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**Maria Laura Guerrero Balarezo**
**Martin Trépanier**
**Léa Ravensbergen**
**Steven Farber**
**Geneviève Boisjoly**

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**Bureau de Montréal**
Université de Montréal
C.P. 6128, succ. Centre-Ville
Montréal (Québec) H3C 3J7
Tél : 1-514-343-7575
Télécopie : 1-514-343-7121

**Bureau de Québec**
Université Laval,
2325, rue de la Terrasse
Pavillon Palasis-Prince, local 2415
Québec (Québec) G1V 0A6
Tél : 1-418-656-2073
Télécopie : 1-418-656-2624

# Developing a Country-Wide Index for Measuring Transport Poverty

**Maria Laura Guerrero Balarezo [1,*], Martin Trépanier[1], Léa Ravensbergen[2], Steven Farber[3], Geneviève Boisjoly[1]**

1. Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT) and Polytechnique Montréal
2. School of Earth, Environment & Society, McMaster University
3. Department of Human Geography, University of Toronto Scarborough

**Abstract.** Transport poverty (an inability to access opportunities due to different social, economic, or personal reasons) causes Transport Related Social Exclusion (TRSE), an inability to participate in social or economic life due to transport scarcity. This work proposes a methodology to calculate a country-wide index to measure transport poverty and the risk of TRSE using Canada as the case study, with the aim of creating an easily interpretable tool to help guide transport-related decisions. This task is challenging due to the need for quality data available for the whole country, and due to the diversity of territories within it. The index is generated for all of Canada at the smallest geographic level with available population data and combines a social disadvantage component with a transport disadvantage component using nationally available data. Results show how social and transport disadvantages shape transport poverty, as well as the need to have different scales to interpret the index depending on the levels of compactness/dispersion of urban fabrics and the urbanity/rurality of the territories being assessed. These distinct scales of interpretation are relevant because they allow for uncovering land use and transport characteristics leading to the variation of index scores. Future research should further refine the index, develop a prioritization framework for transport investment decisions based on the index, go deeper into the relation between transport poverty and TRSE, and longitudinally analyze the impact of major transport investments, among other potential investigations.

**Keywords**: Transport related social exclusion, transport poverty, accessibility, marginalization

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* Corresponding author: maria-laura.guerrero-balarezo@polymtl.ca

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# 1. Introduction

Transport poverty and Transport-Related Social Exclusion (TRSE) are two highly researched and used concepts, owing to the recognition that the distribution of mobility and accessibility levels across population segments impacts social processes, such as social inclusion, participation, and community cohesion (Verhorst et al., 2023). The interactions between accessibility and social conditions are of special interest for transport practitioners in decision-making processes with a focus on equity in the distribution of transport services. There is a need to design, implement, and contextually adapt tools that account for this relation to contribute to planning processes.

Transport poverty tends to be measured at the local scale of analysis. While much has been learnt from this body of work, little research to date has measured these concepts at a national scale of analysis, and none has done so in large and geographically diverse countries such as Canada or the U.S. One possible application is to help guide transport-related investments, because the uniform measure allows for comparing different parts of the country. This research can be used for national benchmarking equity performance over time, to assess how investments impact the indicators in the territory. A third potential use of this research is to compare equity performance across the country, providing a useful instrument for cities to understand their development and to advocate for better services to reduce TRSE.

The measurement of transport poverty and TRSE in a country could imply different types of challenges, from the conceptual to the operational. On the conceptual side, a country's territory is naturally dissimilar: different concentrations of population and different activities and ways of life denote the need for different visions, or at least different assessments or views, about the same problem. Operationally, the various standards of data gathering that local administrations employ make it difficult to measure and evaluate a problem in a standardized manner, at a large scale. In the Canadian case, provincial governments have substantial autonomy in designing their information gathering schemes, varying both the periodicity and the detail of the information. One of the few exceptions is the population census, conducted every five years at the national level. Additionally, national transportation networks and datasets have been developed and made publicly available by Statistics Canada (Statistics Canada, 2023). To respond to the lack of studies considering transport poverty at the national scale of analysis, this contribution proposes a tool to measure this concept for all of Canada and assesses the relevance and challenges towards creating an easily interpretable tool, to help guide transport-related decisions. One of the goals of the tool is that it can be used to compare the situation between areas in the country, but that at the same time it can be used within local boundaries for planning purposes. This tool could be especially useful for countries with similar geographic characteristics: territories with some highly dense urban concentrations and significant areas of rural land, such as Australia, New Zealand, or the U.S.

# 2. Literature Review

## *2.1. Social Exclusion and Its Relation to Transportation*

Social exclusion is a complex concept that relates to economic and material issues, but encompasses many more aspects, such as cultural dynamics, time use, geographical context, etc. Schwanen et al. (2015) define it as a lack of participation in social, economic, and political life, and as a concept claim that it is broader than poverty, is relative to other individuals or groups, and is multi-scalar (individuals, households, neighbourhoods, and local communities experience it). Stanley and Vella-Brodrick (2009), on the other hand, refer to social exclusion as the existence of barriers which make it difficult or impossible for people to participate fully in society or obtain a decent standard of living. Burchardt (2000) states that an individual is socially excluded if they do not participate to a reasonable degree, over time, in certain activities of their society, and (a) this is for reasons beyond their control, and (b) they would like to participate; thus, the powerless and denial of choice inherent in the discourse of social exclusion prevents the extension of the concept to those who self-exclude. Due to the complexity of social exclusion, and its many varied definitions, it is hard to identify its specific causes. Looking across the literature, however, it is usually understood and analyzed as a multivariate phenomenon. Here, income poverty is the most commonly cited cause of social exclusion, and other examples of intervening factors or barriers for inclusion include disability, lack of educational opportunity, inadequate housing, ethnic minority status, unemployment, age, and lack of transport (Kamruzzaman et al., 2016; Stanley & Vella-Brodrick, 2009).

Transport shapes social exclusion. Lucas (2019) identifies that a lack of accessibility to opportunities, whether it is by affordability, safety, security, or other reasons, reflecting people's ability to reach key life-supporting activities, can lead to processes of social exclusion. This lack of accessibility can occur at the scale of personal individual factors, neighbourhood or local factors, and macro-level factors, involving strategic levels or whole systems. Some early definitions of transport-related exclusion in the study of social exclusion defined the concept in terms of the processes that prevent people from participation in the economic, political, and social life of the community, because of reduced geographical accessibility to opportunities, services, and social networks (Schwanen et al., 2015).

Transport poverty refers to a lack of transport-related resources that hinders an individual's potential mobility and, therefore, their ability to access opportunities. Different factors may lead to transport poverty: financial (e.g., inhibiting the purchase of a car or public transport tickets), mental or physical abilities (e.g., a person may not be able to use a public transport service because of a travel-related impairment, or a fear of being harassed in transport), or, lack of available services (Luz & Portugal, 2022). In fact, studies have found strong evidence that significant barriers to participation in key activities (e.g., employment, education, health, and social) are due to either a lack of suitable transport or a lack of accessible opportunities, or a combination of both (Kamruzzaman et al., 2016). Schwanen et al. (2015) propose a more defined term, “transport disadvantage”, as a relational and dynamic outcome of a lack of access to basic resources, activities, and opportunities for interaction; of a lack of cognitive knowledge, know-how, aspirations, and/or autonomy regarding travel and its externalities; and of a lack of influence on decision-making in the context of transport. Transport disadvantage can be both absolute and relative, and it occurs at both individual and collective scales.

To encompass the full complexity of lack of access to opportunities, Lucas (2012b) also considers the socio-economic conditions of the individual, pointing out that transport disadvantage and social disadvantage interact directly and indirectly to cause transport poverty. Many of the studies reflect on the reality of urban areas, but Farrington and Farrington (2005) discuss the application of these concepts to rural areas. In this sense, the authors point to a need to keep the emphasis on opportunities rather than behaviour, pointing towards a view of accessibility as encompassing a wide range of factors, including people’s time budgets, household commitments, physical capabilities, and attitudes to participation. Some care must be taken when thinking about accessibility using private automobiles, a common scenario in Canada and the U.S., since automobile dependency increases social exclusion by reducing non-automobile travel options and increasing total transport costs (Litman, 2003). In fact, car access is still relatively low in the lowest income quintile in relation to access in the highest quintile, where female heads of households, children, young and older people, black and minority ethnic households, and disabled people are overwhelmingly concentrated (Lucas, 2019). In Toronto, Canada wealthier carless households tend to concentrate in neighbourhoods where existing transit accessibility levels are high, while low-income, carless households, are more dispersed in lower-accessibility areas compared to higher-income, carless households, who are more concentrated in the very core of the city (Yousefzadeh Barri et al., 2021), close to most services and opportunities.

Jeekel and Martens (2017) reflect on the interactions between transport poverty, accessibility, and TRSE. The authors note that transport poverty refers to a lack of transport-related resources, limiting the ability to move through space due to financial, legal, mental, or physical reasons, or a combination of them. Accessibility poverty happens when a person has a lack of access to key opportunities, such as employment, education, health care, or social support networks. In this sense, transport poverty does not always have to translate into accessibility poverty, however, transport poverty implies accessibility poverty whenever a substantial level of mobility is needed. Therefore, people who experience transport poverty are at risk of accessibility poverty, especially in mobility-oriented/car-dependent territories. Finally, the authors mention that TRSE refers to the level of participation in a society. People experiencing accessibility poverty over a long period of time are at risk of TRSE. In a similar way, Kenyon et al. (2002) propose a concept called mobility-related exclusion, defined as the process by which people are prevented from participating in the economic, political, and social life of the community because of reduced accessibility to opportunities, services, and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility. Figure 1 presents the interlinkages between the different concepts, based on the framework proposed by Lucas (2012b). Transport poverty happens at the intersection of transport and social disadvantage. Then transport poverty leads to a lack of access to goods and services that can produce TRSE.

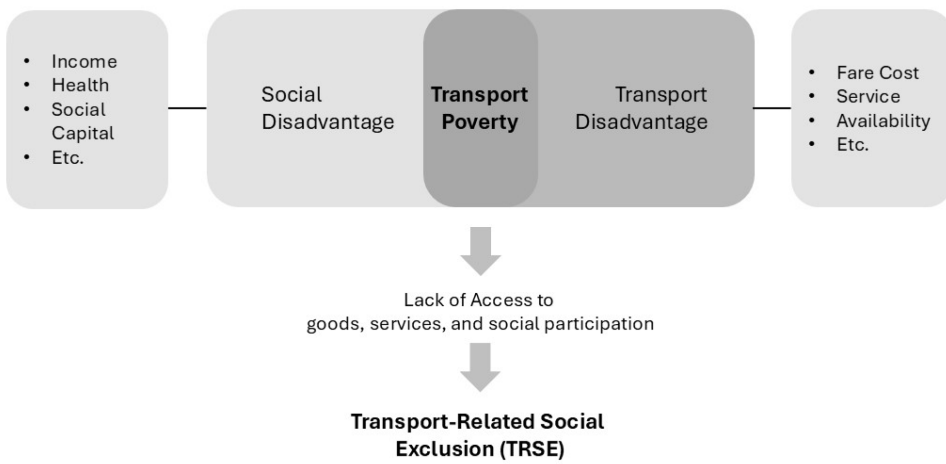


**Figure 1** Conceptual Framework based on Lucas (2012b).

Lucas (2012b) argues that there is no overarching consensus about what precisely constitutes social exclusion, but there is wide agreement that it reaches beyond a description of poverty to provide a more multidimensional, multilayered, and dynamic concept of deprivation. Considering the different definitions and terminology, and the assumptions or terms left undefined, what authors converge on is that Transport-Related Social Exclusion (TRSE) refers to the difficulty of participation in social, economic, and political life due to a lack of access to the transport system, whether this lack of access stems from unaffordability, inadequate service coverage, physical barriers, or other causes. Experts who study TRSE tend to focus on the inability to access key life-enhancing opportunities (employment, education, health, etc.) with a more people-focused and needs-based social policy perspective (Lucas, 2012a). Broadly, in what refers to transport, TRSE is caused by the combination of fragmentation, unreliability, and high costs in the public transport system; poor conditions for walking, cycling, and wheeling in car-dominated environments; and the high levels of car dependency that result from this (Transport for The North, 2022). Fragmentation refers to a lack of continuity in the Public Transport (PT) system, which happens, for example, in conurbations, when autonomous administrative areas fail to properly connect suburbs between each other because they are administered by different organizations, despite in practice forming a functional spatial continuum. The unreliability of the transport system refers especially to the absence of a reliable PT schedule that allows people to properly plan their activities. The high cost of the system refers to when the PT fare is not in accordance with income levels and the basic expenditures of the population, or segments of the population. Poor conditions for walking and cycling may result from high car traffic speeds that endanger cyclists or pedestrians, from narrow, inexistent, or inadequate sidewalks, from obstacles like level or texture changes in the pavement, inadequate infrastructure for cycling, etc. In addition, the lack of servicing or choice in transportation modes and a lack of access to public transit, or a lack of ability to use existing services, are also mentioned as causes of TRSE (Ollier, 2018).

Drawing from the descriptions of transport poverty and TRSE a link can be established, implying that an individual suffering transport poverty is at risk of not being able to participate in his society and access opportunities, therefore, at risk of suffering TRSE. In fact, poverty and social exclusion are closely related, but nevertheless they are distinct phenomena; poverty focuses on distributional issues, while social exclusion attends to relational issues (Madanipour et al., 2015). When speaking about transport, for example, public transport can be a vehicle towards social inclusion or exclusion as residents can be either connected to or obstructed from accessing social and public amenities and facilities, thus social exclusion can either be eliminated or reinforced depending on the availability of means of transport (Bueno Rezendede Castro et al., 2022). Therefore, both phenomena can be studied to know about an individual and its relation to transport and access to resources and activities.

### *2.2. Methodologies for measuring and analyzing transport poverty and TRSE.*

When it comes to measuring transport poverty, many studies use quantitative approaches and have been applied at local or regional scales of analysis. A review of early studies in measuring social exclusion and the role of transport focuses on multiple deprivation approaches, establishing five principles for effectively measuring the phenomenon through composite indices (Stanley, 2011):

- Using the most established and verified measure to build and facilitate systematic knowledge development for policy,
- Grounding measurement in theory through comprehensive reviews of the literature,
- Keeping the measurement as policy relevant as possible and as straightforward as possible,
- Keeping the measurement tools as straightforward or simple as possible without compromising research integrity, and
- Gaining a depth of understanding of the variables that impact the dependent variables.

The authors then establish five general dimensions for the measurement of social exclusion: income, employment, political activity, social support, and participation. These dimensions are measured through different indicators that vary across studies.

Early work on access evaluates the proximity of an area to its closest public transport stop using district centroids for area locations and measuring the Euclidean distance (Murray, 2001). The study then assesses the degree of redundancy and inefficiency of public transport service stops locations using the location set covering problem (LSCP). More recently, Allen and Farber (2019) analyze vertical inequalities in access to employment, understood as the distribution of a resource with a focus towards specific groups (often those who are more vulnerable to social or economic exclusion) in eight Canadian cities to estimate the risk of transport poverty, using open transit network data, accessibility measures, household demographics, and employment census data. Given that transport poverty is still a concept under development, and that it is multidimensional (time, affordability, availability, capabilities, etc.), Verhorst et al. (2023) systematically review the literature to obtain different definitions of transport poverty. They then use survey data from two Dutch cities to measure transport poverty with a scoring system and an indicator derived from factor analysis, before performing a series of linear regressions to understand which transport poverty definition correlates with a different set of predictors, and in which contexts a given definition (measurement scale) can be applied, based on individual responses specifically on TRSE. National analyses also exist; however, they do not cover access to different types of destinations. For example, to study transport poverty in England, Sun and Thakuriah (2021) use General Transit Feed Specification (GTFS) data to measure local-scale PT availability based on service frequency and spatial proximity to PT stops/stations, and then identifies areas with both low availability and low accessibility to employment, defining this as the risk of transport poverty. However, this study focused on the locations of stations/stops and ignored the locations of key services or destinations (e.g. workplace, school, hospital, etc.). Berry et al. (2016) also study transport poverty nationally, this time in France, and focus on fuel affordability by identifying households vulnerable to fuel price increases in France. The authors design a composite indicator that measures financial resources (income), mobility practices (fuel spending, travel time, etc.), and conditions of mobility (spatial matching), though the study was limited to commuting trips. Another article makes a comparison between Sydney and Perth, Australia, with a transportation supply index, using the Lorenz Curve and Gini Index to compare the transport service distribution under different socio-economic characteristics, including housing affordability, employment self-sufficiency, urban sprawl, and transport mode (Xia et al., 2016). All methods present different advantages and disadvantages depending on the purpose of the study. However, an overarching disadvantage of most of the studies is not the methods themselves, but that they are limited to local or regional scales. The amount and detail of data needed for these approaches (GTFS, travel times, disaggregated travel costs, types of destinations, etc.) cannot be guaranteed to be available when scaling to the national scale, or making comparisons between nations. It thereby limits the possibility to identify challenges and opportunities that arise when assessing transport poverty at a national level.

As for the qualitative approaches, Rose et al. (2009) conduct two focus groups in New Zealand to study TRSE: one to identify potential social and economic impacts from temporary or permanent private vehicle loss, and the other to understand people's travel patterns and attitudes towards various transport modes. As with studies of transport poverty, TRSE research also tends to focus on local scales of analysis. In a study of TRSE, Yigitcanlar et al. (2019) use two rounds of a Delphi survey to identify the most significant determinants of TRSE, and find that these are physical, economic, temporal, spatial, psychological, and informational. The authors also find a level of agreement or relevance for each sub-indicator under these topics. Bantis and Haworth (2020) use a capabilities approach to examine TRSE in London, using dynamic Bayesian networks to express the causal relationship between capabilities, functioning, personal, and environmental characteristics with traditional mobility surveys, travel card information, and points of interest (POI). One comprehensive regional scale analysis of TRSE was found: Transport for The North (2022) uses the English Indices of Multiple Deprivation (IMD) and accessibility measures to create scores that allow them to estimate the risk of suffering from TRSE in the North of England.

In general terms, both transport poverty and TRSE are broad concepts that involve many dimensions. Both concepts are still being developed; therefore, there are a variety of ways to measure them. Looking across this research, most studies have been based in a city, or a few cities, and there are fewer studies at the national level, with the Transport for The North (2022) study focusing on the North of England being among the most comprehensive. This represents a gap in the literature, as national-level analyses would provide policymakers with information about transport poverty and risk of TRSE that can be compared across the country. While the regional analysis in the UK from Transport for The North provides a good starting point, their methodology is not directly applicable to countries as geographically diverse as Canada. This means that the interaction between urban and rural areas, and the differences between big and small agglomerations, are less present in transport poverty and TRSE studies. This paper responds to this research gap by putting forward a methodology to measure transport poverty and risk of TRSE at the national level, which can also be applied to other large, car dependent, and geographically diverse countries.

# 3. Methodology

Building on the work by Transport for The North (2022), for measuring transport poverty and risk of TRSE at the national level, we create a tool with two outputs composed of two sub-indices. The two sub-indices are a socio-economic component and a transportation component, which are explained in section 3.1 and 3.2 respectively. The two outputs are a composite continuous index and a categorical ranking, and will be explained in section 3.4. The reason to have two outputs was to keep the tool as flexible and informative as possible for different research and decision-making spaces. Also, the categorical ranking complements certain aspects that can be blurred by the continuous index, and this will also be explained more in detail in 3.4. Several challenges emerged when measuring both socio-economic and transportation factors nationwide, considering the heterogeneity of the territory. The first challenge was data: what types of data sources are available for the entire territory, and will they be updated to facilitate future periodic analyses? A second challenge was how to understand a phenomenon (transport poverty) that is experienced in unique ways across different geographies; for example, urban vs. rural areas, small agglomerations vs. metropolitan areas, etc. The third challenge was more analytical: once a nationwide geographically disaggregated index is available, how do you start processing and understanding such a large volume of data?

To respond to the first challenge, we used Canadian Census and Spatial Accessibility Measures (Statistics Canada, 2023) data, because it is both universally applied to the territory and periodically updated. The second challenge we faced by rescaling the indices at different geographic scales, meaning, producing a tool that can be equally informative and readable at national, regional or local scales, when the geographies can be very different and contrasting between each other. For the third challenge, we propose an analytical approach, described later in this section, as a first attempt to understand, on the national scale, the situation of transport poverty and risk of TRSE, leaving room for other flexible applications. All statistical analyses were produced in R (RCore Team, 2022) and geographical operations in QGIS (QGIS.org, 2022).

Figure 2 summarizes the methodology, with all steps that led to the creation of a measure of transport poverty and risk of TRSE. First, there is a process of measuring the socio-economic and the transportation components, by calculating sub-indices, both fed by secondary data sources. Then, there is a step of spatial matching to transfer both components to the same spatial unit. The following step is to scale both sub-indices to three different spatial scales. Finally, both sub-indices are combined, to obtain a single synthetic measure of transport poverty (a continuous index) and a categorical classification of risk of TRSE. The remaining portion of this section will explain each of these steps in detail.

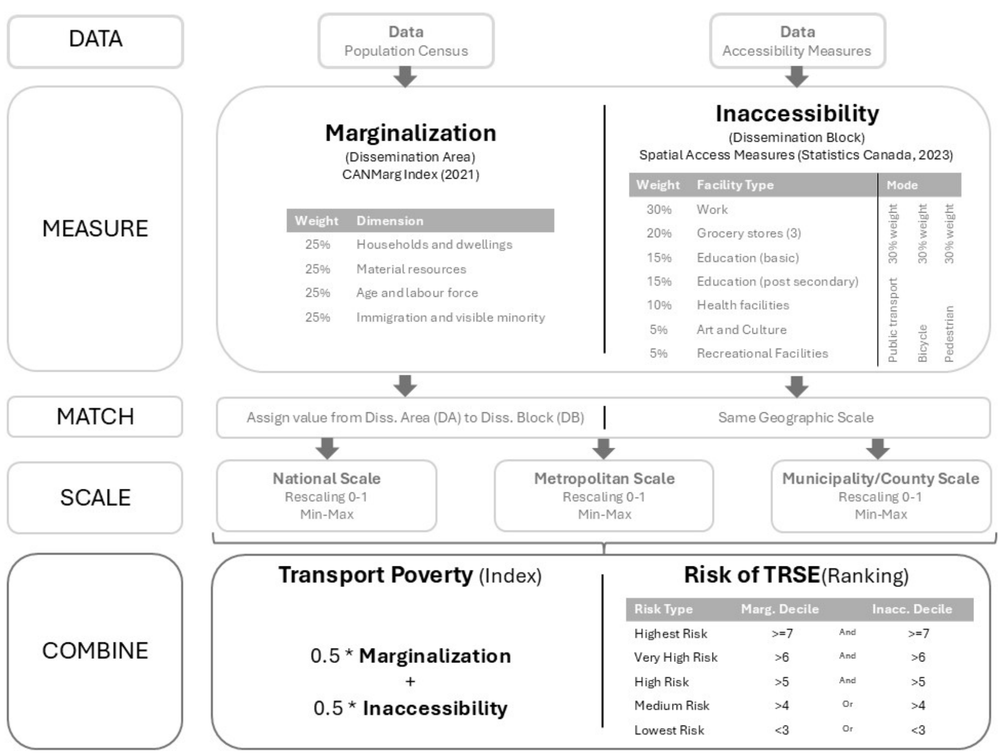


**Figure 2** Methodology

### 3.1. Socio-Economic Component: Can-MARG Canadian Marginalization Index

The socio-economic sub-index was created by Matheson FI et al. (2021). It measures marginalization using 2016 Census data at the Dissemination Area (DA) level and comprises four socio-economic dimensions: Households and Dwellings, Material Resources, Age and Labour Force, and Immigration and Visible Minority. Variables were treated as averages or proportions of the population. The four components were scaled from 0 to 1, and then combined in a synthetic index with equal weights for all variables. Table 1 contains the variables used for each dimension.

**Table 1** Dimensions and variables of Marginalization Index

| | |
|---|---|
| Households and Dwellings | Proportion of the population living alone |
| | Proportion of the population who are not youth (ages 5-15) |
| | Average number of persons per dwelling |
| | Proportion of dwellings that are apartments in a building with 5 or more stories |
| | Proportion of the population who are single/divorced/widowed |
| | Proportion of dwellings that are not owned |
| | Proportion of the population who moved during the past 5 years |
| Age and Labour Force | Proportion of the population who are aged 65+ |
| | Dependency ratio (total population 0-14 and 65+/ total population 15 to 64) |
| | Proportion of the population not participating in labour force (aged 15+) |
| Material Resources | Proportion of the population aged 15+ without a high-school diploma |
| | Proportion of families who are lone parent families |
| | Proportion of total income from government transfer payments for population aged 15+ |
| | Proportion of the population aged 15+ who are unemployed |
| | Average after-tax income for population aged 15+ |
| Immigration and Visible Minority | Proportion of the population who are recent immigrants (arrived in the past 5 years) |
| | Proportion of the population who self-identify as a visible minority |

### 3.2. Transportation Component: Accessibility Index

The transportation sub-index comprises an accessibility index based on measures provided by Statistics Canada (2023). The measures in question compute the ease of reaching destinations by employing gravity models developed by Alasia A. et al. (2021). These measures were calculated at the Dissemination Block (DB) level for the 2021 Census geography for 498,547 census blocks. Diverse types of destinations were included, namely: cultural and arts, health, educational, post-secondary educational, and recreational facilities; employment; and groceries. Three travel modes were selected: public transport, bicycle, and walking. These modes were chosen because they are more sustainable, both economically and environmentally. As for the exclusion of private cars, though access to a car is common in Canada, it is by no means universal, especially amongst marginalized groups, and it has been shown that a greater proportion of people in the low-income group use public transport as their main mode of commuting in Canadian CMAs (Cui et al., 2020). Hence, looking at transport from an equity perspective, where one of the main goals is a redistribution of services, public transportation analyses tend to have a greater impact on the lives of more vulnerable sectors.

In the case of public transport, off-peak accessibility values were used so that the measure would reflect worst-case scenarios, and because vulnerable population groups (women, elderly, etc.) tend to travel more during off-peak hours (Zhang et al., 2021). All measures had a score scaled from 0-1 for all DBs with one exception: accessibility to groceries. This was measured as accessibility to the first three grocery stores to better indicate access to proper nutrition options, rather than measuring accessibility only to the nearest grocery store (the first store, especially in remote locations, can have very limited food options, which is why encompassing more stores is considered a better indicator). Because this resulted in a measure showing the time it takes to reach the first three facilities in minutes, it was scaled from 0-1, and then subtracted from 1 to obtain a measure in the same direction and scale of the others (all other measures were a score of accessibility, where 1 means better conditions, whereas in time, bigger measures mean opportunities are further, implying less access). Then, all modes were combined per destination type with equal weights to obtain components from 0-1. Finally, synthetic indices for each destination type were combined with different weights. The weights were initially based on the proposal of Zheng et al. (2019), whose study weighs activity types according to their relative importance to quality of life. We then adapted the weights to the Canadian context by consulting the Mobilizing Justice team, experts in transportation accessibility in Canada. We maintain the same hierarchy of weights for the available categories as in the Zheng et al. (2019), and adjust the number for a scale of 0-1. The final weights applied can be found in Figure 2.

### *3.3. A Process of Matching Different Geographies*

Since both the socio-economic component and the transportation component base measures were calculated for different geographic scales (DA and DB), and for geographies of different years, all measures of the CAN-Marg index were transferred to the smallest and more updated geography: 2021 DBs. This was done to retain the ability to upscale measures without losing detail. Since CAN-Marg dimensions represent percentages of the population, they were transferred to smaller geographies by using spatial overlay.

### *3.4. Combining Indices*

#### Transport Poverty Index (TRPOV)

To obtain a measure of transport poverty, both the socio-economic (*Marginalization*) and transportation indices were combined with a weight of 0.5 each, obtaining a synthetic continuous measure from 0-1. Since the CAN-Marg index ranges from 0-1, where 1 represents the most deprived areas, and the accessibility index has the same scale, with 1 representing the areas with more accessibility, this measure was subtracted from 1 to obtain two components in the same direction. For convenience, this subtracted accessibility measure will be called *Inaccessibility*.

#### Risk of Transport Related Social Exclusion (TRSE)

The transport poverty measure can obscure the real situation of certain geographies when dealing with extreme values. For example, in the most extreme case, a score of 1 in one component and 0 in the other would have a transport poverty index of 0.5, when, in reality, whoever is at the lower extreme in either of the components is in a less vulnerable position, as they have either social or transport advantages. In addition, a fully continuous measure might be overly abstract when communicating or interpreting results. The interpretation of the measure depends on the knowledge of the distribution of the data, namely, to determine what would represent transport poverty and allow for establishing thresholds and target values.

Instead, a categorical variable might provide a more intuitive understanding of the situation and a more theoretically grounded interpretation. For these reasons, we develop a categorical classification, based on the marginalization and inaccessibility results. The idea is to identify areas that combine high levels of both marginalization and inaccessibility, since a combination of both have been shown to lead to higher risks of TRSE. While we acknowledge that TRSE is an individual condition, it is assumed that areas with high levels of marginalization and inaccessibility are more likely to have a concentration of individuals at higher risk of TRSE. Therefore, this classification enables identifying areas that need attention from authorities. Based on the work of Transport for The North (2022), categories were assigned according to the deciles of each component (marginalization and inaccessibility) following a set of classification rules (Figure 2). These rules assign each geographic unit a category of Low, Medium, High, Very High, or Highest risk of suffering TRSE. In general, if in any DA/DB either marginalization or inaccessibility are in the lowest five deciles, they are medium or low risk. This classification implies that either by socio-economic resources or favourable land use and transport characteristics, the area can be out of risk. With this reasoning, a simultaneity of both, high values of marginalization and inaccessibility is necessary to be considered at risk of TRSE.

### *3.5. Different Geographic Scales*

An aspect to consider when analyzing phenomena like transport poverty and the risk of TRSE is the scale of the area under analysis; roughly, it is expected that outcomes will vary depending on the level of spatial aggregation we consider for analysis. The Modifiable Area Unit Problem (MAUP), a topic of constant study in geography-related fields, has profoundly studied this challenge. It has been observed that the areal unit is independent of the phenomena, for phenomena that are not influenced by sociopolitical factors, which might derive from the governance of politically defined units (Nelson & Brewer, 2017). Given that both socio-economic status and transportation are highly dependent on local policy, a degree of spatial variation and dependence on the spatial unit are expected, in other words, the pattern of variables describing socio-economic status and transportation phenomena are subject to vary if the area unit varies in size.

Canada, like many other countries, has a truly diverse territory, featuring very concentrated metropolitan urban areas, smaller urban agglomerations, and large portions of rural land. Therefore, a single measure or classification with all geographic units can be inaccurate or of limited use, due to the effect of areas with extreme characteristics. For local administrators, a more local depiction of their reality is more useful than a single national scale. To face this challenge, and the MAUP nature of this problem, a rescaling of all measures was made by grouping per Census Metropolitan Areas (CMA) and Census Agglomerations (CA) and then proportioning the original marginalization and inaccessibility values from 0-1, grouping by CMA/CA area code using the min-max scaling. This spatial scale will be called Metropolitan Scale in the following stages. These geographic units are important because they contain most of the country's population. As of 2021 73.3% of Canadians live in urban centres of 100,000 or more people (Statistics Canada, 2022). By definition, CMA/CAs are formed by one or more adjacent municipalities centred around a population centre; CMAs must have a minimum of 100,000 inhabitants and CAs,10,000 (Statistics Canada, 2016b). Additionally, because CMA/CAs are still large, and do not encompass the totality of the territory, another rescaling for local accuracy was made by Census Division (CD), following the same procedure, to ensure that the state of rural areas is considered in the calculations as well. CDs are a group of neighbouring municipalities, joined together for the purpose of regional planning and managing common services (Statistics Canada, 2016a). In the following steps, this scale will be called Municipality/County Scale.

## 4. Analytical Examples

Once the TRPOV index and categorical classification are calculated, there are extensive possibilities for analysis. In this section, as an array of examples of how the tool can be used to inform decision-making in planning processes, we present two distinct analyses to demonstrate the diversity of the information included in the indices, their usefulness, and the possibilities of these measures for transportation practitioners and examples of policy approaches. To frame the analyses, we investigate two questions: what is the state of the population at risk of TRSE? And what is the state of TRPOV/TRSE in the metropolitan areas in Canada? This analysis does not aim to make a report on the state of transport poverty in Canada, but showcase different possibilities of the use of the tool for planning purposes and policy recommendations.

Before presenting these results, we discuss one of the main features of the index we discovered: the importance of geographic scale when looking at nationwide data, a feature that gives the index flexibility in interpretation and adaptability to different realities in the same country.

### *How do results vary across geographic scales?*

Figure 3 shows the differences between the three geographical rescaled measures of both TRPOV and TRSE Risk. The maps use the Montreal Metropolitan area as an example, where the urban area is mainly on the island, and the island is an administrative unit. The National TRPOV image shows most of the poverty concentrated in the rural areas. The metropolitan image shows a small core without transport poverty, surrounded by transport poor areas, almost without intermediate values. The municipality/county picture displays a more nuanced reality, with cores of more contrasting values in smaller areas, closer to the local reality on the ground. Similarly, when exploring the images of TRSE Risk, the national picture shows an urban core in all the island and both shores of low risk, whereas the risk is in the rural areas. In the metropolitan scaling, it is hard to distinguish patterns of areas at risk; some are seen south of the island. Finally, at the municipality/county level, there are more patterns of both extremes of risk inside local jurisdictions, making it more useful for local authorities. Gray areas represent empty values, whether because the census was not applied (national parks, for example), or because they do not belong in the concept of that geography (the area outside a metropolitan in the metropolitan scale).

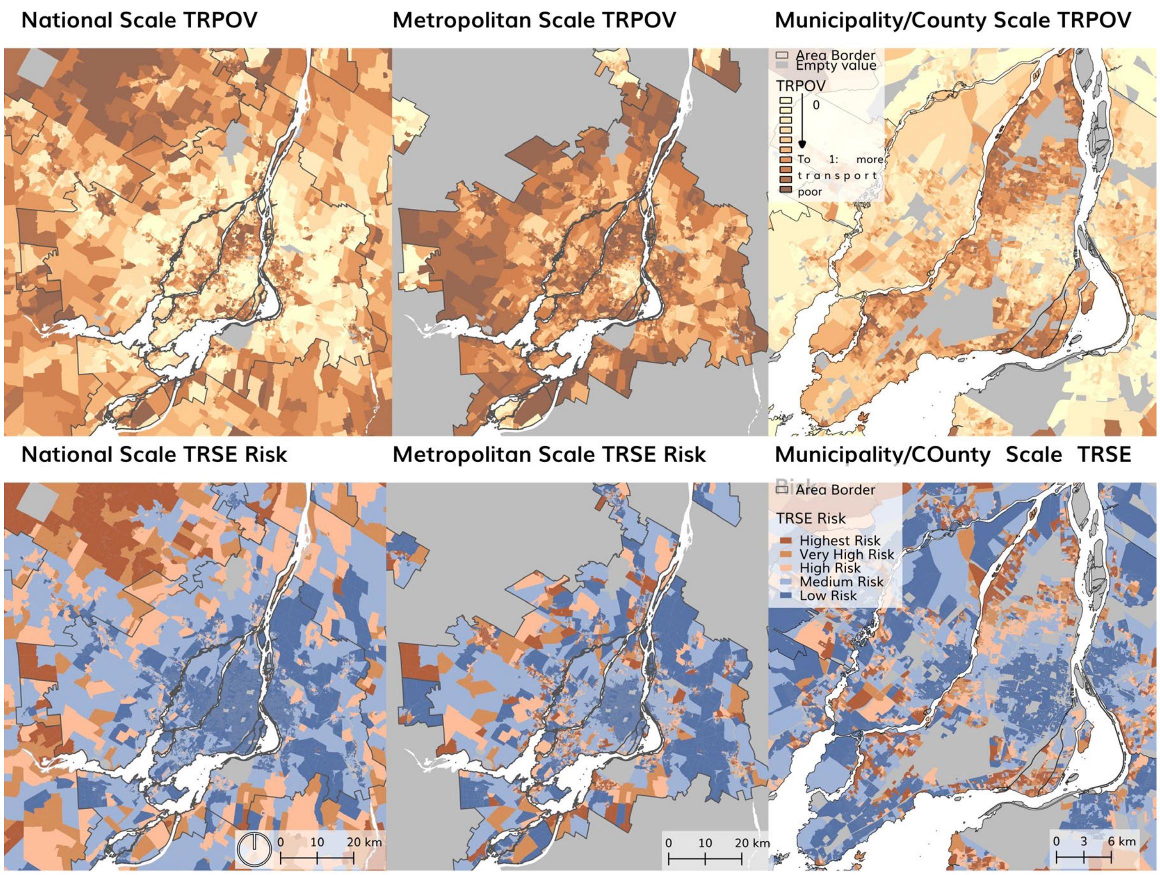


**Figure 3** Geographic patterns of TRPOV and TRSE at different scales in the Montreal Metropolitan area.

Figure 4 displays the amount of the population at risk of TRSE, at each rescaling. At the national level, the ranking compares all DBs in the country, from the densest urban area to the most remote rural area. In this light, any DB close to the Montreal area, or other urban areas, has better accessibility and is often less marginalized than the most remote areas in the country. As the scale decreases, the index will only compare DBs within each limit (metropolitan or municipality/county), meaning that the index will display the phenomenon in a local perspective. Here, from a total of 3,693,107 inhabitants in the metropolitan area, the percentage of the population at the Highest risk varies from 0.02% at the national scale, to 3.5% at the metropolitan scale, and to 9.7% at the municipality/county scale. This increasing trend is similar for the Very High and High risk categories. On the contrary, the percentage of the population in the Middle and Low Risk categories decreases as the geographical scale becomes more local. For local authorities, the measure that best depicts their jurisdiction for intervention is the municipality/county level, when all DBs within the local administrative boundary are only compared with each other.

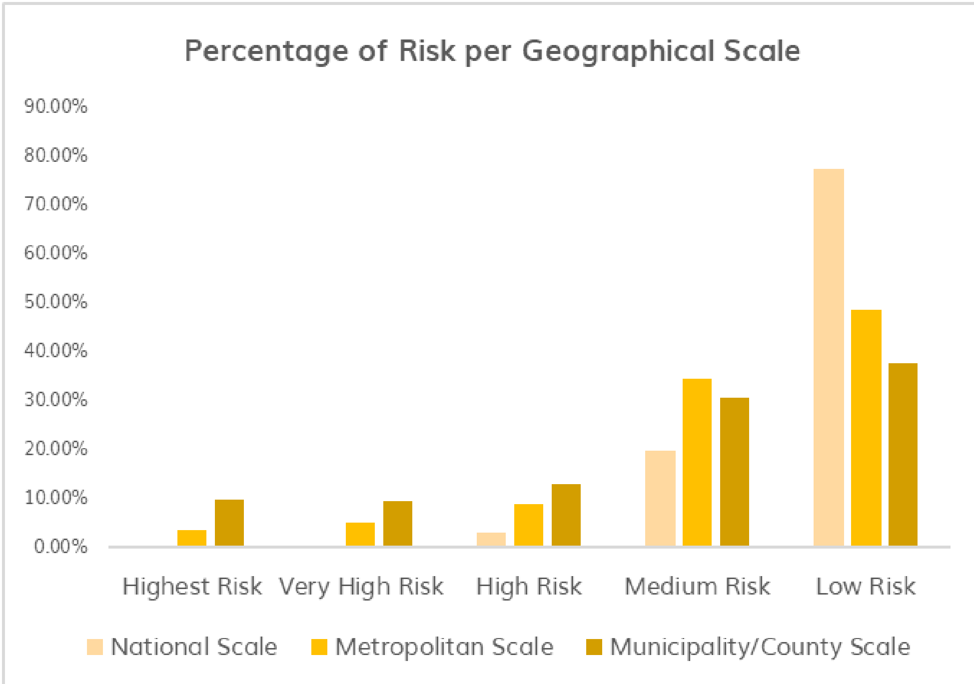


**Figure 4** Percentage of population per risk type in the Montreal Metropolitan area at different geographic scales.

### *4.1. What is the state of the population at Risk of TRSE?*

For the first approach to the population at risk of TRSE, both the raw number and the proportion of the population at risk increase with the metropolitan areas and municipality/county scales. When putting the three categories of high risk together, at the national scale there is 16% of the population at risk, roughly 6.1 million people; there is 27% of the population at risk with the metropolitan areas scaling, meaning around 8.4 million people; and 27% of the population at risk with the municipality/county scaling, which implies around 10.2 million people (Table 2). It is worth noting that the rescaling process allows for a local assessment of the risk of TRSE, which transforms these measures to an operative scale for local authorities. It is also important to remember that the municipality/county scale includes the rural population, but from a local perspective (Table 2).

**Table 2** Population per risk type in Canada

| | National | | Metropolitan | | Municipality/County | |
|---|---|---|---|---|---|---|
| Risk Type | Population | % from total | Population | % from total | Population | % from total |
| Highest Risk | 1,207,409 | 3% | 1,964,240 | 6% | 3,015,660 | 8% |
| Very High Risk | 1,906,820 | 5% | 2,670,190 | 9% | 3,047,013 | 8% |
| High Risk | 3,021,977 | 8% | 3,762,487 | 12% | 4,183,869 | 11% |
| Medium Risk | 12,099,290 | 33% | 10,690,437 | 35% | 11,610,010 | 32% |
| Low Risk | 18,215,927 | 50% | 11,788,701 | 38% | 14,594,871 | 40% |
| Total | 36,451,423 | 100% | 30,876,055 | 100% | 36,451,423 | 100% |

As for a local approach to the population at risk of TRSE, the categories Highest, Very High, and High were aggregated for a general assessment across metropolitan areas. Figure 5 shows how larger urban areas have lower proportions of the population at risk of TRSE (with some agglomerations like Hawkesbury, Wasaga Beach, and Port Albemi close to 100%), and the size of the dot indicates the real number of people. In this case, the amount of population in larger areas is higher than those in small cities with large proportions of the population at risk. This interaction between number and proportions must be considered when prioritizing transportation projects.

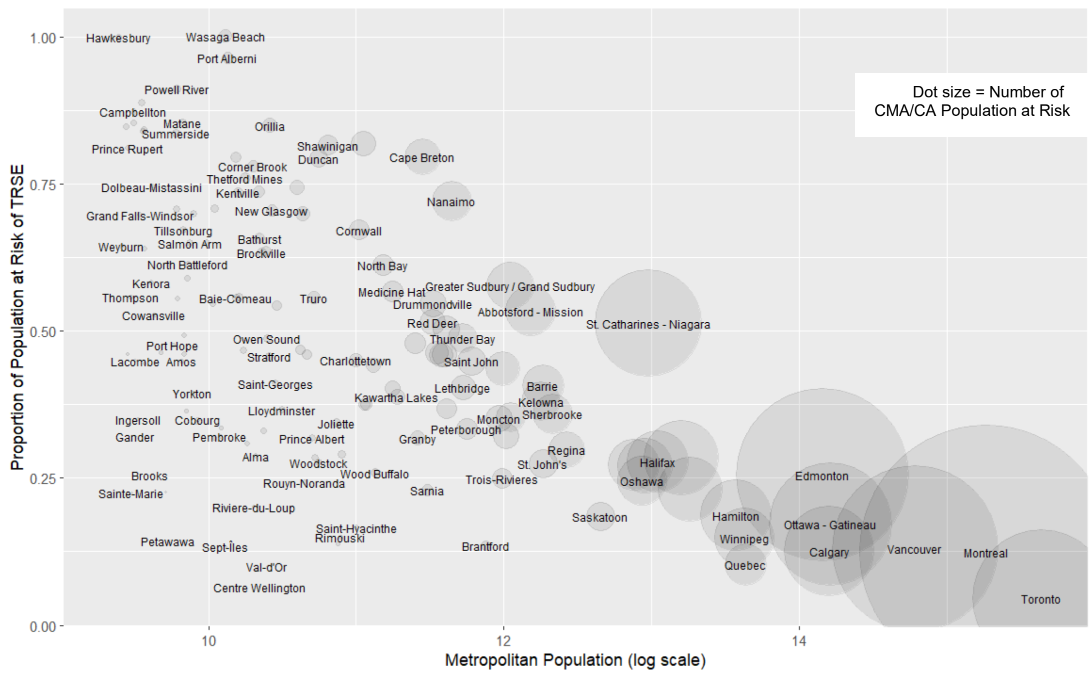


**Figure 5** Relationship between the proportion of the population at risk of TRSE and metropolitan area population size

These results show that the smallest metropolitan areas have larger proportions of the population at risk of suffering TRSE, implying a gap or imbalance of the conditions between the different metropolitan areas. Those working in public policy could use the findings of this tool to design a system of prioritization of investments in transport and infrastructure for metropolitan areas. In this example, the tool can be used to advocate for giving smaller metropolitan areas with a high proportion of the population at risk of TRSE first priority. Then, a second stage of investment could be addressed to larger cities, as though the proportion of people at risk is lower, because they are highly dense areas and the actual amount of population at risk is considerably high. Such a measure could reduce the gap of the population at risk between big and small cities while also improving the conditions of existing transport systems to balance benefits. It is important to remember that by the nature of this index, improvements can focus not only on public transport infrastructure and operations, but also on pedestrian and bike infrastructure quality and land use.

### *4.2. What is the state of TRPOV in the metropolitan areas in Canada?*

To understand the interactions between marginalization, inaccessibility, and transport poverty, Figure 6 shows the Montreal Metropolitan area as an example. The image shows that Marginalization is a mainly urban, central phenomenon, while inaccessibility is suburban/rural. When combined, the highest values of TRPOV can be seen in the areas that surround the urban core, as poor areas are located not immediately next to transport stations, but still relatively close to the service.

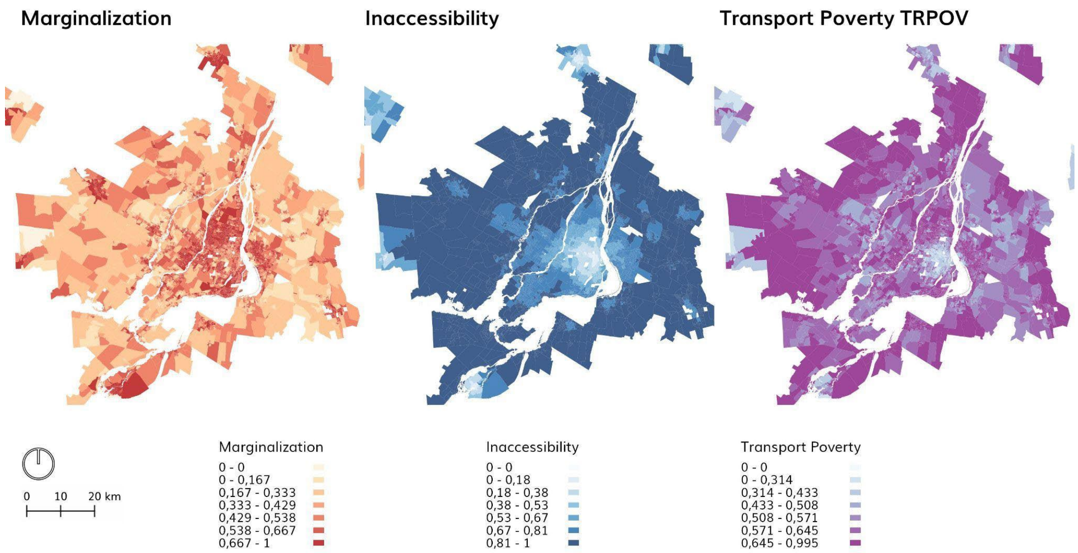


**Figure 6** Interactions between Marginalization, Inaccessibility and TRPOV

An analysis of the mean values of Marginalization, Inaccessibility, and Transport Poverty for the 152 metropolitan areas in Canada shows that Marginalization varies from 0.29 to 0.67. The most populated cities have values around 0.5, while the intermediate cities vary from 0.4-0.5. Then, the group of smaller cities is heterogeneously distributed, indicating a variety of conditions of marginalization (Figure 7).

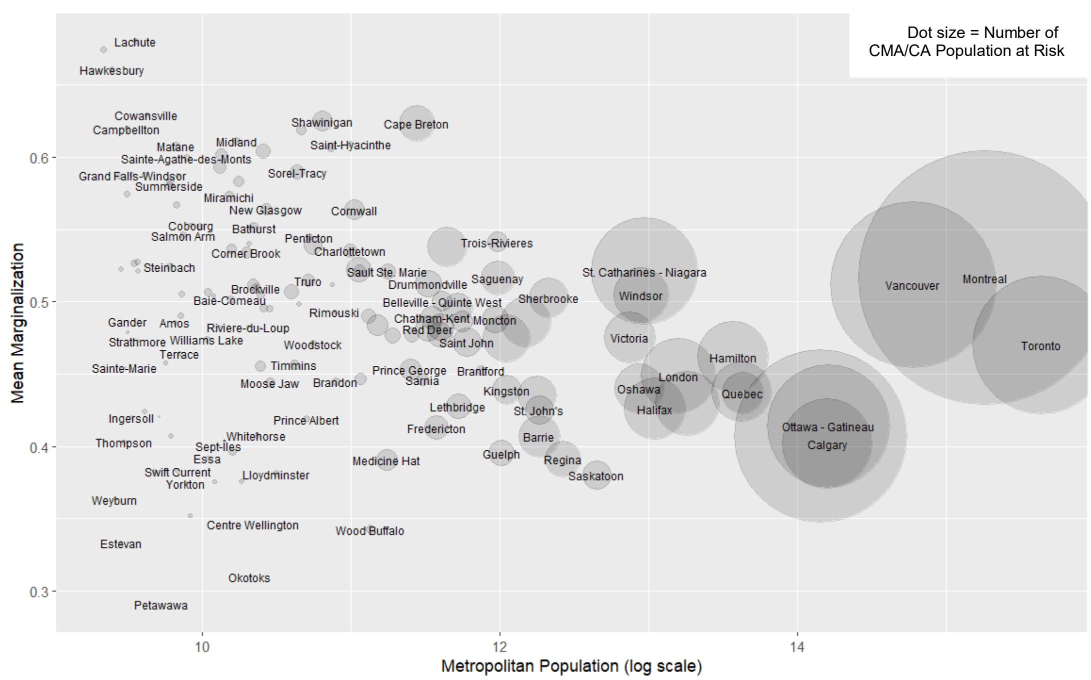


**Figure 7** Relationship between Marginalization and metropolitan area population size

Figure 8 shows the state of mean Inaccessibility across metropolitan areas, with a variation from 0.75-1. The three largest cities are the least inaccessible. There is a clearer cluster of intermediate cities (Edmonton, Calgary, Winnipeg, Victoria, Regina, etc.), grouped between 0.83-0.93, slightly more inaccessible than the bigger ones. Finally, there is a large group of small cities with higher values of inaccessibility from 0.9-1, although there are also some small cities at the same level of the intermediate ones. The general trend in the Figure is for larger cities to be more accessible, but a detailed look calls for a deeper reflection on why small towns like Stratford, Victoriaville, etc. have such low levels of inaccessibility, similar to Calgary, Victoria, or Quebec, despite their size. Transport infrastructure and systems in these towns can be investigated as examples of good practices.

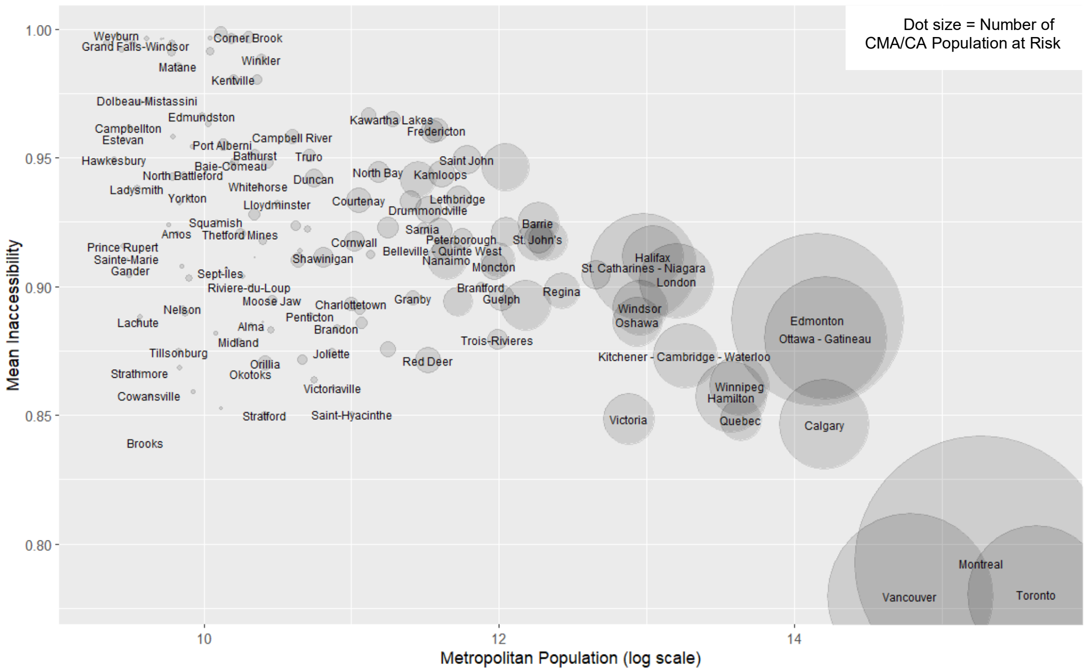


**Figure 8** Relationship between Inaccessibility and metropolitan area population size

Transport poverty shows a variation from 0.65-0.83. The biggest cities, and most intermediate cities, are at the lowest end of transport poverty, until around 0.67. Then, the cloud of smaller cities is spread roughly from 0.67-1, with some exceptions. This indicates that, based on the current methodology, smaller municipalities or administrative units face starker situations of transport poverty (Figure 9).

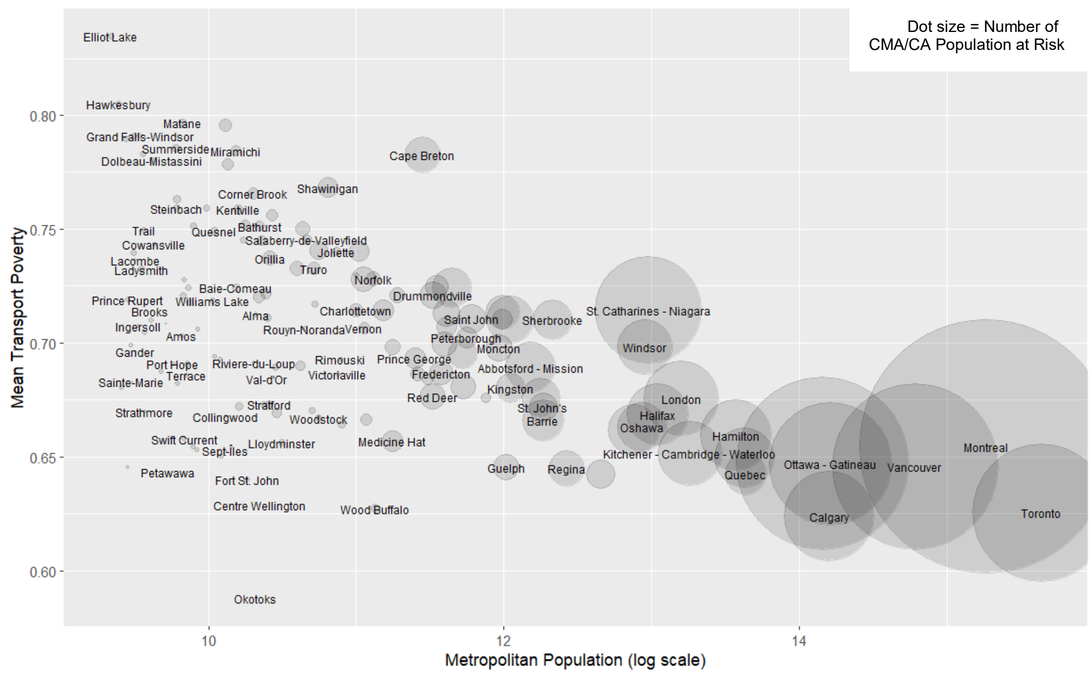


**Figure 9** Relationship between Transport Poverty and CMA/CA population size

An analysis of the distribution of Marginalization in relation to Inaccessibility in the nine largest urban areas, where Marginalization quintiles are in the horizontal axis (quintile 5 means more marginalized), shows that in larger urban areas (Toronto, Montreal, Vancouver), and Quebec and Winnipeg, the population in the fifth quintile has less inaccessibility than in the first, a condition that shows more equity in the distribution of transport services in these cities. In contrast, in other cities (Calgary, Edmonton, Hamilton, Kitchener-Cambridge-Waterloo), all quintiles of marginalized population are exposed to relatively the same level of inaccessibility, which gives a sense of where efforts to improve accessibility should be directed in these cities (Figure 10). Figure 10 could help to understand what supports greater vertical equity (a concern for distributing more resources for the most disadvantaged groups (Camporeale et al., 2019)) in metropolitan areas.

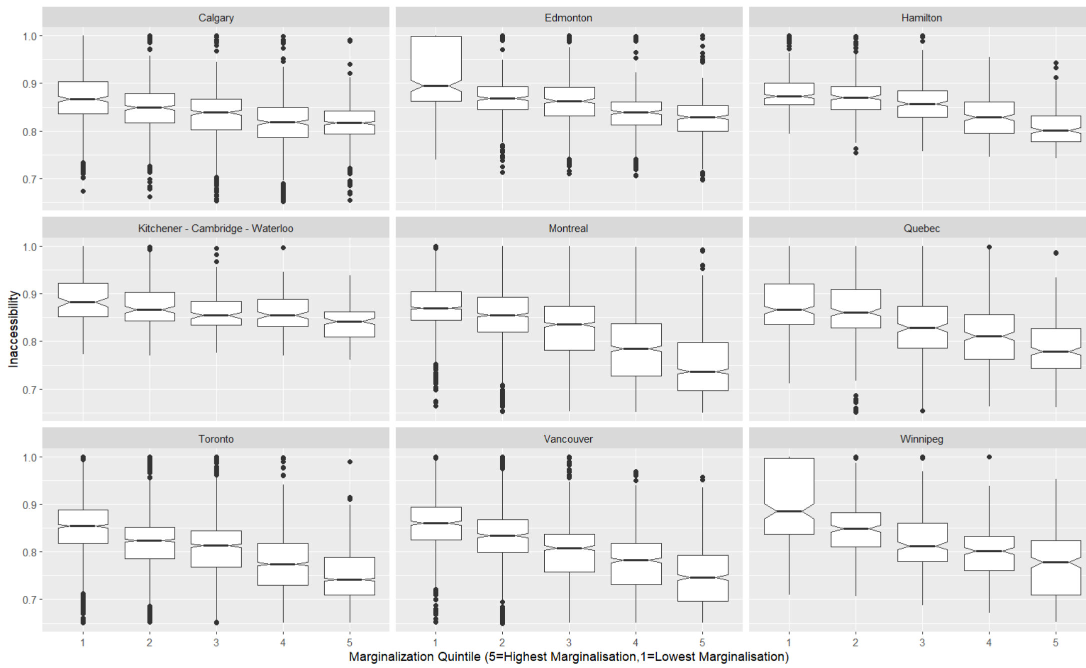


**Figure 10** Distribution of Marginalization in relation to Inaccessibility

These analyses show that to improve transport poverty conditions in Canada, transport resources could have a double target. First, be directed to smaller metropolitan areas. Second, within the intermediate metropolitan areas where there is not yet enough vertical equity, improvements in the transport systems can be targeted to the areas where people in the 4th and 5th quintiles of marginalization live, with a combination of increasing the capacity of the public transport system and improving the conditions for walkability/bikeability and land use.

## 5. Discussion and Conclusion

The design of a method to measure transport poverty and the risk of Transport-Related Social Exclusion at the national level in a country like Canada imposed many conceptual and practical challenges; among them, how to assess under the same principles a territory as heterogenous and extensive as Canada, with different urban fabrics, sizes, and urban/rural dynamics; how to make it easily readable and interpretable for communicating with different actors in the transport sphere and the public; the availability of quality data for the whole country; and, how to read and interpret such a volume of information. These challenges were addressed by designing a flexible tool, capable of assessing the situation at the national and local scales with the possibility of being upscaled and rescaled; by using simple concepts and techniques that produced measures that can be easily understood by different professionals; by using census data at the smallest geographical scale with accessibility measures calculated for the whole country, using free software; and, by exploring different avenues to interpret the results. These characteristics make this tool easy to operationalize, easy to interpret and communicate, and appropriate for social and economic evaluations, which are important characteristics of useful indicators in the assessment of accessibility (Geurs & van Wee, 2004). In addition, this operational and conceptual simplicity make this tool highly reproducible for geographic contexts similar to Canada.

The tool can be applied for the assessment of the current state of the territory in relation to transport, and local authorities can use it as a tool for planning targeted interventions in their administrative boundaries. Further, the scaling to different geographic boundaries gives the tool enough flexibility to be used, for instance, to connect isolated areas in large national rail projects, to plan regional transport interventions within metropolitan areas, or to direct new projects and reorganize local services within municipal boundaries, all with the aim of targeting these interventions to the most vulnerable sectors of the population.

It is important to remember as well that both TRPOV and TRSE are still concepts in development and are therefore in constant refinement and evolution. One of the limitations of this study is the weighting system, which was based on the conventional equal weights for the final TRPOV index and the paper by Zheng et al. (2019) for the Inaccessibility component. In this light, future research can perform sensitivity analyses with different weights to understand potential variability in the results, especially testing differences in the weight of transport modes. Given that the Marginalization index varies more than the Inaccessibility index, there is an effect on the results, implying that different weights could balance this difference in range. Additionally, future research can refine both measures, TRPOV and risk of TRSE, and should validate them on the grounds of evaluating the representativeness of the index.

## 6. Acknowledgments

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