance, with factor loadings shown in Table 2. As can be observed from Table 2, the factor loadings are

Table 2
Descriptive statistics, factor loadings and change in Cronbach's alpha for items included as perceived accessibility indicator.

Indicator	Mean	Std. dev.	Factor loading	α if item deleted
How often reachable when needed?				
Work	4.84	0.62	0.75	0.93
Education	4.79	0.69	0.80	0.92
Grocery store	4.92	0.38	0.75	0.93
Hospital	4.83	0.58	0.79	0.92
General practitioner	4.86	0.53	0.82	0.92
Train station	4.78	0.70	0.83	0.92
Local public transit	4.80	0.69	0.80	0.92
Family and friends	4.80	0.56	0.70	0.93
Sport	4.80	0.67	0.84	0.92

relatively high, all above 0.70, whereas the Cronbach's alpha equals 0.93. In addition, the Cronbach's alpha does not improve when excluding one indicator from the reliability analysis. While the destinations are quite distinct, the indicators have a high internal consistency and, thus, these indicators measure the same concept. In line with this, Pot et al. (2023) observed that the lowest levels of perceived accessibility are generally speaking determined by social rather than transport or spatial aspects, which explains why a single factor for perceived accessibility is retained while destinations differ from each other.

In addition to Table 2, which shows the overall perceived accessibility of individuals for each destination, Fig. 2 provides an initial exploration of the variation in perceived accessibility based on the level of urbanization (which is the most direct measure of the spatial component of accessibility). From Fig. 2 can be observed that individuals' experienced level of urbanization does not differ extensively between urbanity levels. In general, perceived access to the various destinations does not fall below a score of 4.75. Still, there is some heterogeneity. For instance, perceived access to family and sports is lowest for very strongly urban-living individuals, while rural-living individuals score highest on these accessibility indicators. In contrast, these rural-living individuals experience the lowest level of access to public transport. Interestingly, access to grocery stores is perceived to be high for all levels of urbanization.

In addition to differences in perceived accessibility to various destinations for each level of urbanization, Fig. 3 highlights individuals' overall perceived accessibility on a geographical map of the Netherlands. As detailed in Fig. 3, individuals in general experience good access, with most individuals always having access to destinations. Those who experience lower levels of accessibility, as shown in Fig. 4, are spatially distributed across the Netherlands. Hence, in line with Fig. 2, individuals living in rural and urban areas of the Netherlands do not necessarily experience different levels of accessibility.

4.3. Analytical approach

A regression analysis is conducted to study the role of combinations of disadvantages on perceived accessibility levels. To do so, principal axis factoring is applied to retain a single factor from the perceived accessibility indicators, elaborated on in section 4.2.2. This factor is used as the dependent variable. All objective accessibility measures (see section 4.2.1.) are included in the regression analysis as exogenous variables. In addition, interactions between these measures are included as well. Ordinary least squares is used as a technique to estimate the effect of single and combined effects of objective accessibility measures on perceived accessibility.

For this, all combinations of transport and geographical disadvantages are included in the model. The level of urbanization is interacted with ownership of a car, an e-bike, and a driver's license. Pot et al. (2023) suggested that car and e-bike ownership may have a significant beneficial effect on perceived accessibility scores in rural Dutch areas. In line with this, both Zijlstra et al. (2022) and Jorritsma et al. (2023) concluded that the need to offer an extensive public transport system in rural areas of the Netherlands is reduced by a large share of car owners in rural areas. Therefore, it is crucial to evaluate the effect of transport disadvantages such as a lack of car or e-bike ownership on perceived accessibility scores for both rural and urban areas.

To control for the interplay between transport and social disadvantages, which has a well-established effect on perceived accessibility scores in earlier studies, each disadvantage in the transport dimension is interacted with a single social disadvantage. Car ownership is interacted with income since Pot et al. (2023) concluded that low income is often translated and captured by a lack of car ownership in rural Dutch areas. It remains still uncertain whether this is the case for urban areas too. For e-bike ownership, we assess the effect on perceived accessibility scores for different age groups. As stated by the Dutch National Institute for Public Health and the Environment (2022), a third of the individuals 12 years and older possess an e-bike, whereas half of the elderly possess an

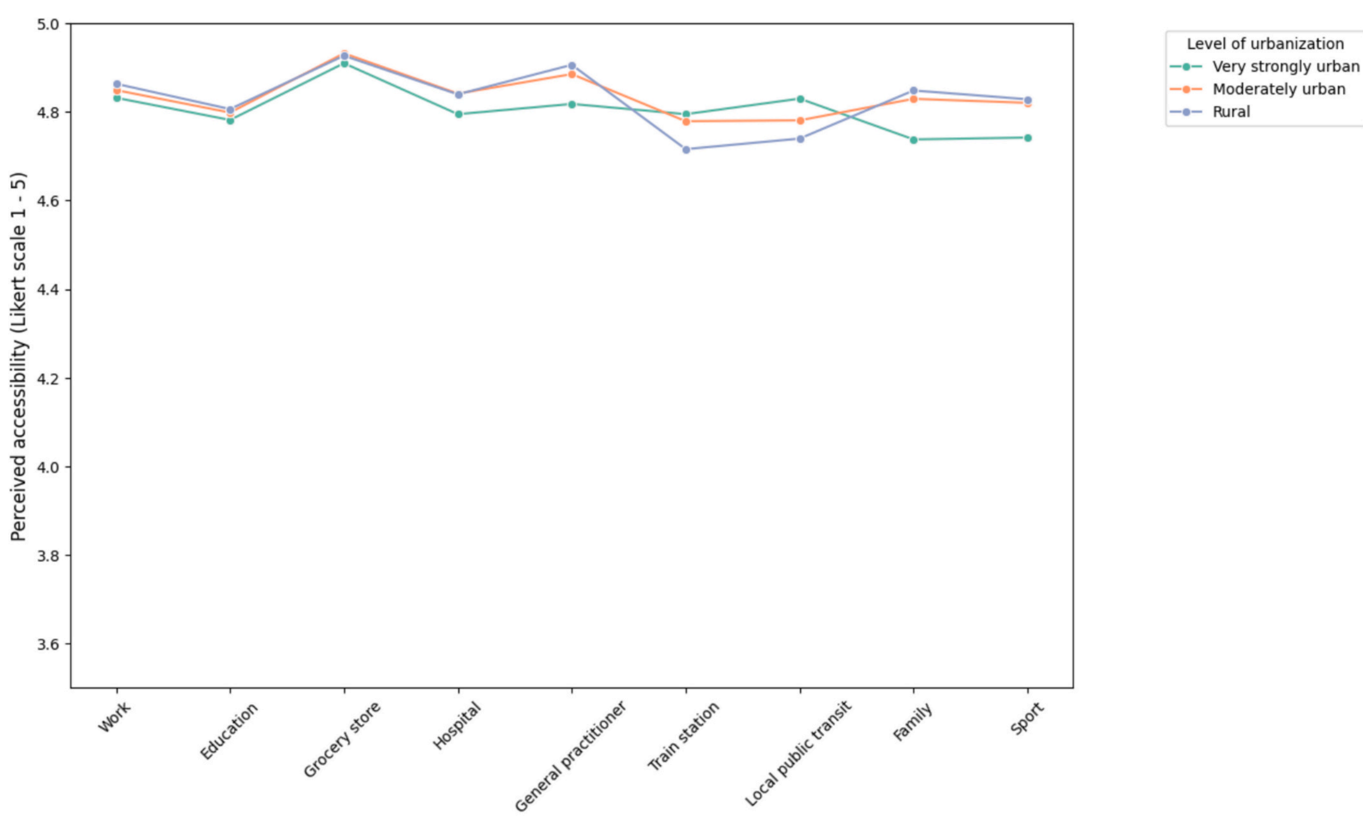

Fig. 2. Heterogeneity in perceived accessibility indicators for different levels of urbanization.

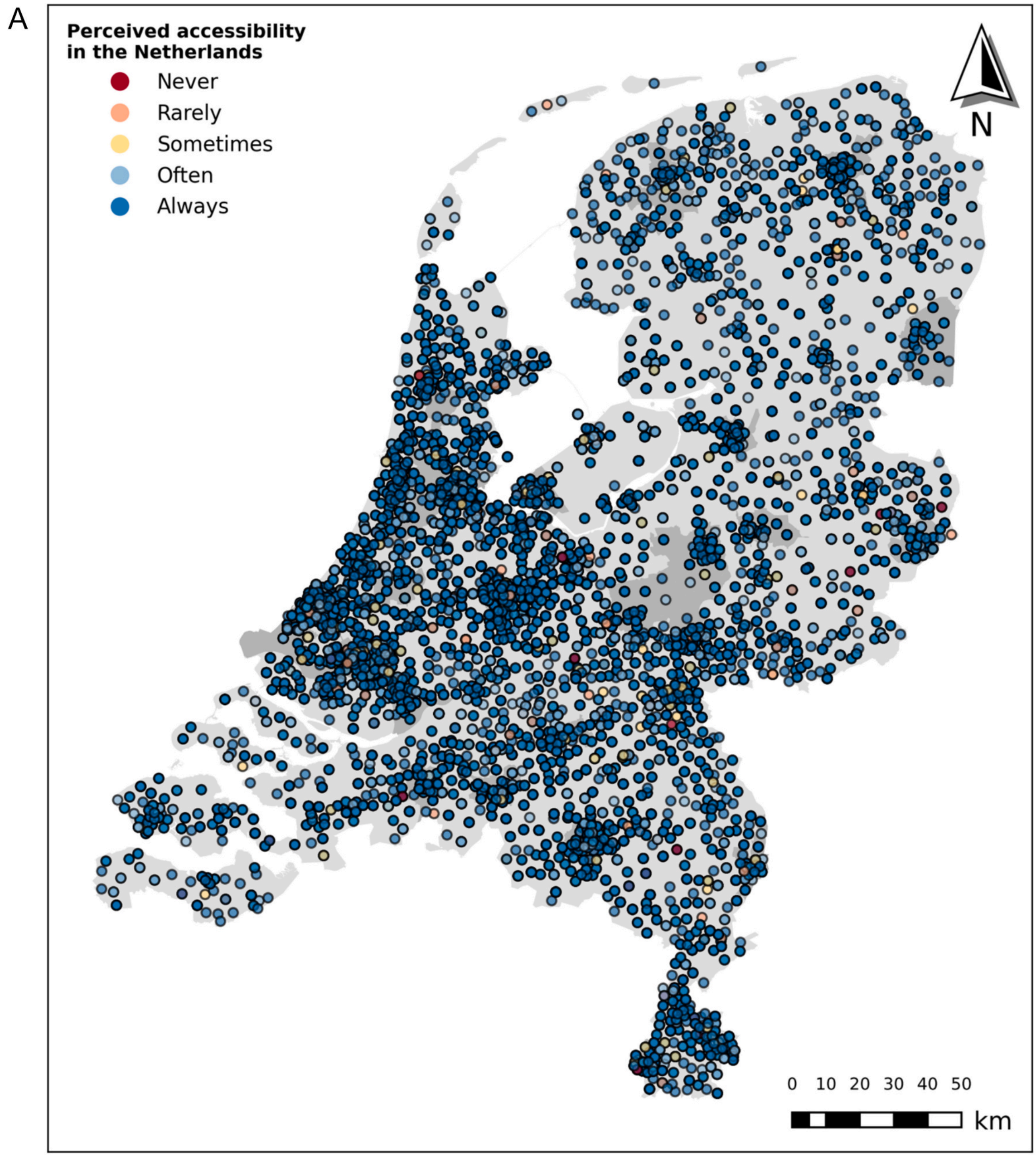

Fig. 3. Spatial distribution of perceived accessibility in the Netherlands for all individuals.

e-bike. Overall, e-bike ownership has a significant positive impact on perceived accessibility scores for rural-living individuals (Pot et al., 2023). Whether this holds for urban-living individuals and for different age groups is not yet examined. Lastly, possessing a driver's license is evaluated for both females and males. Studies often underline that females may be disadvantaged due to travel behaviour patterns in combination with car usage and time constraints (Pot et al., 2023). Whether not possessing a driver's license is a part of these disadvantages remains unexplored. As of this, the combined effect of possessing a driver's license and gender on perceived accessibility scores is estimated too.

5. Results and discussion

Table 3 presents the regression results in which perceived accessibility is explained by objective measures in the social, geographical, and transport dimensions of transport poverty. Both standardised parameter estimates as well as *p*-values are provided. The model fitness highlights that the explained variance of perceived accessibility by the objective measures is rather low. The adjusted R-squared value is 0.148, implying that objective accessibility measures can explain 14.8 % of the variance in are perceived accessibility. The F-statistic indicates that the model is significant with an error probability of 0.0 (p-value <0.001).

In general, perceived accessibility has significant associations with several individual objective measures. As earlier findings highlighted, females are associated with lower perceived accessibility. In addition, increasing age and a non-Western background also result in lower perceived accessibility. Contrary, university/college degrees, employment, high spendable incomes, car owners, and driver's licenses all result in higher accessibility. With regard to the level of urbanization, people living in very strongly urban areas often perceive higher accessibility than people living in moderately urban or even rural areas. Rural-living individuals perceive the lowest accessibility levels. Lastly, while e-bike ownership contributes positively to accessibility levels of individuals, the estimate is not significant implying that this objective

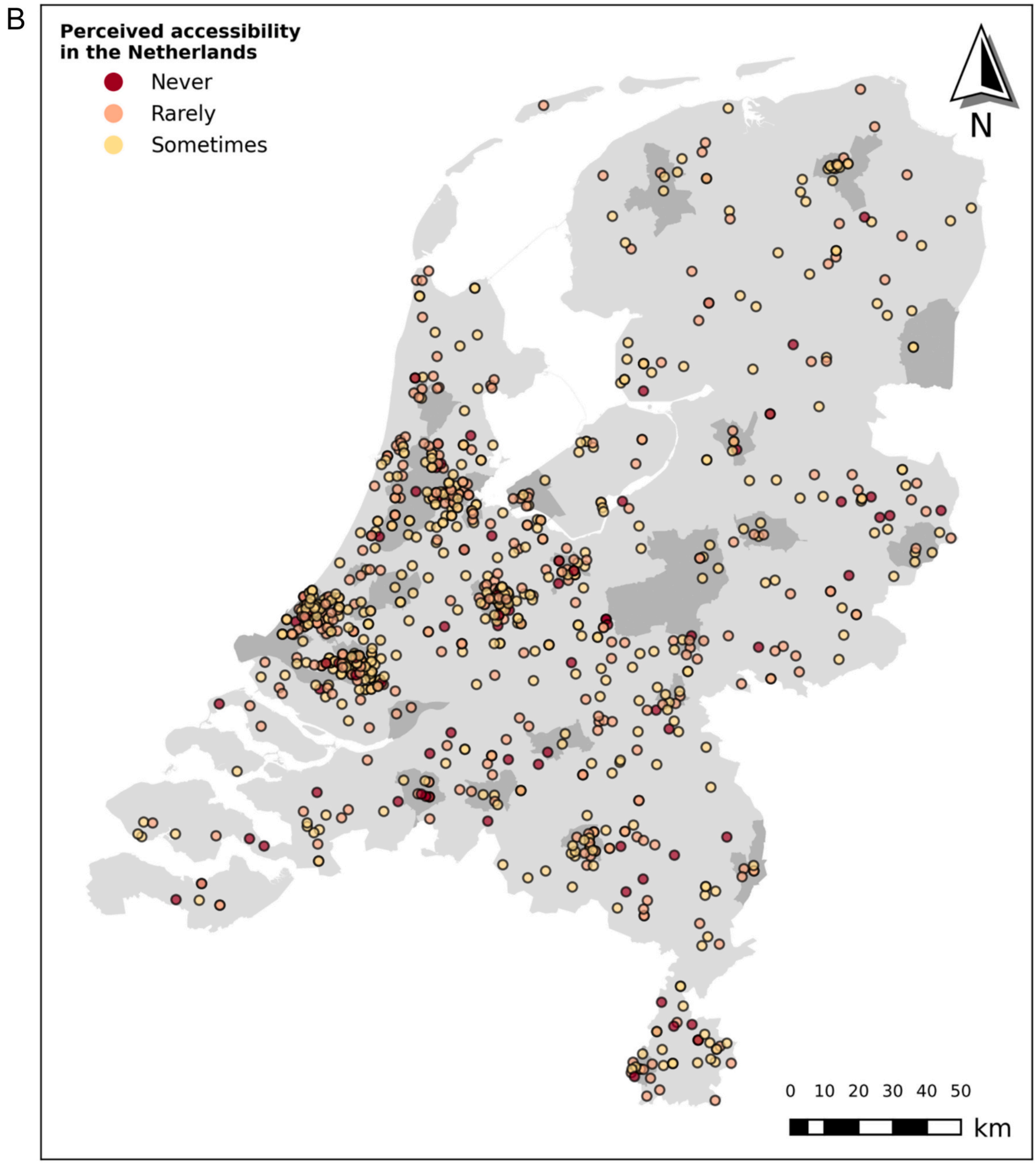

Fig. 4. Spatial distribution of perceived accessibility in the Netherlands for those individuals that experience lower levels of accessibility.

measure does not affect the level of perceived accessibility.

Besides the significant associations between perceived accessibility and single objective measures, combined effects between objective measures also determine perceived accessibility. Six research findings are obtained from these interactions between disadvantages. First, the model shows that rural-living individuals who do not possess a car suffer from lower perceived accessibility compared to rural-living individuals who possess a car. This aligns with earlier research findings. Yet, this interaction effect is not significant, implying that the effect is not generalisable to the population.

Second, the lack of a driver's license has a greater effect on perceived accessibility scores than a lack of car ownership for individuals living in rural areas of the Netherlands. A driver's license increases accessibility to a large extent for these rural-living individuals. Consequently, not possessing a driver's license seems to be the first barrier to overcome, in order to increase perceived accessibility scores. Vega-Gonzalo et al. (2024) suggested that shared mobility could potentially reduce the perceived car dependency. In general, the potential of shared mobility is perceived to be lower for car owners and frequent car users compared to those who do not own a car or do not use a car frequently (Vega-Gonzalo et al., 2024). Consequently, a driver's license might become more essential in increasing perceived accessibility scores than car ownership.

Third, the ownership of an e-bike does not result in higher perceived accessibility scores for rural-living individuals compared to urban-living individuals. In general, e-bike ownership increases perceived accessibility scores. However, the ownership of an e-bike is not differently appreciated by rural-living individuals compared to urban-living individuals. Earlier, Pot et al. (2023) concluded that e-bike ownership positively affects accessibility scores for rural-living individuals. Yet, scores for rural-living individuals were not compared with urban-living individuals' scores. However, the model findings shown in Table 1 underline that urban- and rural-living e-bike owners perceive accessibility indifferently.

Fourth, car owners with a low spendable income perceive higher

Table 3
The single and combined effect of transport, social, and geographical disadvantages on perceived accessibility (*p*-value in parentheses).

Variable	Estimate
Social dimension	
Gender	- 0.058
0 = male, 1 = female	(< 0.001)
Age	- 0.249
0 = 15–74 years, 1 = 75 years and older	(< 0.001)
Background	- 0.160
0 = Western background, 1 = Non-Western background	(< 0.001)
Level of education	0.059
0 = no university/college degree, 1 = university/college degree	(< 0.001)
Employment status	0.080
0 = not employed, 1 = employed	(< 0.001)
Standardised spendable income	0.098
0 = low spendable income, 1 = high spendable income	(< 0.001)
Transport dimension	
Car ownership	0.036
0 = no car, 1 = car	(0.002)
Driver's license	0.080
0 = no driver's license, 1 = driver's license	(< 0.001)
E-bike ownership	0.005
0 = no e-bike, 1 = e-bike	(0.475)
Geographical dimension	
Moderately urban areas	- 0.016
0 = very strongly urban, 1 = moderately urban	(0.017)
Rural areas	- 0.050
0 = very strongly urban, 1 = rural	(0.004)
Transport dimension x Social dimension	
Car ownership x Income	- 0.027
'Car ownership for individuals with a high spendable income'	(0.027)
Driver's license x Gender	0.060
'Driver's license for females'	(< 0.001)
E-bike ownership x Age	0.066
'E-bike ownership for individuals 75 years and older'	(< 0.001)
Transport dimension x Geographical dimension	
Car ownership x Rural areas	- 0.006
'Car ownership in rural areas'	(0.466)
Driver's license x Rural areas	0.039
'Driver's license in rural areas'	(0.025)
E-bike ownership x Rural areas	- 0.001
'E-bike ownership in rural areas'	(0.873)
Model fitness	
F-statistic	233.631
	(< 0.001)
R-squared	0.149
Adjusted R-squared	0.148

Note. The F-statistic tests the hypothesis that the coefficients of the model equal zero, whereas the R-squared shows the explained variance of perceived accessibility by the regressors.

accessibility levels than car owners with a high spendable income. One reason could be the occurrence of adaptive preferences, meaning that a disadvantaged individual (due to, for example, a low income) might downgrade their expectations and preferences to their circumstances (Pot et al., 2023). Consequently, one might report a sufficient level of accessibility. Another reason could be that low-income individuals' job locations are more difficult to access by public transport, resulting in a higher appreciation of car ownership compared to high-income individuals. Overall, spendable income seems to be a relevant determinant of perceived accessibility in combination with car ownership, as Pot et al. (2023) emphasised earlier.

Fifth, the model highlights that females who possess a driver's license perceive higher accessibility levels than females who do not possess a driver's license. In line with this, females are able to compensate their social disadvantage by possessing a driver's license. In other words, being a female might not necessarily translate in lower perceived accessibility scores, if one has a driver's license.

Last, the model highlights that the ownership of an e-bike is perceived to increase accessibility scores for elderly. While elderly perceive lower accessibility scores compared to younger people, the ownership of an e-bike increases the perceived accessibility scores of elderly in urban and rural areas to a large extent. Whereas Pot et al. (2023) concluded that e-bike ownership has an overall beneficial impact on accessibility scores, model findings highlight that this impact is greater for elderly compared to younger people.

While both single and combined effects of various objective measures on perceived accessibility are significant, the model highlights that individuals are not always able to offset a disadvantage in one dimension with an advantage in another dimension. To illustrate, let us take the case of an elderly person. An individual aged 75 years or older has a significant decrease in perceived accessibility compared to younger individuals since the estimate equals −0.249. However, e-bike ownership is perceived as beneficial for an elderly person. This ownership lowers the effect of age by 0.066, resulting in a combined, reducing effect of −0.183 on perceived accessibility. Since the effect is still negative, older individuals are just slightly able to compensate for their age disadvantage by e-bike ownership (from −0.249 to −0.183).

In addition, the combined effects of transport and social disadvantages on perceived accessibility are still larger than the combined effects of transport and geographical disadvantages. In line with the findings of other studies on transport poverty and transport-related social exclusion, the model indicates that it is the interplay between transport and social disadvantages that mostly determines whether one will perceive inaccessibility. Contrary, transport disadvantages do not necessarily deviate across urban and rural areas, while a minor difference between urban and rural areas regarding possessing a driver's license is present, and as of these differences in perceived inaccessibility between urban- and rural-living individuals are not likely to be affected extensively by transport disadvantages.

In recent years, more research has been conducted on the effects of transport, social, and geographical aspects on perceived inaccessibility. Of this increasing body of research, Pot et al. (2023) has studied the interplay between such aspects in rural Dutch areas. Here, Pot et al. (2023) highlighted that transport and social disadvantages rather than geographical disadvantages determine perceived inaccessibility in rural areas of the Netherlands. Major contributors to lower levels of accessibility seem to be gender, education, employment, disabilities as well as car and e-bike ownership. A driver's license is also associated with perceived accessibility in rural Dutch areas. Overall, Pot et al. (2023) conclude that social rather than transport disadvantages seem to determine perceived inaccessibility to a large extent.

Contrary to Pot et al. (2023), the regression analysis conducted in this paper evaluated the interplay of transport, social, and geographical disadvantages encountered by individuals by examining the effect of transport and social disadvantages in both rural and urban Dutch areas. Using this approach, the regression results highlighted that not possessing a driver's license seems to be the first barrier to overcome for rural-living individuals, rather than a lack of car ownership. In addition, e-bike ownership is beneficial for the elderly in both urban and rural areas of the Netherlands. While Pot et al. (2023) already showed that e-bike ownership is associated with perceived accessibility in rural areas, the regression analysis conducted in this paper also showed that such an ownership is beneficial for urban-living individuals too. Furthermore, the results revealed that the interplay between transport and social disadvantages have a much stronger effect on perceived inaccessibility compared to the interplay between transport and geographical disadvantages. While single effects of disadvantages on perceived accessibility have been studies extensively in earlier studies, this paper complements the existing body of research with the observation that perceived inaccessibility is mainly the result an interplay between transport and social disadvantages. Spatial disadvantages encountered by an individual will have less impact on the level of accessibility experienced by that individual.

6. Conclusions

An uptake in research on perceived accessibility in relation to transport-related social exclusion has occurred in the past decade. Yet, the effect of combinations of transport, social, and geographical disadvantages on perceived accessibility is not extensively addressed. This paper explored whether and which combinations of disadvantages affect perceived accessibility.

The first finding is that, generally speaking, individuals perceive a satisfactory level of accessibility with most scores of around 4.8 or higher on a scale of 5. For only a small group of individuals, the level of accessibility is experienced as unsatisfactory. Interestingly, the variance in these scores are explained by objective measures to a limited extent. In other words, these scores are not determined by such measures alone, also other factors play a role. The adjusted R squared slightly increased after accounting for the combined effects of disadvantages, resulting in an explained variance of 14.8 %. However, a large share remains unexplained.

The second finding is that not possessing a driver's license seems to be the first barrier for rural-living individuals to overcome, rather than a lack of car ownership. Contrary to other studies, the analysis showed that a driver's license has a greater effect on perceived accessibility scores than car ownership. While individuals suffer from both a lack of car ownership as well as a driver's license, the effect of a driver's license on accessibility scores is greater in rural Dutch areas.

The third finding is that the ownership of an e-bike for elderly in both rural and urban areas increases perceived accessibility scores to a large extent. Interestingly, the e-bike is not perceived to be beneficial among respondents of all ages in rural versus urban areas. However, by making the distinction between younger and older people, the regression analysis showed that the possession of an e-bike is able to slightly offset age in light of accessibility poverty and perceived inaccessibility.

The fourth finding is that combinations of transport and social disadvantages determine perceived accessibility to a larger extent, compared to combinations of transport and geographical disadvantages. Possessing a driver's license seems to effect perceived accessibility differently in rural compared to urban areas of the Netherlands. In contrast, the effect of having a car or an e-bike on perceived accessibility does not significantly varies between rural and urban contexts. In other words, whereas the effect of a driver's license on perceived accessibility is appreciated in a different manner between rural- and urban-living individuals, this does not hold for car and e-bike ownership. All combinations of transport and social disadvantages evaluated in the regression analysis had significant effects on perceived accessibility.

Overall, we conclude by underlining that it is not straightforward that an individual can compensate a disadvantage in one dimension by an advantage in another dimension. We illustrated this point by showcasing that elderly persons benefit extensively from e-bike ownership, yet their social disadvantage is still not fully compensated for. Here, we want to emphasize that whether this is the case for a specific individual depends on the context. This finding does not suggest that each individual that encounters a disadvantage is unable to compensate this disadvantage with an advantage in each given situation. Whether this is the case depends on the (dis)advantages an individual perceives as barriers to their perceived accessibility. Still, the notion that perceived inaccessibility may lurk for individuals who are not able to offset a disadvantage in one dimension with an advantage in another dimension seems to hold for combinations between transport, social, and geographical disadvantages too, in addition to single effects of advantages and disadvantages.

These findings have several implications for policymakers and practitioners. Firstly, most individuals experience a sufficient level of accessibility, with only a minority of individuals denoting scores lower than 4.8 out of 5. Therefore, the inaccessibility of destinations is not a widely supported problem in society. Policies designed to increase the perceived accessibility of those individuals that perceive inaccessibility should focus on not only objective accessibility measures as assessed in this paper but also on other factors that might play a role since objective accessibility measures explain perceived accessibility scores to a limited extent, implying that other factors that affect these scores should be accounted for. Secondly, the interplay between transport and social disadvantages has a stronger association with lower accessibility levels perceived by individuals than transport and geographical disadvantages. As of this, more emphasis should lie on addressing transport and social disadvantages, when assessing the lowest levels of accessibility among individuals. Thirdly, not possessing a driver's license lowers perceived accessibility scores more than a lack of car ownership. Shared mobility and car sharing are trends that might increase perceived accessibility scores since the perceived car dependency by car owners reduces, yet individuals still need to possess a driver's license. Lastly, it is not straightforward for individuals to compensate for a disadvantage in one dimension with an advantage in another dimension, which is likely to translate into perceived inaccessibility. As of this, policies should consist of multifaceted measures that offset a disadvantage to a larger extent to prevent perceived inaccessibility.

While the regression analysis effectively estimated the effects of combinations of disadvantages between the transport poverty dimensions, some limitations of this study can be addressed in future research. First, three-way interactions between transport, social, and geographical disadvantages remain unexplored. These interactions may also play a role in explaining perceived accessibility scores. Second, a limited number of objective accessibility measures is used for each dimension to examine the notion that combinations of disadvantages effect perceived accessibility. Only the level of urbanization is used to study the geographical dimension of transport poverty, whereas ownership of a car, e-bike, and driver's license are used to operationlize the transport dimension. For these transport aspects, car ownership may overlap with holding a driver's license as well. Other objective accessibility measures within these dimensions, and combinations of such other measures, may affect perceived accessibility too. In addition, perceived accessibility is operationalized through a set of nine indicators measuring a person's access to key destinations, which differs from the conventional PAC scale developed by Lättman et al. (2016, 2018). Whereas the PAC scale focuses on access to daily activities, the measurement scale used for the regression analysis is concerned with assessing the access to a set of destinations (not necessarily traveled to on a daily basis). While this enables to assess the accessibility to destinations experienced by individuals, a specific drawback is that only a few destinations are measured which do not necessarily represent all destinations one may value to be accessibility. The perceived access to, among others, the woods, lakes, farms is not assessed by this scale. Hence, the overall perceived accessibility to all destinations an individual (might) travel to might not be examined. In addition, it is likely that individuals attribute different weights to each (pre-defined) destination. Hence, measuring the perceived access to each destination might not fully reflect the overall perceived level of accessibility, or in turn an individual's risk of being socially excluded when applying this scale. In line with this, the level of urbanization used as operationalization of the geographical dimension might be closely related to the measurement scale of perceived accessibility since most destinations included in this scale are, generally speaking, located in urban areas. This may also serve as an explanation of the low explanatory power of the regression model. Therefore, an interesting avenue for future research would be to evaluate the various scales used to measure perceived accessibility and to assess whether these scales overlap. Thirdly, the explained variance of perceived accessibility levels by objective accessibility measures is rather low, implying that other factors also play a role. Which factors affect accessibility perceived by individuals remains unknown. Lastly, the dynamics of transport disadvantages on perceived accessibility scores over time stay unexplored, however, these dynamics might provide further insights in the effect of mobility trends such as shared mobility and e-bike usage.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Milan L. Moleman: Writing – Review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Maarten Kroesen:**Writing – Review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

Nothing to declare.

Acknowledgements

None.

Data availability

The authors do not have permission to share data.

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