



Geographia Polonica
2025, Volume 98, Issue 3, pp. 255-276
<https://doi.org/10.7163/GPol.0302>



INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES
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TRANSPORT POVERTY IN POLAND – A SPATIAL APPROACH TO PUBLIC TRANSPORT DEMAND AND SUPPLY

Piotr Rosik  • Patryk Duma 

Institute of Geography and Spatial Organization
Polish Academy of Sciences
Twarda 51/55, 00-818 Warsaw: Poland
e-mails: rosik@twarda.pan.pl • p.duma@twarda.pan.pl (corresponding author)

Abstract

The paper aims to provide an initial evaluation of transport poverty in Poland by examining both the demand and supply of public transport services at the municipal level. Due to the lack of comprehensive data, median earnings from the Central Statistical Office are used as a proxy for transport demand and income inequality, while a composite index of public transport accessibility (PTAI), incorporating three indicators, represents the supply side (rail and bus services). The study provides the first analysis in Poland to identify areas at risk of transport poverty, focusing on public transport accessibility at the municipal level. Through spatial analysis, it identifies vulnerable areas including those along national borders (excluding certain parts like the eastern Polish-Czech border), marginalized municipalities, internal peripheries of voivodeships like the Greater Poland-Łódź border, and certain areas in developed voivodeships like Greater Poland and Pomerania. It highlights that some at-risk areas, such as southern Kashubia or counties like Międzychód, have not been previously recognized in other studies. The findings stress the need for further methodological development, especially refining indicators for monitoring transport poverty at the municipal level.

Keywords

transport poverty • public transport accessibility • Polish municipalities • median earnings

Introduction

The concept of 'transport poverty' is relatively new, with no universally accepted definition in academic or policy frameworks thus far (Lucas et al., 2016a,b; Robinson & Thagesen, 2018; Allen & Farber, 2019; Churchill & Smyth, 2019). Typically, this term

is employed to describe situations where individuals lack access to essential services of general interest (ESPON, 2013; Rosik & Stępnik, 2013) or employment and education opportunities due to unaffordable or unavailable transport options. Therefore, defining transport poverty based solely on unmet household needs is challenging.

Transport poverty is experienced at the individual level rather than across the household. For example, one family member may face transport poverty while another may not, with notable gender disparities in how it is experienced (Lucas et al., 2016a; Robinson & Thagesen, 2018). Additionally, mobility primarily serves as a means to access essential goods, services, and activities – each shaped by specific social, temporal, and geographic contexts – complicating the development of a single, definitive measure of transport poverty. Consequently, it remains unclear whether transport poverty should be defined by a lack of transport supply, a minimal level of mobility, or adequate accessibility to essential services and daily activities (Lucas et al., 2016b). Nevertheless, literature on the topic has identified several contributing factors, including:

1. Lack of available transport options (limited services or low frequency, often termed as ‚mobility poverty’) (Kuttler & Moraglio, 2021; Székely et al., 2023);
2. Inaccessible transport (e.g., for people with disabilities (Taylor & Józefowicz, 2012; Puławska-Obiedowska, 2017; Zmuda-Trzebiatowski et al., 2023));
3. High transport costs, which make transport unaffordable, often result from insufficient individual or household resources to cover transportation expenses, typically related to car use in developed countries or public transport options (Carruthers et al., 2005; Serebrisky et al., 2009; Litman, 2015);
4. Excessive travel time (also known as ‚time poverty’) (Aitken et al., 2024);
5. Unsafe or inadequate transport conditions (Jones, 2016);
6. Exposure to transport externalities; the consequences of disproportionate exposure to the transport system’s negative impacts, such as road traffic accidents and long-term health issues or fatalities due to pollution from traffic (Booth et al., 2000).

The issue of transport poverty is comprehensively addressed in Regulation (EU) 2023/955 of the European Parliament and

of the Council of 10 May 2023, establishing a Social Climate Fund and amending Regulation (EU) 2021/1060 (Regulation, 2023). This document notes that transport poverty can broadly impact individuals or households who have access to affordable transport options; however, because these expenses represent a substantial share of their income, they become vulnerable to any price increases. Transport poverty often intersects with other social vulnerabilities, such as unemployment and limited mobility. Particularly affected groups include women, the elderly, young people, low-income earners, and individuals with disabilities. Moreover, living in disadvantaged areas, such as rural, remote, or peripheral regions – including outermost regions – further exacerbates the risk of experiencing transport poverty. According to the EU Regulation 2023/955 “transport poverty means individuals’ and households’ inability or difficulty to meet the costs of private or public transport, or their lack of or limited access to transport needed for their access to essential socioeconomic services and activities, taking into account the national and spatial context” (Regulation, 2023; article 2.2, L 130/10). While this definition leans towards a broader and more holistic perspective, it is important to emphasize that transport poverty can occur in any type of community where public transport services fail to adequately meet the needs of households (Dorantes & Murauskaite-Bulll, 2022). Moreover, this definition highlights two critical aspects: demand, relating to users’ financial capacity to access transport services, and supply, referring to the spatial accessibility of transport services on a national level.

In Poland, the motorization rate is relatively high, and access to a private car is no longer as problematic as it was a decade or two ago. However, there are notable methodological issues regarding the spatial differentiation of the motorization rate at low levels of data aggregation (e.g., the so-called ‘dead souls’ problem) (Jamroz et al., 2018; Strykiewicz & Kołsut, 2024). Additionally, there has been a reported decline in access

to public transport in Poland (Wolański et al., 2016; Komornicki, 2019). This makes the availability of public transport services especially crucial (Saif et al., 2019), particularly in peripheral areas, both along the national borders and in so-called internal peripheries, which are increasingly visible in Poland along regional borders (Rosik et al., 2021; Rosik et al., 2025 a,b).

The purpose of the paper is to propose a preliminary assessment of transport poverty in terms of demand and supply for public transport services at the municipal level in Poland. In the article, we aim to address the question of how to systematize knowledge regarding both the demand and supply aspects of transport poverty in Poland. To this end, we propose a research hypothesis that areas characterized by low levels of public transport accessibility are also inhabited by residents with low average earnings, resulting in a specific kind of feedback loop of transport poverty in peripheral areas, including the so-called internal peripheries of voivodeships.

Due to the lack of sufficient data on various aspects of this phenomenon in Poland, the decision was made to utilize the latest data from the Central Statistical Office (GUS, 2024) regarding median earnings (wage and salary) by place of residence as a determinant of demand capacity for transport services and as an indicator of income disparities among residents of Polish municipalities. On the supply side, a composite spatial accessibility index for public transport services (PTAI) was developed for this article, consisting of three accessibility indicators (RTAI, BRAI, and RCAI). Examining both demand and supply allowed for the creation of a unique typology of municipalities based on the interaction between demand and supply of transport services. Identifying the population in areas of each type enables the formulation of recommendations for both transport and spatial policy.

Literature review: Transport poverty at a low level of aggregation in the context of the entire country

An overview of research on transport poverty indicates that this is a relatively new topic, with studies mainly conducted over the past decade, particularly in the British Isles (RAC, 2012; Sustrans, 2012, 2016; Mattioli et al., 2017; Kelly et al., 2023). However, recent years have seen a surge of studies on this issue in other countries as well, such as the Netherlands, Germany, the Czech Republic, Spain, Australia and Canada (see Tab. 1). Particularly interesting is the comparison of possible approaches in the context of leveling transport accessibility (Biscaro Uliana, 2022): egalitarianism (reducing transport poverty for everyone), sufficientarianism (reducing particularly high levels of transport poverty observed in a given area), utilitarianism (maximizing utility for entire communities), or the so-called capabilities approach (reducing high levels of transport poverty while considering individuals' capabilities, personal differences among citizens, and perceived accessibility) (Tab. 1).

In Poland, there has so far been a lack of comprehensive attempts to define transport poverty on a national scale at a low level of data aggregation. Most analyses focus on local or regional examples of studies on transport exclusion and poverty, such as those by Ciechański et al. (2021) and Ciechański (2023) for the Beskid Niski and Bieszczady regions, or Kiciński et al. (2015) for the Greater Poland region. On a larger spatial scale, an in-depth analysis of public transport accessibility at the local level was conducted for six voivodeships (Pomeranian, West Pomeranian, Warmian-Masurian, Łódź, Lesser Poland, and Kuyavian-Pomeranian) as part of the project 'Analysis of Functional and Spatial Relationships between Urban Centers and Their Surroundings' (Śleszyński, 2019; Guzik & Kołoś, 2021). Interesting results related to transport poverty and exclusion are also presented in the *Monitoring*

Table 1. Transport poverty direct metrics

Term	Region/Country	Description	References
Transport Poverty	UK	Over 10% of household spending allocated to car usage or an equivalent transport option	RAC, 2012; Sustrans, 2012; Mattioli et al., 2017
Transport Poverty risk score	Scotland	A multifaceted concept that considers household income, car accessibility, and proximity to public transportation within each Scottish data zone. The data is sourced from the Scottish Index of Multiple Deprivation (SIMD), the Scottish census, and public transport frequency statistics. Each component is rated on a scale from 1 to 3 (with 1 indicating low risk and 3 indicating high risk).	Sustrans, 2016
Transport Poverty Risk	Ireland	A detailed spatial index of TPR (TPRI) is developed, grounded in three key components: transport affordability, mobility, and accessibility.	Kelly et al. (2023)
Perceived Transport Poverty	Netherlands	A model utilizing socioeconomic and transport characteristics as well as perceived accessibility	Biscaro Uliana (2022)
Transport Poverty	Eastern Germany and Czechia	Car dependency: a GPS tracking study of socially disadvantaged groups	van Dülmen et al. (2022)
Transport Poverty	Spain	Data from the Household Budget Survey (HBS), a standardized database available annually in many countries, was used to test three indicators addressing the affordability aspect of transport poverty (10%, 2M, LHIC), as well as an additional indicator that incorporates the accessibility dimension (VTU).	Alonso-Elpede et al. (2023)
Transport poverty	Canada	Identifying low-income or otherwise vulnerable residents residing in areas with the poorest access to public transportation. Cluster analysis approach.	Allen and Farber (2019)
Transport poverty	Australia	Transport accessibility and affordability. Two-stage least squares (2SLS) estimates, where transport poverty is instrumented using NYSE Arca Oil Stock Prices.	Churchill and Smyth (2019)

Source: Own elaboration incorporating Mejía Dorantes & Murauskaite-Bulll (2022).

of *Rural Area Development* (Stanny et al., 2023), where the authors analyzed this phenomenon at the local level in Poland, utilizing surveys in selected villages.

In terms of continuous annual monitoring of transport exclusion among municipalities in Poland, the Multimodal Transport Accessibility Index (WMDT) has been in place for over a decade. This index is developed through regular analyses conducted by a team from the Institute of Geography and Spatial Organization Polish Academy of Sciences for the Ministry of Development Funds and Regional Policy (Komornicki et al. 2018).

The passenger rail transport accessibility index (RTAI) was selected as one of the indicators included in the comprehensive public transport accessibility index (PTAI) for this study (see more: Methodology on the supply side (accessibility)).

Methodology on the demand side (affordability)

A key definitional issue in transport poverty is the proper understanding of demand-related aspects, which distinguishes two often interchangeably used terms: 'transport poverty'

and ‘transport exclusion’. Transport poverty is more focused on financial constraints and the lack of available transport options, whereas transport exclusion refers to a broader range of barriers that affect an individual’s ability to fully participate in social and economic life (Ciechański et al. 2021; Ciechański 2023; Żukowska et al. 2024; for an interesting elaboration on the concept of social and transport exclusion and poverty, see also: Jaroš, 2017). Both terms are used in the literature to analyze marginalization related to access to transport, although transport exclusion often encompasses a wider scope of barriers (Kamruzzaman et al. 2016, Pérez-Peña et al., 2021).

The division into demand and supply sides in this article stems, firstly, directly from the definition of transport poverty (Regulation, 2023; article 2.2, L 130/10), which clearly highlights these two “sides of the coin” of poverty. Secondly, in traditional studies on the relationship between land use and transport, both the demand and supply sides are considered important. Furthermore, some researchers point to the advantages of using two-dimensional (demand-supply) indicators that balance both sides in transport analyses (Higgs et al., 2019, Ballantyne et al., 2024).

On the demand side, a determinant of individuals’ and households’ inability or difficulty in covering the costs of private or public transport’ can certainly be an individual’s or household’s income. A good way to spatially specify the phenomenon of transport poverty on the demand side at the municipal level is by using the median gross earnings by place of residence for March 2024, based on the new data from Statistics Poland (GUS, 2024), which has been available since September 4, 2024. The spatial distribution of this variable reveals extensive ‘wealth’ areas, primarily including the country’s largest metropolitan areas (Fig. 4). It is also worth noting that for the wealthiest metropolitan areas, the suburban zone, where people with above-average incomes tend to settle, is particularly extensive (compare the Warsaw, Poznań, and Wrocław metropolitan areas). Besides metropolitan areas, higher wages and lower

risk of transport poverty on the demand side also pertain to industrial regions, such as the Katowice conurbation or the Legnica-Głogów Copper District. However, from the perspective of transport poverty, it is crucial to properly delineate peripheral areas, where the median income is particularly low. These peripheries can be defined in a narrower and broader sense. In the narrower sense, these are areas where median earnings are particularly low, such as the border area of the Masovian, Kuyavian-Pomeranian, and Warmian-Masurian voivodeships. Another approach is to compare the median earnings in a municipality to the national median. This would reference the so-called relative poverty, defined in the document: *Poverty and Social Exclusion in Poland and Other EU Countries from 2008-2016* (Siergiejczuk, 2018) as the At Risk of Poverty rate (AROP), which shows the percentage of individuals living in households where the annual disposable equivalent income is below the poverty threshold, set at 60% of the national median annual disposable equivalent income. However, the publicly available GUS data do not provide information on the decile distribution of earnings by place of residence. Additionally, in recent years, with the significant increase in minimum wages, there has been a flattening of wage levels and a reduction in disparities between the wealthier and poorer regions of the country. It should also be noted that relative poverty at the household level is different from relative poverty at the spatial unit level, such as a municipality. For these reasons, the median earnings value related to the risk of relative poverty has been raised in this analysis to 85% of the national median, compared to the AROP definition above.

Methodology on the supply side (accessibility)

The definition of transport poverty highlights a key spatial aspect at both local and national levels, directly related to transport accessibility on the supply side of transport services. A national and spatial approach to the issue

requires the use of appropriate databases covering the entire country at a relatively low level of data aggregation (preferably at the municipal level), and at the same time encompassing access to basic public transport services. However, a significant problem in Poland is the lack of sufficient data on the schedules of railway and bus operators. Even databases that feed into nationwide traffic models (CUPT, 2017; CPK, 2023) heavily rely on incomplete external data obtained for bus transport from commercially operating entities, such as e-podróżnik.pl, often provided during pre-pandemic periods. Access to these data is limited, very costly, and essentially attainable only by the largest institutions – for example, within the framework of nationwide traffic models. Therefore, an alternative is to use databases for the entire country for defining transport poverty on the service supply side – NCN MULTIMODACC (Rosik et al., 2017b) and WMDT (Komornicki et al. 2018; Rosik et al., 2017a). It is proposed to use the following databases to calculate the public transport accessibility index (PTAI): (1) Rail Transport Accessibility Index (RTAI) for passenger services; (2) Bus-Rail Accessibility Index (BRAI); (3) Rail Connection Accessibility Index (RCAI). A brief description of each index is provided below. All indices are based on the potential model, and for this reason, it is essential to briefly present the basic features of the potential model associated with two components – demographic (land-use) and transport-components (Geurs & van Wee, 2004), as well as the so-called half-life approach.

The potential model is an analytical tool used in geography and economics to measure the strength of interaction between various locations. It is based on the principle of gravity, where the strength of interaction is proportional to the size of the objects (e.g., cities) and inversely proportional to the distance between them. The destination attractiveness (land-use component) refers to factors or places that attract travelers, such as cities, tourist areas, or workplaces. This is a fundamental element in transport models

that accounts for travelers' motivations and destinations. As part of the land-use component, the variable used in the research was the population size, which is the variable most commonly applied in studies on accessibility in the national or European context (Spiekermann et al., 2015). Meanwhile, the distance decay function (transport component) is a mathematical description that determines how distance or other spatial factors affect the flow of people, goods, or information. The greater the distance or other barriers, the higher the impedance, which reduces the intensity of interaction between locations. The measure of spatial impedance is an indicator used to assess the difficulty of overcoming the distance between different points in space. It can encompass physical distance, travel time, transportation costs, or other barriers that impact accessibility or spatial flows. As regard to the transport component, we used travel times as a measure of decay and the exponential curve as a function of impedance (see the discussion on the use of the exponential function in accessibility studies at the national level in: Rosik et al., 2015). The calculation of the intra-regional potential is carried out separately for each transport zone based on the self-potential formula proposed by Rich (1978; see also: Keeble et al., 1982; Gutiérrez et al., 2011, Rosik, 2009) which is used for the estimation of the internal road travel time (t_{ii}). The surface of the transport zone is equated to a circle, the average travel distance is half the radius, $0.5 \sqrt{\frac{area}{\pi}}$ (Kota-vaara et al., 2011). The potential accessibility indicator for all transport zones is calculated according to the formula 1:

$$A_i = POP_i \exp(-\beta t_{ii}) + \sum_j POP_j \exp(-\beta t_{ij}) \quad (1)$$

where POP_i and POP_j are the population of the municipalities and transport zones i and j , respectively, $POP_i \exp(-\beta t_{ii})$ is the value of the self-potential of transport zone i , and $\sum_j POP_j \exp(-\beta t_{ij})$ stands for the sum of potentials resulting from travel times t_{ij} between the municipality i and municipalities j . Following

Östh et al. (2014) we differentiate the exponential function based on the so-called half-life (Stępiak & Rosik, 2018) otherwise known as the CATCH-time (Rosik et al., 2020). This approach posits that a typical (median) trip length (\bar{t}) for a specific purpose should be achieved when the attractiveness of the destination is reduced by half:

$$-\beta = \frac{\ln(0.5)}{\bar{t}} \tag{2}$$

We assume the possible range of travel lengths, i.e. from short trips limiting the attractiveness of travel to half, which already occurs at the 20-minute travel time, gradually extending the length of the trip, ending with 60 minutes of half-life, depending on the selected indicator.

In summary, all three indicators used (RTAI, BRAI, and RCAI) are based on the potential model, in which destination attractiveness decreases as travel time increases. For all three, the attraction, in the sense of the destination, is the population size at the municipal level. The distance decay function is an exponential function, expressed

as $\exp(-\beta t_{ij})$, with travel time between two transport regions (municipalities), i and j , serving as the measure of spatial impedance. However, the indicators differ from each other in terms of how travel time is calculated, the potential for using different transport modes to reach a railway station, and the parameterization of the distance decay function (Tab. 2).

Passenger Rail Transport Accessibility Index (RTAI) for 2023 is calculated as part of the ongoing monitoring of accessibility across various transport modes, commissioned by the Ministry of Development Funds and Regional Policy, as an integral component of the Multimodal Transport Accessibility Index (WMDT). The RTAI passenger index is based on the maximum technical speeds for passenger trains, according to data obtained from PKP PLK (Polish Railway Lines). Municipalities that lack direct access to the rail network are ‘connected’ to the network via connectors assigned relatively low speeds (40 km/h). This configuration creates a network that enables the calculation of a potential index, where the mass (attractiveness) is the population

Table 2. Key differences and similarities between the RTAI, BRAI, and RCAI indicators comprising the public transport accessibility index (PTAI)

Indicator Acronym	Full Indicator Name	Method of Travel Time Calculation (Spatial Impedance Measure)	Means of Access to Railway Station	Travel Length	
				decline in Destination Attractiveness to Half (value t_{ij})	parameter β in the Distance Decay Function $\exp(-\beta t_{ij})$
RTAI*	Passenger Rail Transport Accessibility Index	Maximum technical speeds of passenger trains on the network	Individual transport	30 minutes	0.0231
BRAI**	Bus-Rail Accessibility Index	Timetabled travel times for rail and bus routes	Bus transport or rail transport	20 minutes	0.0347
RCAI**	Rail Connections Accessibility Index	Timetabled travel times for rail routes	Rail transport	60 minutes	0.0116

* A detailed methodology of the RTAI (WKDT) indicator in the publication: Komornicki et al. (2018) and Rosik et al. (2017a).

** A detailed methodology of the BRAI and RCAI indicators in the publication: Rosik et al. (2017b); The acronyms of both indicators were adopted for the purposes of this article; however, in the book monograph, the results are presented in Fig. 10.9 (p. 222) – the BRAI indicator (in the monograph referred to as bus-rail accessibility (bus+rail variant) – short trips ($\beta = 0.0347$)) and in Fig. 10.8 (p. 221) – the RCAI indicator (in the monograph referred to as rail transport accessibility – long trips ($\beta = 0.0116$)).

of each municipality in 2023. The travel time between any pair of municipalities is primarily based on the capabilities of the railway infrastructure (maximum technical speeds for passenger trains). This index illustrates the spatial disparities within Poland in terms of the opportunities provided by the rail network. Given that a relatively mild spatial impedance is applied in the potential index, the RTAI passenger index can be interpreted as the level of accessibility provided by the rail transport infrastructure for longer journeys (Fig. 1)

The RTAI index does not specifically address transport poverty related to a lack of access to bus transport. However, as part

of the ‘Multimodal Public Transport Accessibility in Polish Municipalities (MULTIMODACC)’ project (Rosik et al., 2017b) at Institute of Geography and Spatial Organization Polish Academy of Sciences, several indicators were developed, including bus routes crossing county borders. Among them were the Bus-Rail Accessibility Index (BRAI) for short trips.

Bus-Rail Accessibility Index (BRAI) for short trips (Rosik et al., 2017b) considers the following: (a) the condition of road infrastructure as of the end of 2015, (b) the condition of rail infrastructure used for passenger transport (including active railway stations) as of the end of 2015, (c) bus schedules for routes cross-

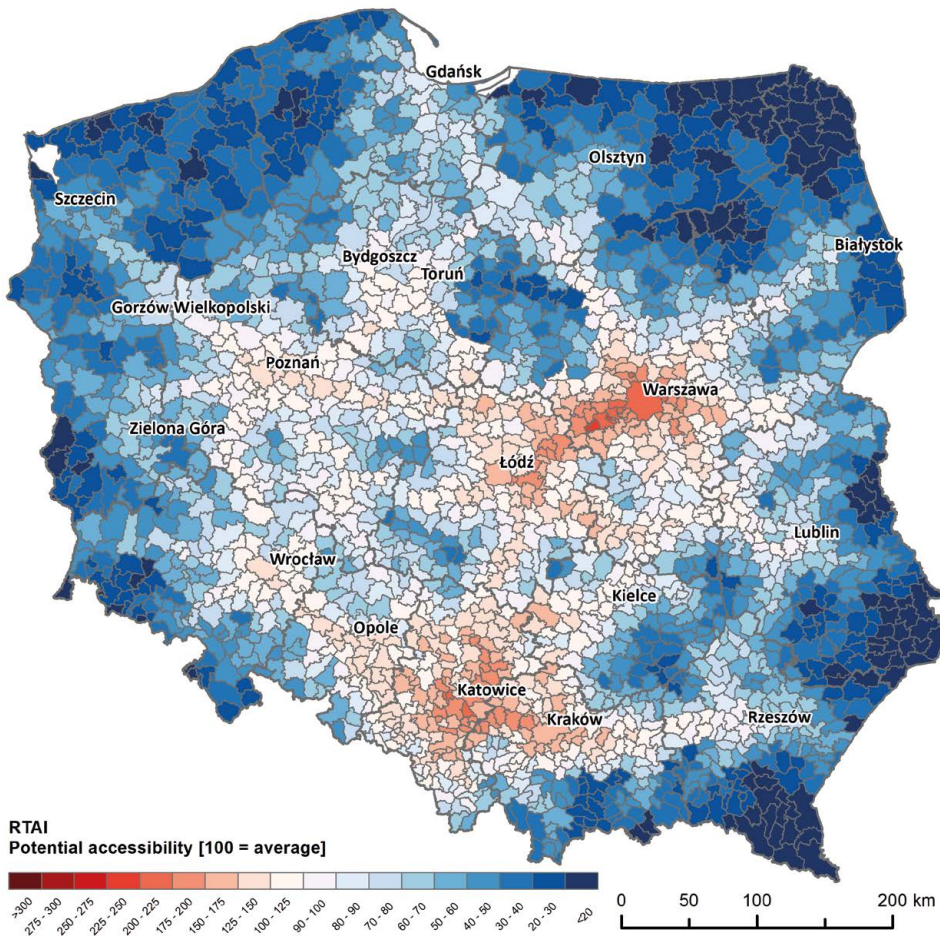


Figure 1. Passenger Rail Transport Accessibility Index (RTAI) for 2023

ing county borders collected from 2014–2015 (permits issued by all 16 Voivodeship Marshal Offices), (d) schedules for suburban buses in 66 cities with county rights collected in the first half of 2016, and (e) the 2015/2016 train timetable (effective from December 13, 2015). Although these data primarily hold historical significance—almost 10 years have passed since their collection—it still seems justified to use them to supplement public transport service accessibility (at least until new nationwide data become available) (Stępień et al., 2021). The bus-rail accessibility index for short trips, while also based on the potential model, is parameterized to focus on shorter

trips than the RTAI index, thus providing valuable supplementary information. The usefulness of the MULTIMODACC project data on bus-rail accessibility can be justified by the following considerations: (a) ‘equalizing’ potential at the edges of the study area (the RTAI index, like any other long-distance potential index, underestimates the level of accessibility at the edges of the study area, e.g., in Koszalin, Suwałki, or Przemyśl); (b) the use of information on Poland’s uneven bus network coverage, e.g., historically, bus accessibility and network density are significantly higher in southeastern Poland than in the north-west; (c) highlighting accessibility disparities

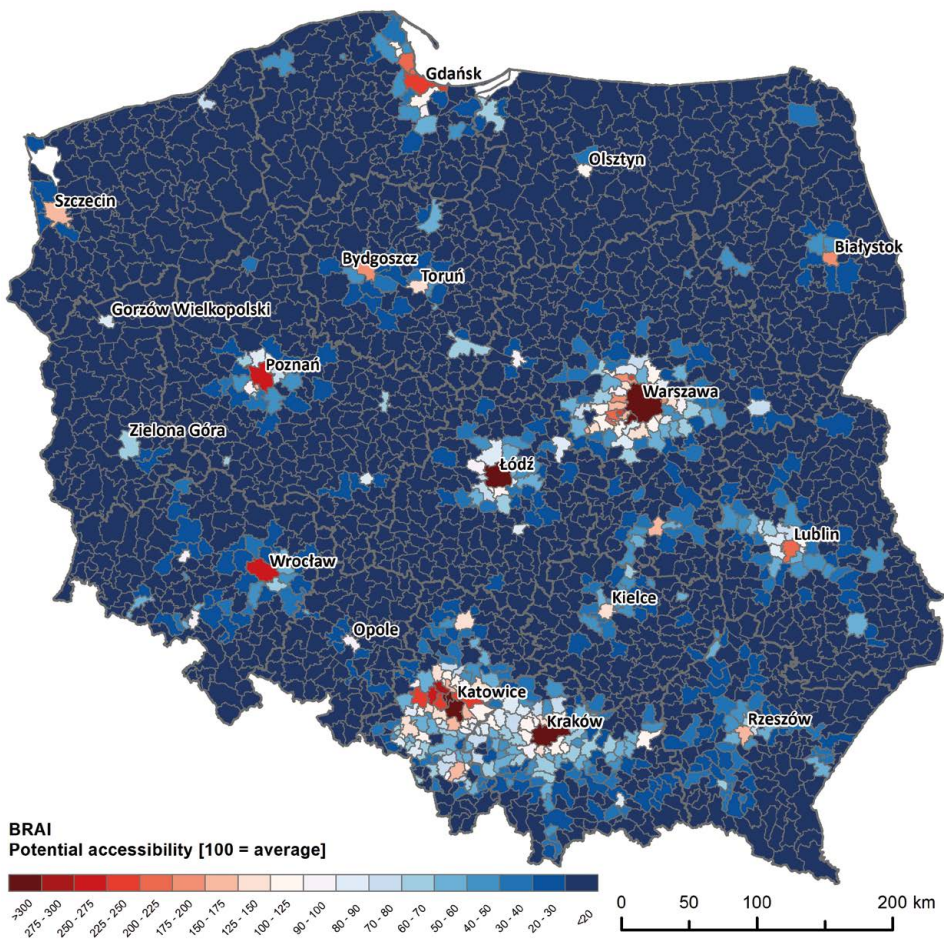


Figure 2. Bus-Rail Accessibility Index (BRAI for short trips)

between metropolitan areas, large cities, including subregional centers, and peripheries, including internal provincial peripheries; (d) taking into account actual schedules and frequencies of train and bus services.

The third indicator included in the public transport accessibility index (PTAI), is the Rail Connections Accessibility Index (RCAI) for long-distance travel (Rosik et al., 2017b). This index is similarly determined by using the potential model and rail routes and timetables but without the option of reaching stations via bus or private transport. Therefore, this indicator perfectly complements the two

indicators described above by further accentuating accessibility differences between municipalities with active railway stations and those where residents lack direct access to rail connections (Fig. 3). It has the added advantage of focusing on long-distance travel while considering the potential for transfers between rail routes. As such, this indicator is highly correlated with operational and transport work performed within the rail sector in Poland (Fig. 3).

In summary, the indicators used in this study, which make up the PTAI index, have been combined for the first time within a single

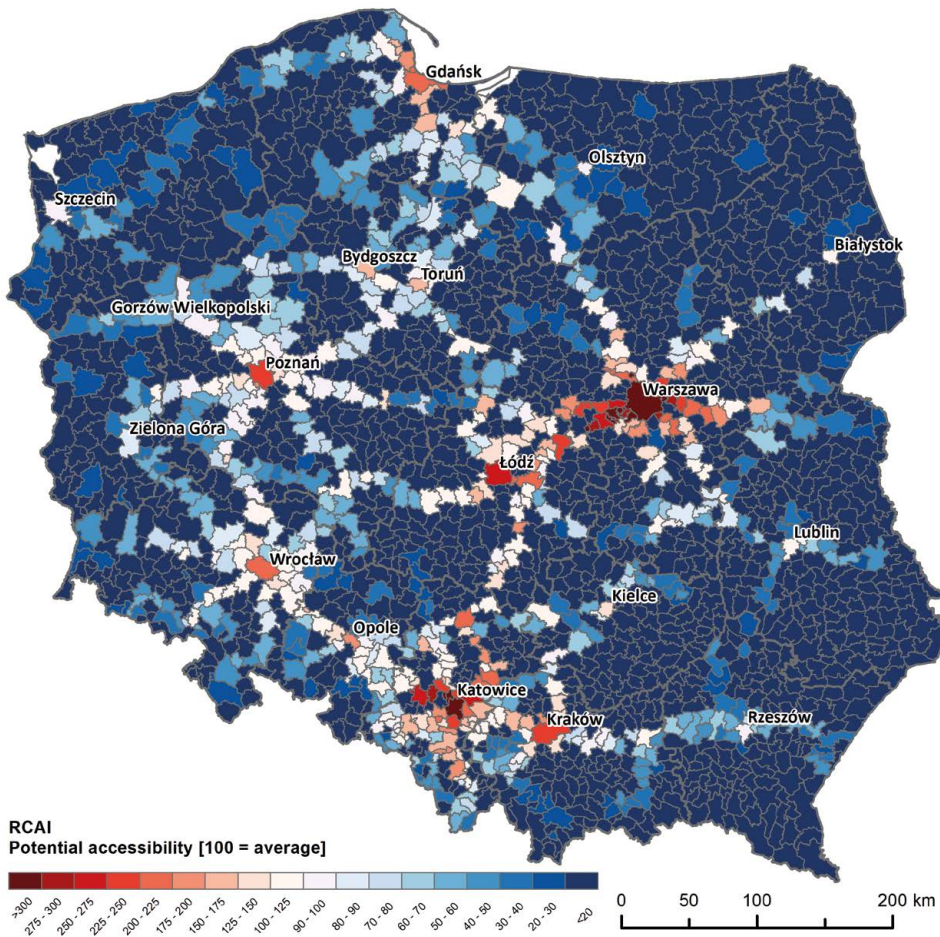


Figure 3. Rail Connections Accessibility Index (RCAI) for long-distance travel

index. Thus, for the first time in Poland, such diverse aspects of transport service supply have been taken into account as follows:

1. Spatial differences in the accessibility of high- and low-quality rail infrastructure, i.e., infrastructure with very good or poor technical parameters (high or low technical speeds for passenger trains) – RTAI index;
2. Spatial differences in the accessibility of bus transport combined with the opportunities provided by rail transport, for example, differences between metropolitan areas, larger cities, and densely populated areas traditionally well-served by bus transport (e.g., southeastern Poland) versus peripheral areas lacking access to both bus and rail transport – BRAI index;
3. Spatial disparities in access to nearby railway stations providing connections to other locations nationwide – RCAI index;
4. Spatial differences in the potential to reach all places in the country under various assumptions of travel attraction decay with increasing travel times – all indices RTAI, BRAI, and RCAI.

Results

Ultimately, to delimit the area of transport poverty and to prepare the final version of the map illustrating the occurrence of transport poverty in Poland based on available spatial data, the following databases and indicators will be used:

1. Median monthly earnings in the national economy by municipality (according to place of residence) on the demand side of transport services (2024);
2. Rail Transport Accessibility Index (RTAI) for passenger rails in 2023 – on the supply side of transport services;
3. Bus-Rail Accessibility Index (BRAI) for short-distance travel from the MULTIMODACC project (supplementary indicator, data from 2014-2016) – on the supply side of transport services;
4. Rail Connections Accessibility Index (RCAI) for long-distance travel from the MULTIMODACC project (supplementary indicator,

data from 2014-2016) – on the supply side of transport services.

The integration of data to determine the level of transport poverty in municipalities in Poland involves a three-step process:

Demand Side. After obtaining data on the median monthly earnings in the national economy by municipality (according to the place of residence) in September 2024, it was assumed that for the purposes of identifying areas suffering from transport poverty, the median level should not exceed 100%, i.e., the national median level (Fig. 4). These are usually areas located far from metropolitan regions, mainly in the internal peripheries of provinces (e.g., a strip of municipalities with particularly low median earnings on the border between the Warmińsko-Mazurskie and Kujawsko-Pomorskie provinces) and in regions at risk of marginalization (e.g., the intersection of the Lubelskie and Podkarpackie provinces). Interestingly, beyond the obvious examples, areas affected by transport poverty on the demand side also include southeastern Greater Poland (Wielkopolska) as well as the Podhale region (Fig. 4).

Supply Side. Calculation of the Public Transport Accessibility Index (PTAI) based on three indicators (RTAI, BRAI, and RCAI). The following steps were defined to calculate this index

- 1) Standardizing the three indicators so that for each, the reference point is the national average value per Polish resident (population-weighted average indicator value = 100), according to formulas 1-3:

$$RTAI_{stand,i} = \frac{RTAI_i}{\frac{\sum_{j=1}^n RTAI_j \times POP_j}{\sum_{j=1}^n POP_j}} \times 100, \text{ where } i \in j \tag{3}$$

$$BRAI_{stand,i} = \frac{BRAI_i}{\frac{\sum_{j=1}^n BRAI_j \times POP_j}{\sum_{j=1}^n POP_j}} \times 100, \text{ where } i \in j \tag{4}$$

$$RCAI_{stand,i} = \frac{RCAI_i}{\frac{\sum_{j=1}^n RCAI_j \times POP_j}{\sum_{j=1}^n POP_j}} \times 100, \text{ where } i \in j \quad (5)$$

where:

$RTAI_i$ - the value of the RTAI indicator in municipality i ,

$BRAI_i$ - the value of the BRAI indicator in municipality i ,

$RCAI_i$ - the value of the RCAI indicator in municipality i ,

POP_j - population in municipality j ,
 $\sum_{j=1}^n POP_j \exp(-\beta t_j)$ the total population of all n municipalities in Poland.

2) Calculating the arithmetic mean of the sum of the three indicators, where each one has an equal weight according to the formula 4, provides the value of the public transport accessibility index (PTAI) for municipality i :

$$PTAI_i = \frac{1}{3} RTAI_{stand,i} + \frac{1}{3} BRAI_{stand,i} + \frac{1}{3} RCAI_{stand,i} \quad (6)$$

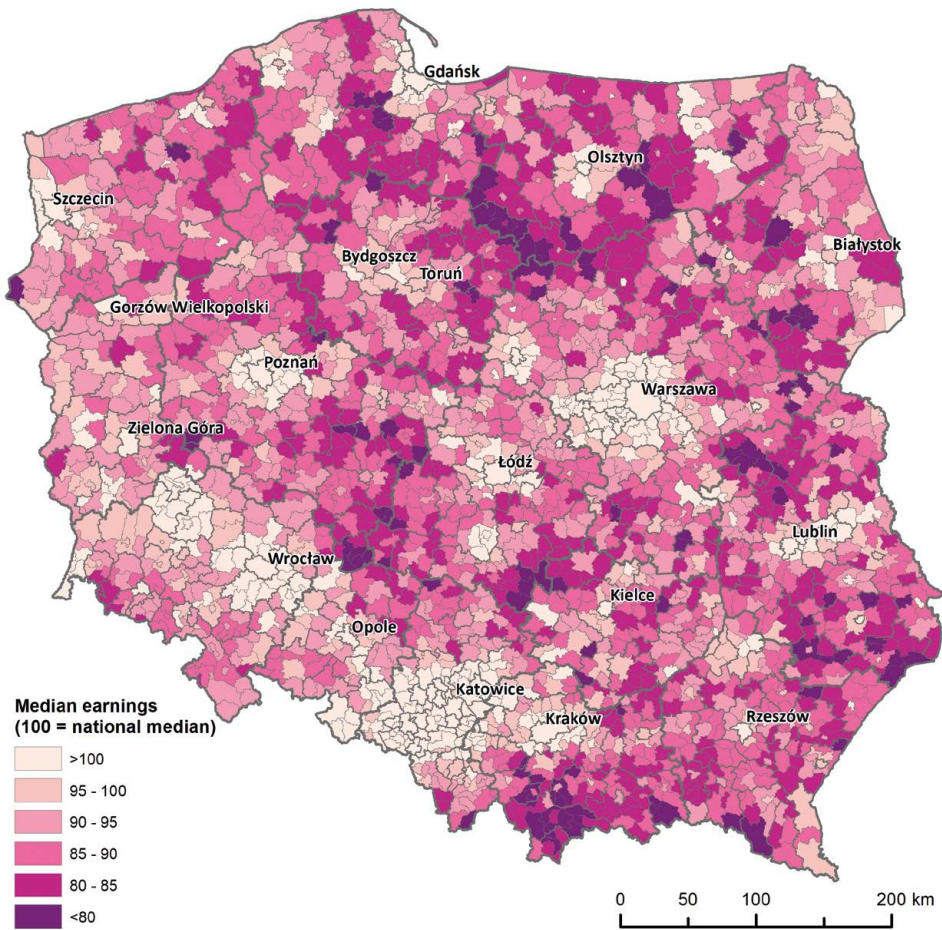


Figure 4. Median Earnings by Place of Residence in Poland: An analysis with a particular focus on areas where median earnings fall below the national median (demand-side transport poverty – peripheral areas)

Source: Own elaboration based on GUS, 2024

The higher the value of the indicator, the greater the accessibility of public transport services, and the lower the value of the indicator, the lower the accessibility of services and the higher the risk of transport poverty on the supply side of transport services in the given municipality.

- 3) Defining the threshold level of transport poverty on the supply side of public transport services (PTAI indicator) according to two levels set at 30% (below 30% indicates an extremely low level of transport service supply) and 60% (a PTAI value in the range of 30-60% indicates a very low

level of accessibility). Determining levels of peripherality depending on the indicator's value relative to its average is a relative method of defining peripherality. For example, labeling accessibility as 'extremely low' is a categorical classification method. This method involves dividing indicator values into different categories or levels. Such terms as 'extremely low' are often applied to indicator values that fall in the lowest range of the scale, far below the average, e.g., for PTAI below 30%. The results are shown in Figure 5.

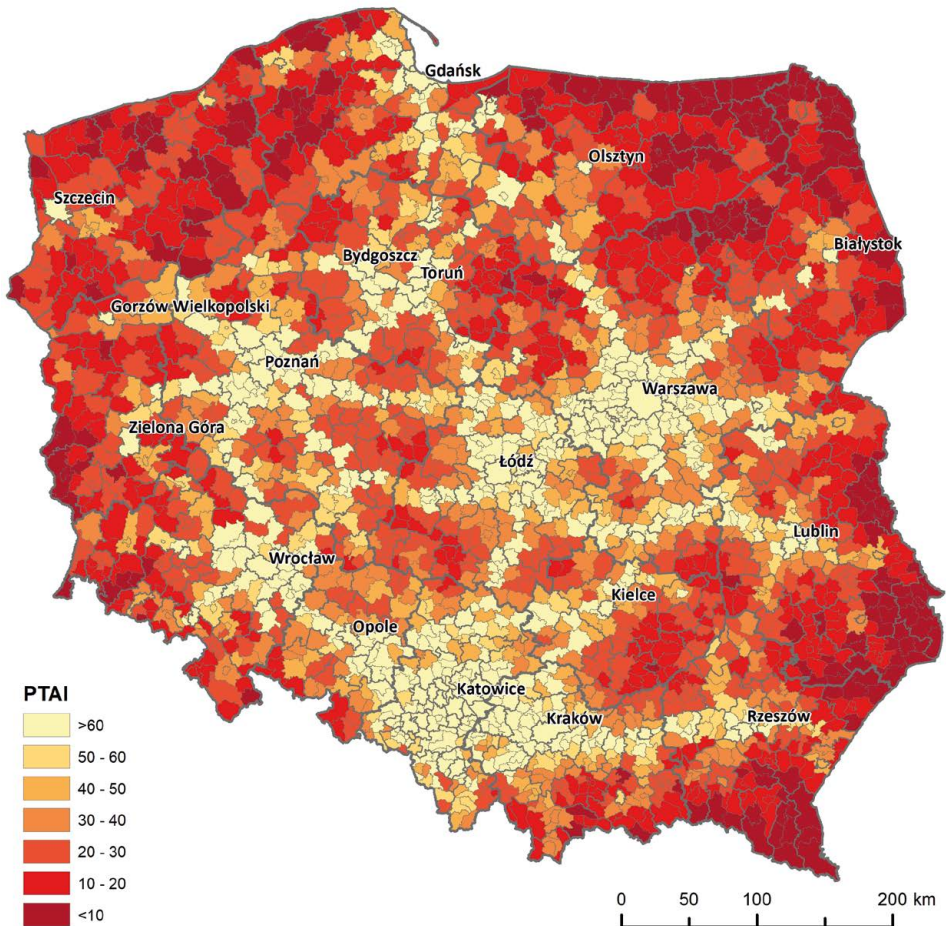


Figure 5. Public Transport Accessibility Index (PTAI) – Focused analysis of areas with PTAI < 60% (peripheral areas)

The cartographic image for the $PTAI < 60\%$ indicator confirms that:

1. Transport service supply poverty primarily affects areas located near the country's borders.
2. Transport service supply poverty also affects certain internal peripheries of regions, such as the junction of the Mazowieckie and Kujawsko-Pomorskie or Warmińsko-Mazurskie and Podlaskie regions; Central Pomerania; or the border areas of the Lubelskie, Podkarpackie, and Świętokrzyskie regions.
3. Regional and sub-regional centers generally have higher levels of accessibility due

to good connections with their immediate surroundings via bus services and the operation of railway stations enabling long-distance connections. However, medium-sized centers located on the country's peripheries have lower levels of public transport service accessibility compared to similarly sized centers situated along railway lines in central Poland.

4. The population residing in areas where $PTAI < 60\%$ is approximately 18.0 million, representing 47.9% of Poland's population, while the population residing in areas where $PTAI < 30\%$ is about 9.7 million, accounting for 25.8% of Poland's population.

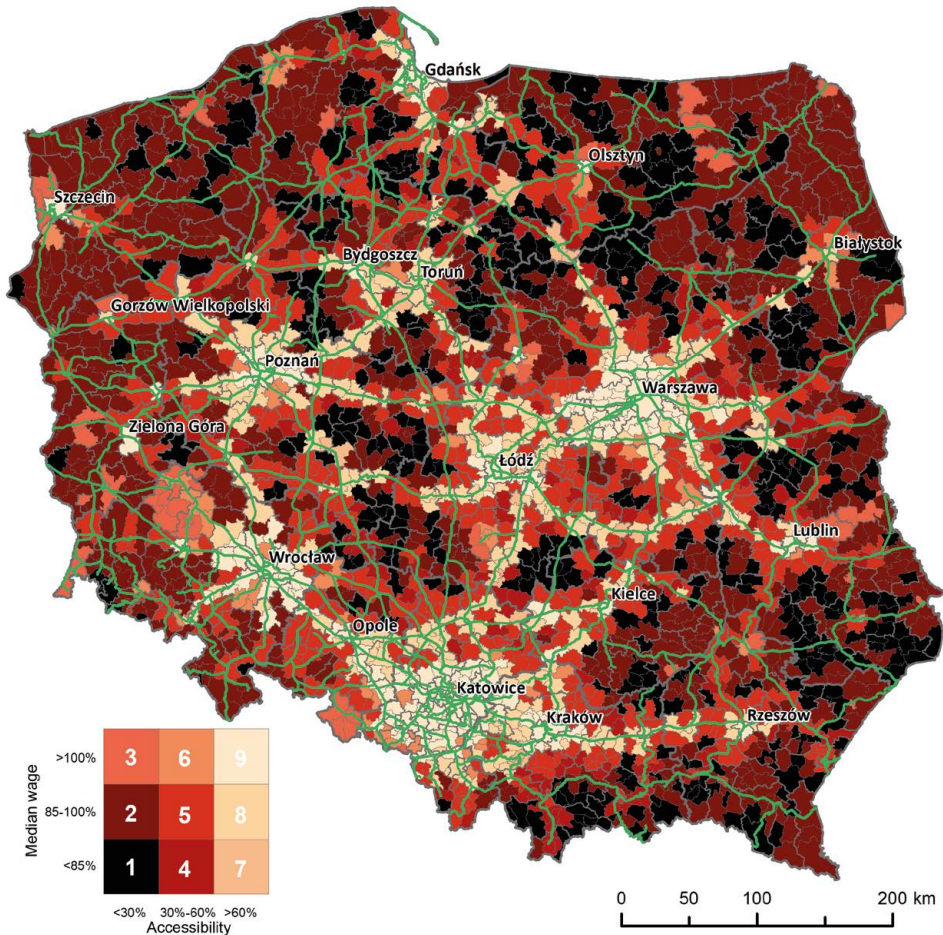


Figure 6. Areas at Risk of Transport Poverty Against the Background of the Railway Network in Poland

Integration of transport poverty demand and supply aspects. The analysis primarily focuses on areas where the median wage by place of residence is below the national median and accessibility (PTAI indicator) does not exceed 60%—these areas are marked with darker colors. However, transport poverty may also affect other areas, such as those experiencing issues on the supply side only or the demand side only. Therefore, the analysis has been appropriately expanded to include an illustration of the phenomenon across the entire country (Fig. 6).

It is essential to define the population size and the number of households (in absolute numbers and percentage terms) for each type of area (1-9) affected by transport poverty (Fig. 7)

In the worst situation (category 1, areas marked in black, characterized by a median wage below 85% of the national median and public transport service accessibility below 30%), there are nearly 2.5 million Poles (6.5% of Poland’s population). On the other hand, relatively favorable conditions (category 9, areas marked in light beige, with a median wage above the national average and public transport service availability above 60%) affect

13.3 million Poles (about 35.3% of Poland’s population). The remainder of Poland’s population lives in areas that, to varying degrees, experience either low public transport service accessibility, low wages, or a combination of both, indicating varying levels of transport poverty on the supply or demand side. It is worth noting that areas with poor accessibility often also have low wages, while areas with high accessibility typically feature higher wages. For instance, only 870,000 people (2.3% of Poland’s population) live in areas with extremely low accessibility (PTAI <30%) and at the same time, a median wage above the national median. Conversely, areas with relatively good accessibility exceeding 60% of the PTAI indicator, yet with a median wage below 85% of the national median, are also relatively rare, affecting only 172,000 Polish residents (0.5%).

Conclusions

The approach outlined in this study represents the first attempt in Poland to identify areas at risk of transport poverty, with a particular focus on public transport accessibility at the municipal level. Through the spatial

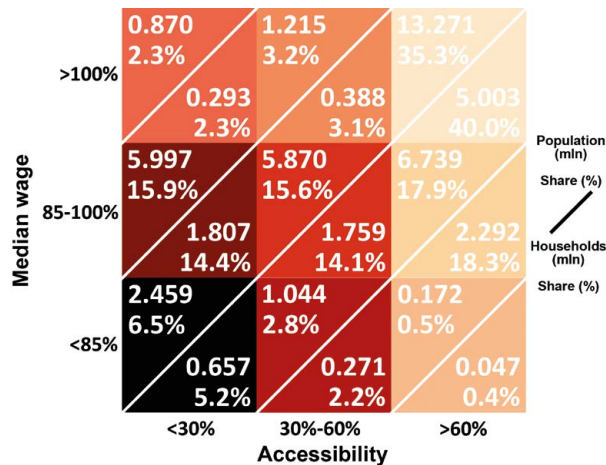


Figure 7. Number and share of population and households in various types of areas depending on the accessibility of public transport services and the level of median wages

Source: Own elaboration based on BDL GUS (population and households by communes)

analysis conducted, compact areas in Poland particularly vulnerable to transport poverty have been defined:

1. Areas located along national borders (with the exception of the eastern part of the Polish-Czech border (Kołodziejczak, 2020), the Turoszów Basin, and the areas around Szczecin and the Tri-City), particularly mountainous areas (the Carpathians and the Sudetes), as well as areas along the eastern border (borders with Ukraine, Belarus, and Russia);
2. Most areas considered to be at risk of marginalization (list of municipalities at risk of permanent marginalization: 2021-2027 programming), as defined in a project funded by the Ministry of Regional Development as part of the 'In-depth analysis of areas at risk of permanent marginalization and the provision of advisory-consulting services regarding remedial actions to overcome development barriers in these areas,' (Śleszyński, 2020).
3. Selected other areas mainly located on the so-called internal peripheries of voivodeships, such as an area that has so far been 'invisible' on other maps and studies related to areas at risk of marginalization, namely, the border area between the Greater Poland (Wielkopolskie) and Łódź (Łódzkie) voivodeships
4. Some areas in voivodeships traditionally considered to be more developed, including in the Greater Poland (Wielkopolskie) voivodeship (e.g., Międzybóże or Kępno counties), the Lesser Poland (Małopolskie) voivodeship (e.g., Nowy Targ and Nowy Sącz counties), and the Pomeranian (Pomorskie) voivodeship (e.g., southern Kashubia).

The above conclusions indicate that the research hypothesis stating that areas characterized by low levels of public transport accessibility are also inhabited by residents with low average earnings, resulting in a specific kind of feedback loop of transport poverty in peripheral areas, including the so-called internal peripheries of voivodeships, has been confirmed to be true.

The proposed research method, based on the typology of municipalities in Poland depending on the demand and supply aspects of transport poverty, requires further work within the framework of continuous monitoring of transport poverty. The proposed static approach is currently the only feasible one in Poland due to database limitations. However, in the future, with the emergence of new database possibilities, it will be essential to incorporate the dynamic nature of the phenomenon, particularly in the context of potential burdens associated with additional climate fees and rising fuel prices. Therefore, the primary conclusion is the need for further work on the issue of transport poverty in Poland, taking into account possible modifications to the indicator discussed, especially in the context of ongoing monitoring of the phenomenon at the municipal level.

Discussion and recommendations

Like any new indicator or typology, those proposed in this article also require further work and modification, and are not without certain limitations. A key issue is the data infrastructure needed to develop the indicator's methodology on both the demand and supply sides (Ballantyne et al., 2024). On the supply side, it would be valuable to supplement or replace the indicators used as digitization of public transport timetables in Poland progresses over the coming years or decades (e.g., GTFS; Goliszek & Połom, 2016; Goliszek et al., 2020). Ultimately, this would enable a permanent monitoring system for transport poverty, and in the short term, the indicator could be expanded with new data if such data emerge from ongoing research projects.

On the demand side, similar to approaches used in Western European countries (see Table 1), it would be worth considering the addition of certain variables that define transport poverty and socioeconomic characteristics (Biscaro Uliana, 2022). A fundamental issue would be to refine and accurately define poverty in terms of income level, as well as the level of expenditure devoted

to mobility and the use of transport resources (Kelly et al., 2023). If data on income at the decile level by place of residence were available, these should be included in the indicator. Additionally, it may be beneficial to consider extending the demand-side indicator with variables not directly related to income but, for example, to socially disadvantaged groups (van Dülmen et al., 2022) or age, such as the proportion of the population aged 6-18 (students) and those over 60/65 years of age (seniors). Based on the research by Fiedeń and Štraub (2023), conducted in several peripheral municipalities in Poland, it can be concluded that the price of public transport tickets is particularly important (influencing their transport decisions) for older adults (65+), while this issue is much less relevant for youth and students. Younger individuals have higher incomes and are therefore more resilient to potential fare increases. In general, well-designed mitigation strategies must take into account the diverse needs of different social groups and the specific local conditions in order to effectively counteract transport exclusion. The selection of suitable mitigation strategies in a spatial context at the local level, for instance, by municipal authorities, is challenging due to the limited diagnosis of the situation. The authors of this article believe that the information presented in the article regarding the spatial diversity of transport poverty in Poland will enhance decision-makers' understanding of the phenomenon and assist in making appropriate choices for mitigation strategies.

Last but not least, the results presented in terms of nine types of transport poverty, in the authors' view, can be easily interpreted by authorities at various levels—from local governments, through national institutions, to even the EU level (e.g. in the context of applying for funding from the Social Climate Fund). These nine types allow for the identification of areas that require special attention. In other studies and reports dedicated to transport poverty, the number of types is often lower—for example, in Scotland, where only three types were distinguished (Sustrans, 2016),

or the methodology is significantly more complex, such as the TPRI index in Ireland (Kelly et al., 2023), which includes eight indicators forming a composite index. In the most recent review publication covering EU countries, the "Transport Poverty Vulnerability Index" comprises as many as ten sub-indicators (Primc et al., 2025).

The index proposed in our article aims to strike a balance—on the one hand, accessibility is calculated using three indicators, while on the demand side, only one is applied. One limitation is certainly the exclusion of income data for individuals outside the labor market, such as pensioners. The authors intend to propose a future modification of the index that would include pension income on the demand side (Kato & Yoh, 2025).

Acknowledgments

This research was funded by the Polish National Science Centre allocated on the basis of the decisions no. 2024/53/B/HS4/00304 and 2020/37/B/HS4/00544.

Editors' note:

Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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