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NIMBY effect algorithm for railway construction in functional urban areas: A Polish case study

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Abstract: The limitation of land causes conflicts over how it is used, particularly in functional urban areas. Although Not in My Backyard (NIMBY) effects are often associated with established residential neighborhoods, they may also arise in rapidly developing suburban and peri-urban zones, where transport investments intersect with existing settlements and ongoing land-use change. Due to their specific nature, projects for new railway lines are more likely to receive a negative reception, because they can adversely affect property values, cause buyouts and expropriations, and introduce significant changes to a settlement's spatial layout. The feasibility of different infrastructure project variants could be affected by varying levels of risk. Therefore, the occurrence of the NIMBY phenomenon necessitates a precise, standardized approach to its assessment. For this reason, the main aim of this study is to develop an algorithm to assess the scale of NIMBY responses for railway construction investments in densely populated Functional Urban Area (FUA) commuting zones, involving multicriteria spatial analysis. The algorithm is tested in the selected Łomża FUA railway construction project located in northeastern Poland. The project involves both the restoration of the railway line and its construction in a new location. This study highlights the analyses of spatial structural change that are crucial for understanding local resistance, since in suburbanizing areas, the intensity of NIMBY is strongly correlated with demographic shifts and patterns of land-use transformation. The Łomża FUA case confirms this.

Keywords: functional urban areas, not in my backyard, railway investment, suburbanization

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1 Introduction

The limitation of land causes conflicts over how it is used, particularly in urban areas that are attractively located. This refers to projects that have a negative impact on their neighborhoods, making them undesirable in certain locations, even though everyone is aware that they are necessary. This phenomenon is called Not in My Backyard (NIMBY).

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NIMBY is a term in the social sciences and urban planning that describes the social tendency to oppose projects or initiatives that may negatively affect the immediate environment but are considered necessary or beneficial to society in general (Hermansson, 2007). This phenomenon is manifested by resistance to the expansion of infrastructure such as motorways (Hamersma et al., 2016), railways (Ding et al., 2021; Navone, 2013), nuclear power plants (Sun et al., 2014), waste treatment plants (Rabe et al., 1994), high-voltage power lines (Cain & Nelson, 2013), and wind farms (Boyle et al., 2019), which are developed in close proximity to residential areas. At the same time, it should be emphasized that transport investments often generate support among local communities because of the improvement of accessibility, mobility, and potential increases in property values. The ambivalence of responses—ranging from support to opposition—depends strongly on whether the project is perceived primarily as an accessibility-enhancing transport improvement or as a disruptive change in land use and local development patterns.

In Poland, work has now intensified on a national and even Europe-wide strategic investment called the Solidarity Transport Hub, which integrates air, rail, and road transport. The current phase of the project involves analyzing various design options for the location of investments connecting the Solidarity Transport Hub to existing road and rail systems. Many communities neighboring the infrastructure investment sites were raising their objections (Grodzisk News, 2022). The urban fringe has a high potential for linear investment, and due to its rapid development, the NIMBY phenomenon is likely to occur (Dmochowska-Dudek & Bednarek-Szczepańska, 2018). This is also influenced by the relatively low population density (in relation to urban areas) and the dynamic changes in the ownership structure. Suburban municipalities are often characterized by a spatial layout that differs from typical rural areas (Wolny et al., 2017) and by a distinct demographic structure (Gnat, 2012). In particular, municipalities classified as high-density areas—according to the Delimitation of Rural Areas (DRA), conducted by the Central Statistical Office (2022a)—require more attention and a specific approach. Hence, the feasibility of different infrastructure project variants may be affected by varying levels of risk.

In this context, it is essential to distinguish between attitudes toward transport infrastructure itself—often positive—and attitudes toward the accompanying land-use transformations and construction developments that may trigger stronger NIMBY reactions. Therefore, the occurrence of the NIMBY phenomenon necessitates a precise, standardized approach to its assessment.

Previous studies have not provided a universal solution for assessing the NIMBY phenomenon, and most of them focus on case studies due to the complex and personalized nature of the issue. They consider various indicators, such as local conditions, project diversity, and community interests (Chung et al., 2016; Zhao et al., 2022). The conclusions of these studies are valuable for specific examples. However, given the dynamics of transport infrastructure development not only in Poland, there is a need to standardize and automate the process of determining the potential and scale of NIMBY responses. This improvement would enhance the time-consuming and labor-intensive design phase of community consultations, and interviews. Furthermore, consultations are usually attended by individuals who are interested, have the time, or represent local interests (including authorities), which does not yield a representative social study. Finally, many empirical studies on NIMBY tend to rely on Nomenclature of Territorial Units for Statistics 5 (NUTS5) municipality-level data (Lindén et al., 2015; Lindvall, 2023), while a more detailed approach is needed for spatial and demographic analyses within the Functional Urban Area (FUA) commuting zone, which is identified as a heterogeneous and diverse area. Hence, the analysis of various factors should be conducted at the local, sub-municipal level. For this reason, the main aim of the study was to develop an algorithm to assess the scale of NIMBY responses for railway construction investments in densely populated FUA commuting zones, involving multi-criteria spatial analysis. This algorithm should complement previous studies of the NIMBY phenomenon from a spatial-demographic perspective during the initial investment planning phase.

The algorithm was tested on the selected case of the Łomża FUA railway construction project located in north-eastern Poland. The choice of this site was deliberate, as the project envisaged the railway running through the core city and through high-density areas with strong functional links to the city. Each variant strongly impacts areas with high urbanization dynamics resulting from urban sprawl. Due to the local variability of this phenomenon within basic local government units (municipalities), the intensity of NIMBY may vary from locality to locality in FUA commuting zone. Thus, there is a need to analyze the determinants of NIMBYs in greater detail than the most commonly adopted municipal level (NUTS 5).

A research gap exists in the study of local NIMBYs, specifically in the missing connection between demographic studies and dynamic analyses of spatial development where the phenomenon occurs. Particularly in non-agglomeration densely populated areas, the need for new methods of assessing the NIMBY scale is relevant and urgent. Previous studies on NIMBY have rarely addressed the development of local real estate markets and changes in land-use patterns, which are important in assessing local conflicts in dynamically changing suburbs. Therefore, multi-criteria spatial analysis in the FUA commuting zone is an original approach in NIMBY analysis for units experiencing suburbanization.

Traditional demographic studies have been supplemented by the dynamic analysis of land development as an effect of suburbanization. This is particularly important as the new group of residents who have come to suburban areas (due to the effect of the spatial transformation) is more likely to disagree with the investment location. The study hypothesizes that NIMBY is a phenomenon that increases in suburban areas under investment pressure. In turn, there is support for the investment where it is less onerous and improves accessibility locally. Accordingly, this paper addresses the research gap by developing and testing a methodological approach that allows for the systematic assessment of NIMBY responses at the sub-municipal level in FUAs.

2 Literature overview

The following section synthesizes the state of knowledge on the NIMBY phenomenon with particular attention to its etymology, manifestations in transport management, evaluation criteria, and the role of individual interest groups. The review is structured to identify how previous studies conceptualize and measure NIMBY and to highlight their limitations. Importantly, the section concludes with a systematic articulation of research gaps and research questions that directly inform this paper's methodological contribution.

2.1 Etymology of NIMBY

There are several key factors and motivations that shape the NIMBY phenomenon. Residents are often concerned about the negative impacts of certain projects on their health and safety, such as noise and toxic emissions (Dear, 1992). Another significant aspect is the potential effect on property values, which such developments can reduce (Dubé et al., 2023; Wen et al., 2022). Given steadily rising land prices and construction costs (Gościniak, 2024; Sitek, 2022), residents of newly built homes—who have recently made significant financial investments—may feel particularly anxious about potential changes. Aesthetics and environmental considerations also play an important role, as people often oppose projects that affect the integrity of their neighborhoods, such as power plants or wind turbines (Good, 2006). Additionally, the lack of community participation in the decision-making process can contribute to NIMBY sentiments, as residents may feel ignored and excluded. Finally, social and ethical values (Chung et al., 2016) also influence NIMBY attitudes, as some individuals base their objections on moral or ethical grounds (Nonami et al., 2021), perceiving certain projects as incompatible with their values.

The NIMBY phenomenon has been investigated from different perspectives: psychological (Pol et al., 2006), political (Feinerman et al., 2004; Zhao et al., 2022), social (de Souza et al., 2023; Dmochowska-Dudek, 2013; Staniszewska, 2014; Wang et al., 2022), economical (Dubé et al., 2023; Jarvis, 2025), environmental (Hager & Haddad, 2015) or spatial (Brown & Glanz, 2018; Gallo, 2019). It is worth mentioning that the NIMBY phenomenon has both positive and negative aspects. On one hand, it allows citizens to defend their interests and protect their environment and quality of life. On the other hand, it can delay or even lead to the cancellation of important public infrastructure projects. This is why maintaining a balance is a significant challenge for authorities and decision-makers (Gibson, 2005).

The NIMBY phenomenon is often associated with related terms such as LULU (Locally Unwanted Land Use), CAVE (Citizens Against Virtually Everything), and BANANA (Build Absolutely Nothing Anywhere Near Anything). These attitudes frequently emerge during the planning phase—typically at the stage of public consultation and the submission of comments on zoning or land-use plans (Talarek & Chodźko, 2020) —or during consultations aimed at determining the final investment scenario. It is also worth noticing that an alternative trend, YIMBY (Yes In My Back Yard), is gaining traction due to rising real estate prices and the decreasing supply of housing (Stahl, 2017).

2.2 Transport management and NIMBY

The NIMBY phenomenon is also evident in specific study areas, including urban-rural zones, particularly in relation to large linear infrastructure projects such as motorways and railways (Ding et al., 2021; Hamersma et al., 2014, 2016; Navone, 2013; Zucchetti, 2013). Building transportation infrastructure on government reserve land serves as the catalyst to foster urban development (Xiao et al., 2018). However, the construction of such infrastructure involves significant changes to the road network, including the development of new bridges or pedestrian crossings to ensure traffic safety in the surrounding areas. These developments affect the existing transport network, road capacity, and the performance of public transport systems such as buses and trams.

Moreover, motorways or railways may be perceived as physical barriers that hinder access to certain FUAs, particularly their rural parts (Dudzińska et al., 2019), significantly impacting daily mobility. While motorways or railways can offer faster and more efficient transport compared to alternatives, FUA residents who use them only occasionally may face increased travel costs due to changes in traffic patterns. Additionally, the construction of a railway line can impact the environment and landscape—especially when it involves the removal of greenery—and may require land acquisition and expropriation, potentially resulting in the demolition of existing buildings (Teo et al., 2019; Wójcicki, 2021).

Furthermore, an additional challenge to the integrated management of transport investments in Poland is the variety of transport governance models (Cieśla et al., 2020; Gross et al., 2024), with nearly every municipality adopting its own locally tailored approach. This leads to challenges such as divergent interests, the absence of a unified strategy, difficulties in decision-making, limited community access, and issues related to environmental protection.

2.3 Criteria related to NIMBY

The factors influencing the implementation of linear infrastructure investments can be divided into objective and subjective categories. A summary of these factors has been compiled and categorized accordingly (Table 1). It is assumed that if a factor appears at least once in the literature on NIMBY related to linear infrastructure investments, it is considered relevant and included in the compilation.

Table 1. Factors relevant to infrastructure linear investments development

Group	Name	Literature
Objective	Geology and topography	(Tercan et al., 2020)
	Economic costs and benefits	(Geurs et al., 2010; Oosterhaven & Knaap, 2003)
	Environmental impacts	(Broniewicz & Ogrodnik, 2020; Teo et al., 2019)
	Noise and vibrations	(Dear, 1992; Sinha & Labi, 2011)
	Existing infrastructure location	(Dudzińska et al., 2019)
	Social needs and concerns	(Chung et al., 2016)
	Real estate values	(Dubé et al., 2023; Wen et al., 2022)
Subjective	Social acceptance	(Cohen et al., 2021)
	Place attachment	(Devine-Wright & Batel, 2017)
	Lack of coordination and bureaucracy	(Castillo, 2018)
	Politics	(Ahlstrand, 2001)
	Involvement of participants	(Pagliara & Di Ruocco, 2018)
	Risk management	(Lewandrowski, 2019)

2.4 Individual interest groups (identification of actors)

In the social conflicts—such as NIMBY—it is possible to identify different stakeholder groups and the subject types of conflicts (Dudek-Mańkowska & Lackowska-Mudrowicz, 2012). There are conflicts:

a) between the community and local government,
b) within local government,
c) between the local authority, the community and an external actor (including the investor),
d) between the local community and the communities of other municipalities,
e) between the local authority and the community of another municipality,
f) between a local government and another local government (or central administration),
g) between local social organizations and regional authorities.

Taking into account the subject criterion (Dudek-Mańkowska & Lackowska-Mudrowicz, 2012), NIMBY-type conflicts can be classified as spatial conflicts. These include:

I. infrastructural conflicts—concerning the alignment of technical infrastructure (e.g., roads, power lines),
II. environmental conflicts—resulting from the potential negative impact on the natural environment and related nuisances (noise, pollution, landscape degradation).

Conflicts driven by the interests of various stakeholders tend to intensify with the allocation of financial resources, the loss of existing benefits, or the emergence of nuisances. An especially interesting dimension of the NIMBY phenomenon is the occurrence of conflicts along the urban-rural fringe, where the interests of city authorities and residents often clash with those of suburban populations and their administrative representatives (Elbakidze et al., 2015; Jensen et al., 2019). There are also instances where local communities join forces to prevent or mitigate the impact of investments perceived as being imposed by the central government (Bednarek-Szczepańska & Dmochowska-Dudek, 2015; Michałowska, 2008). The phenomenon may be particularly pronounced in suburban areas, where development has often involved significant expenditures by future residents, such as the purchase of a home or self-building through individual construction efforts.

2.5 The research gaps and research questions

The literature review highlights several shortcomings in existing research on the NIMBY phenomenon in the context of transport infrastructure. First, there is a lack of standardized and transferable methods for assessing the scale of NIMBY responses. Existing studies are dominated by case-specific analyses, which, although insightful, limit the possibility of comparative and predictive applications. Second, most studies rely on aggregated data at the municipal (NUTS 5) level, whereas the dynamics of suburbanization and demographic change call for more detailed, sub-municipal approaches. Third, the interplay between demographic processes and land-use change remains underexplored. Previous studies rarely connect real estate market development, suburbanization trends, and spatial transformation with the occurrence of NIMBYism. Furthermore, while ambivalence toward transport infrastructure (support vs. opposition) is recognized, the specific mechanisms by which land-use change linked to infrastructure investment triggers local conflicts have not been sufficiently addressed. In light of these gaps, this study seeks to answer the following research questions:

1. How can the risk and scale of NIMBY responses to railway construction projects in suburbanizing FUAs be systematically assessed?

2.Which spatial and demographic factors most strongly influence the intensity of NIMBYism at the sub-municipal level?

3. How can multi-criteria spatial analysis contribute to improving the planning and consultation phases of transport investments by identifying potential areas of conflict in advance?

3 Materials and methods

3.1 Study framework

The research methodology consists of six main stages. The first stage, identification of the research problem and desk research, literature analysis, was conducted through a literature analysis using the following keywords: backyard, transport investment, spatial conflicts, and local protests. This included 50 pieces of literature. As a result, criteria identified in the literature that impact the NIMBY phenomenon were recognized. The theoretical part outlines the essential aspects of NIMBY, including the key players and the areas affected by the phenomenon. Criteria that may indicate the location and extent of the potential ("assessed") NIMBY effect were selected through deduction. Based on these criteria, an algorithm for assessing the NIMBY effect was developed.

The practical part of the research begins with stage 2 and included a case study of the Łomża FUA, where the development of a new railway line was planned. For spatial analyses (stage 3), demographic data, information on the distribution of built-up areas, and significant risks associated with the investment in the selected zone were gathered to validate the study results. This data was obtained from Polish public databases and registers, including the Central Statistical Office (CSO) and the Central Geodetic and

Cartographic Resource. Additionally, data from geoportals (Spatial Data Infrastructure) maintained at various levels of public administration were utilized, such as the Database of Topographic Objects (DTOk10) (Geoportal.gov.pl, 2023) on a scale of 1:10,000 and orthophoto maps, as well as open sources of spatial data like OpenStreetMap (2023) and information published by the railway line investor and its subsidiaries on their websites. Furthermore, data collected from interviews with local administration representatives were included. The visualization of land use spatial structure, land-use changes, and population density was conducted using QGIS software (QGIS 3.34). The study highlights the necessity of incorporating these analyses into the process of assessing the NIMBY phenomenon. Figure 1 presents the components of the research process.

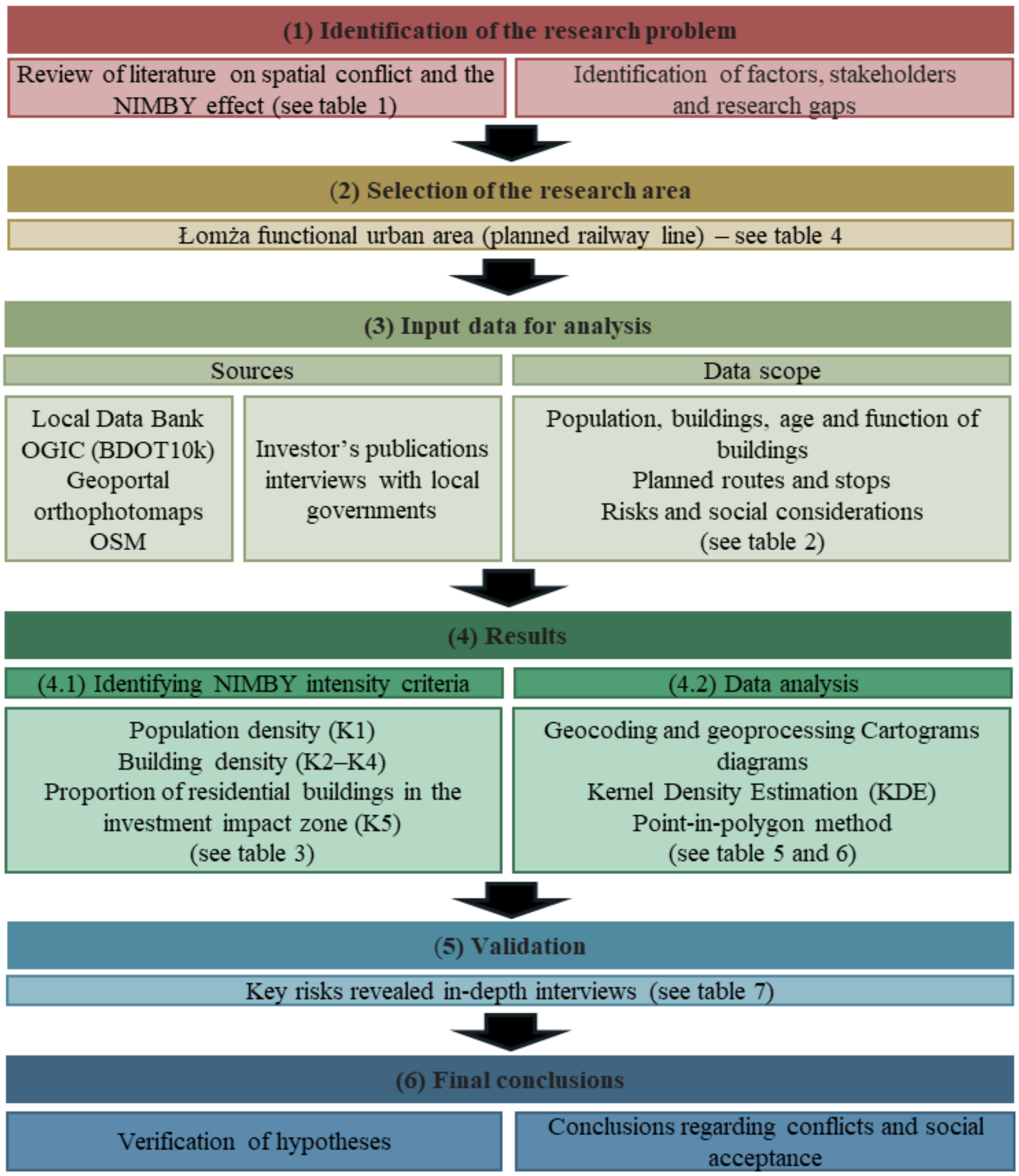


Figure 1. Research framework
Source: Authors' elaboration

3.2 Criteria selection (stage 3)

For the study on changes in the spatial and demographic structure within the selected FUA, data from diverse sources were collected and processed. Table 2 presents a comprehensive summary of the data used for the analyses, along with its source and validity (time of creation). The rationale for using this data to assess the NIMBY effect has also been explained.

In some cases, despite the availability of recent data that was too general (collected at the county or municipality level), it was decided to rely on older data that offered a greater degree of detail, allowing for analysis at the level of individual settlements within the municipality (e.g., data on the population density of settlements was obtained from the National Census 2021) (Statistics Poland, n.d.). Additionally, data on building development was collected for three periods of five years each, starting from 2008. This approach is related to the cycles occurring in the real estate market in Poland and takes into account periods of stagnation, revival, and investment boom (Santos, 2018; Siemińska & Krajewska, 2019).

Table 2. Classification of the indices used for the analyses

No	Indices	Data source	Data type	Access level and date of data creation	Purpose
1	Population density Population change	National Census	*Demographic:* Statistics on population	Settlement, 2021	Confirmation of suburbanization and a large group of potential protesters
2	Settlement density	SDI, local geoportals, OpenStreetMap, DTOk10	*Geospatial:* Data on the spatial distribution of buildings	Parcel and building, 2023	Confirmation of suburbanization
3	The extent of direct impact of the railway line and changes in development	Geoportals, project variants on the site prepared by the developer	*Infrastructural:* Data on the planned route of the railway line	Parcel and coordinates of points/linear objects, 2023	Confirmation of rail route through area under investment / suburbanization pressure Determination of buildings at risk of demolition
4	Number and spatial distribution of buildings constructed after the transition period, categorized by their period of use:(1) less than 5 years, (2) 5-10 years,(3) 10-15 years	Historical orthophoto maps DTOk10	*Geospatial:* Age of buildings	Building, 2008 – 2023	Confirmation of continuing suburbanization and investment pressure
5	Share of residential buildings in the settlement, classification of buildings by function	DTOk10, OpenStreetMap	*Geospatial:* Data on the function of building	Building, 2008 – 2023	Confirmation of suburbanization and investment pressure
6	Number of stations and distance from the nearest housing area	Project variants on the site prepared by the developer	*Infrastructural:* Location for future railway stops	Coordinates of points/linear objects, 2023	Improving local accessibility
7	Level of attitude towards investment	In-depth interviews	*Social:* Information on risks/objections to the investment	Municipality authorities, 2023	Determining the scale of NIMBY

Source: Authors' elaboration

3.3 Methods of data analysis (stage 4 and 5)

The cartogram and carto diagram methods were employed to visualize demographic data on the populations of different administrative units within the municipalities belonging to the commuting zone. These methods were used to present:

1. The population density of individual administrative units,
2. Changes in population between 2009 and 2021.

The density of development, comparable to urban development, was illustrated using Kernel Density Estimation (KDE). This technique allows for the calculation of the intensity of a phenomenon in space by smoothing point data. KDE function estimates the density at point x according to the formula:

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

Where n is the number of points, h is the kernel width (defining the degree of smoothing) and K is the kernel function. Through this method, the distribution and intensity of development in the study area was visualized.

The analysis of the impact of the new railway line variants was conducted using buffering techniques. Buffers were established for the lines representing the different rail route variants. Planned railway stations and stops were also indicated on the maps as reference point objects.

The analysis of development was based on a study of historical orthophoto maps. Changes in development were assessed using orthophotos from 2008 to 2023, analyzing development intensity and dynamics over three five-year periods in relation to changes in the property market (2008–2013, 2013–2018, and 2018–2023). On the raster map bases, point layers were applied in the form of building centroids. The distribution of approximately 4,500 buildings was analyzed using the "points in polygon" method on a hexagonal grid (1 ha) in QGIS (QGIS 3.34).

The assessment of potential NIMBY occurrence was based on a set of factors related to suburbanization. Their selection depended on the main symptoms of suburbanization identified in the literature, particularly in areas similar to the case study area. On this basis justification is provided. Considering the possible negative impacts of development, a set of criteria was developed to identify areas with a higher intensity of the NIMBY phenomenon (Stage 4), and selected factors were taken into account for the final assessment. Their specifications, justifications for application, and rankings are provided in Table 3.

Factors influencing the NIMBY phenomenon were assessed on a three-level scale (1-3), to create a uniform rating. Class ranges were determined individually using methods popular in spatial analysis for dividing a quantitative dataset into classes, such as equal interval and equal count. The assessment of the variants was based on the sum of the points and considered the presence of the route in the settlement (with assigned ranks: 1 when the variant runs through the settlement and 0 when the variant bypasses the settlement). This allowed determination of the NIMBY probability (low, medium, or high). The adopted factors were assigned ranks (1 or 2), where a higher value denotes greater significance for the intensification of the NIMBY phenomenon. In this type of assessment, it is assumed that the rank reflects the potential of a factor to generate spatial conflicts.

Table 3. List of factors for the final assessment (stage 4)

Factor	Code	Justification	References	Rank
Population per housing unit in the settlement	F1	Villages mainly inhabited by families	(Jończy et al., 2021)	1
Increase in the number of buildings between 2008 and 2023	F2	The dynamic spatial development of settlements	(Źróbek-Różańska & Zadworny, 2016)	1
Share of housing in new development	F3	The high contribution to demographic and spatial development of the settlement	(Szmytkie, 2020)	1
Share of buildings constructed between 2018 and 2023 in the number of new buildings	F4	A high proportion of the newest buildings reflecting recently expended costs for their construction and often a higher value.	(Coulson et al., 2019)	1
Share of residential buildings within the railway line's vibration impact range	F5	The high speed railway generates vibrations with maximum impact distance 120 m from the railway line axis.	(Stypuła & Kozioł, 2016, 2019).	
		In settlements with access to the train station or stop accessibility benefits may partially offset disamenities for residential buildings 600 m from the station/stop.	(Debrezion et al., 2007; Diao et al., 2017)	
		The impact is more significant in dense core cities than suburbs with less developed transport network.	(Mulley et al., 2016; Vichiensan et al., 2022)	
		Therefore two variants were created: A) The impact of vibration in settlements with railway stop is partially balanced by the benefits resulting from increased accessibility.		1
		B) The impact of vibration in settlements without railway stop due to the close proximity to the source of nuisance and lack of benefits.		2

Source: Authors' elaboration

Among the analyzed variables, the share of residential buildings in areas exposed to railway vibrations was identified as the most significant, since it captures the inherently conflict-prone location of dwellings in close proximity to the source of nuisance. This factor was assigned up to rank 2, based on the results of consultations conducted in the studied areas, which confirmed its crucial role in the emergence of NIMBY and thus justified the allocation of the highest rank.

The factors adopted are assigned ranks (1 or 2). In this type of assessment, it is usually assumed that the rank indicates the significance of the factor for the intensification of the NIMBY phenomenon – i.e., the higher the value (e.g., 2), the greater the significance of the factor in shaping potential spatial conflicts. Among the analyzed variables, the share of residential buildings in the area affected by railway vibrations is of the greatest importance, as it directly reflects the conflictual location of the buildings (proximity to the source of nuisance). It is crucial for the occurrence of NIMBY. In addition to the literature review rank 2 was assigned based on the results of consultations conducted in the studied areas, which indicated that the most significant factor is the proportion of residential buildings in areas exposed to railway vibrations. This factor directly reflects the conflict-prone location of buildings in the vicinity of the source of nuisance and is key to the occurrence of the NIMBY phenomenon. In particular, this occurred in settlements without benefits resulting from a new railway location, such as improved accessibility.

Interviews with municipal representatives were used to validate the results. Two in-depth interviews were conducted in each municipality. Each interview involved two participants: the mayor of the municipality or the deputy mayor responsible for development, and the officer responsible for public transport and transport infrastructure in the municipality (the total number of participants was 4). They also participated in the public consultation previously organized by the investor of the railway line and were familiar with social attitudes towards investment. The research relied on in-depth interviews aimed at identifying innovations and threats affecting travel-related behavior (Gross et al., 2024). Data collection was based on an electronic interview form developed using the Google Forms platform, which enabled the use of questions with different structures: open-ended, closed-ended, and semi-open-ended. The questionnaire was organized into four thematic sections: (1) public transport, (2) infrastructure and maintenance, (3) transport management (TM) and strategy, and (4) innovations, threats, and monitoring (Gross et al., 2024). The study encompassed six FUAs: Olsztyn, Suwałki, Elbląg, Włocławek, Gdańsk, and Łomża. The survey was conducted in municipalities belonging to the analyzed FUAs. During the preparations for data collection in the Łomża FUA, preparatory works for the construction of a new railway line through the area had already begun. Consequently, the interview scenario for this FUA was expanded to include additional questions regarding the planned investment and its possible implementation variants.

The purpose of these questions was to explore the attitudes of local authorities and residents towards the proposed project. Specifically, the questions addressed the perceived overall impact of the investment on municipal development (economic, social, and infrastructural), the areas of greatest concern among stakeholders, and the key risks associated with different project variants. Such risks included the demolition or dismantling of buildings, transformations of the functional and spatial structure of settlements, changes in public transport systems, land ownership conflicts, and the fragmentation of historically or culturally valuable landscapes. Respondents were also asked to indicate additional threats or challenges not listed in the predefined categories, to suggest actions that the investor should take to mitigate adverse effects, and to assess the role of the municipality in supporting consultation processes and communication with residents. Furthermore, the interview explored the identification of particularly sensitive areas (e.g., natural sites, heritage zones, socially significant places) as well as the factors most strongly shaping the level of social resistance (NIMBYism). These included, among others, the demolition of residential or farm buildings, loss of agricultural land, increased noise and pollution, landscape degradation, deficiencies in communication by the investor, lack of public awareness regarding the benefits of the project, or other locally specific conditions.

3.4 Study area

The research was conducted in Łomża FUA, where a national-scale investment, Railroad 29, was planned as part of the infrastructure for the Solidarity Transport Hub. Łomża FUA (PL047) was classified as a small FUA in the OECD classification (Dijkstra et al., 2019); it had a population of 90,000 in 2015. It consists of the central area (urban core), Łomża - as well as two rural municipalities and one urban-rural municipality (Figure 2).

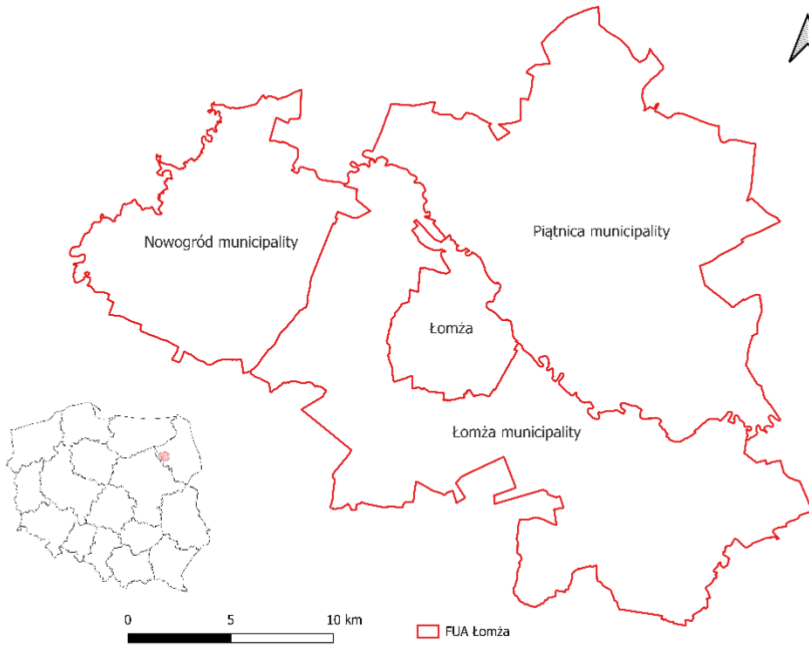


Figure 2. Study area
Source: Authors' elaboration

Table 4 presents basic statistical data for the analyzed municipalities, including population and population density, according to CSO data from 2022 (as at the time of analysis). The population of the Łomża FUA decreased to 86,290 inhabitants compared to 2015. The average population density in the commuting zone is 48 persons/km^2, with the rural municipalities of Łomża and Piątnica belonging to the non-agglomeration areas of high density.

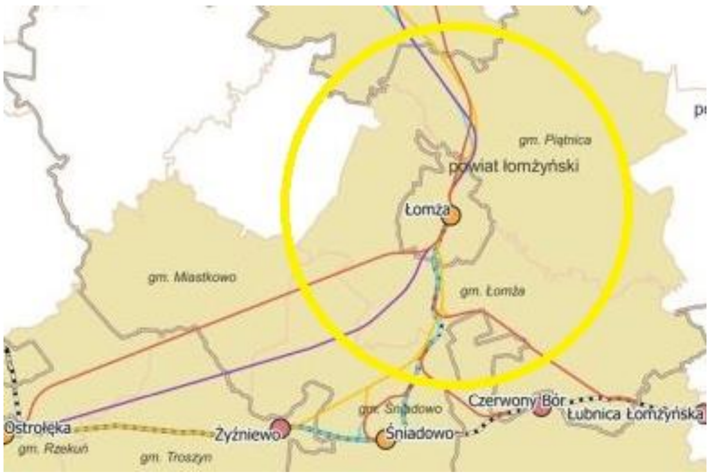
Table 4. Basic geographic and demographic data from Łomża FUA

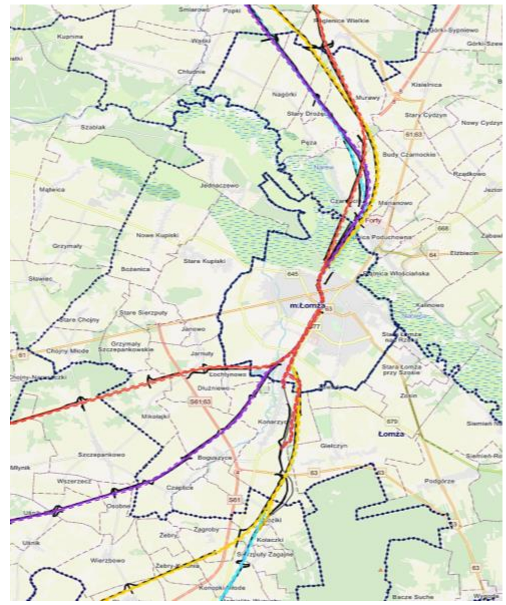
Name and type	Area (km^2)	Population (2008)	Population (2022)	Population density (2022)	Migration from the city	DRA class (2022)
Łomża (urban)	33	63,304	60,130	1,840.5	-	6 - other cities
Łomża (rural)	207.4	9,994	11,980	57.9	2,531	3 – high density non-agglomeration areas
Piątnica (rural)	218.7	10,606	10,290	47.0	1,219	3 – high density non-agglomeration areas
Nowogród (urban-rural)	101	4,016	3,890	38.3	405	4- low density non-agglomeration areas

Source: Central Statistical Office (2022b)

Between 2008 and 2022, more than 2,500 city residents moved to the rural municipality of Łomża, meaning that 21% of its population had not previously lived in the suburban area. In the municipality of Piątnica, it is 11%, and in the municipality of Nowogród, 10%, respectively (Table 2). It should be emphasized that the population of Łomża and the municipalities of Piątnica and Nowogród decreased by 3- 5%, while in the rural municipality of Łomża, it increased by 20% (this is a phenomenon on a national scale, where negative population growth was recorded in most municipalities in Poland, particularly during the COVID-19 pandemic).

Railroad 29 Ostrołęka – Giżycko was planned as part of the largest infrastructure investment of strategic importance to the country. This is partly the restoration of passenger rail transport to the city of Łomża (suspended in the 1990s), partly the construction of a completely new line from Łomża towards the north in municipalities where there were no rail connections. Figure 3 presents the investment course in the Łomża FUA area.





(**a**) (**b**)

Figure 3. NIMBY background – route of the investment Railroad 29 Ostrołęka – Giżycko in Łomża FUA **a)** alternative variants nearby Łomża FUA **b)** the route of the individual investment variants in 2 municipalities of Łomża FUA: Piątnica and rural municipality of Łomża
Source: CPK OST-GIZ V2 (2023)

The planned investment runs through the city center, as well as the southwestern part of the rural municipality of Łomża and the northwestern part of the rural municipality of Piatnica (Figure 3). The study's scope was limited to these two municipalities from the Łomża FUA commuting zone.

4 Results

4.1 Demographic study

Firstly, the importance of population density was analyzed from the perspective of the NIMBY effect in the Łomża FUA commuting zone. It is presented as a cartogram (Figure 4), where the division classes were created with reference to regional and national statistics from the Census 2021 data (CSO). The average population density in Poland was 121 persons/km2, while in the Podlaskie Voivodeship (where the Łomża FUA is located) it was 58 persons/km2. In the analyzed area, 7 administrative units are characterized by a population density above the national average. In particular they are located close to the city borders and Piątnica Poduchowna stands out an above-average population density (in the highest 5th class). Two of the 4 proposed railway development options pass through this village; the other 2 in its closest neighborhood. On the other hand, the village of Konarzyce in the municipality of Łomża, located south of the city and in the fourth density class (121-363 persons/km²), also deserves attention because three of the four proposed route variants run through it (Figure 4).

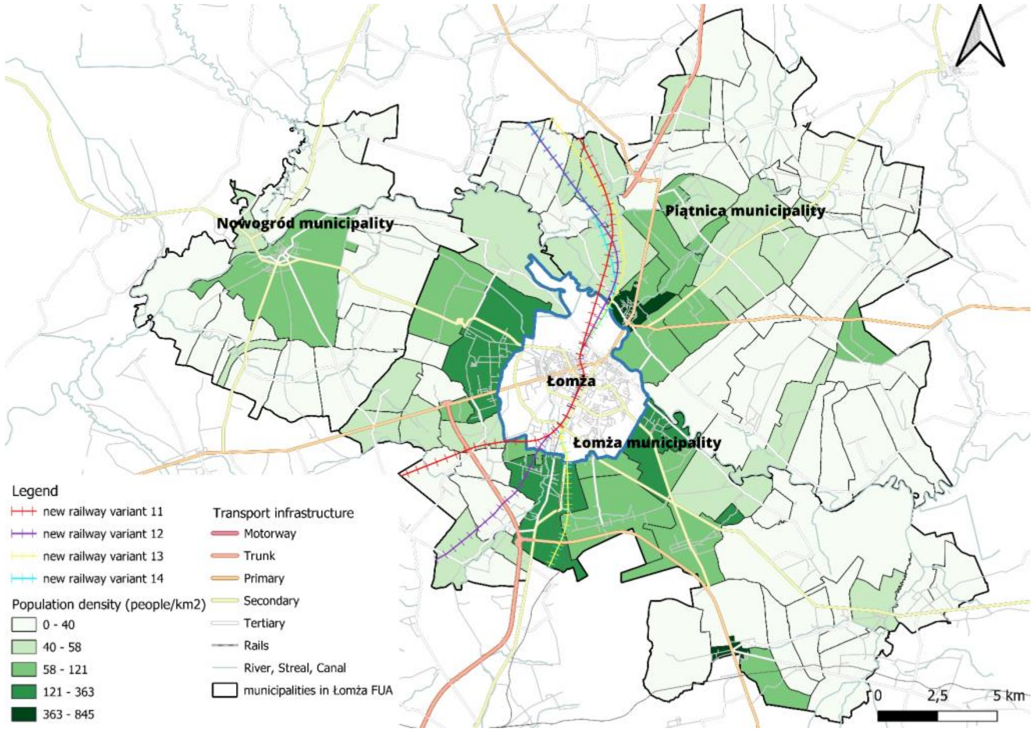


Figure 4. NIMBY background: population density in the Łomża FUA commuting zone and changes in transport system
Source: Authors' elaboration based on Central Statistical Office (2022b), CPK OST-GIZ V2 (2023) and OpenStreetMap (2023) data

Comparing the local data with the DRA classification, where high density areas start at 40 persons/km², it can be seen that most of the settlements located in the central and western part of Łomża municipality qualify as high density areas. This applies to the five villages through which the railway variants are routed. In the Piątnica municipality, high density is recorded in 4 of the 7 included villages. Areas of high density, however, are relatively few and located mainly near the city borders, with three exceptions. Therefore, the study area is more densely populated than typical rural areas and the closer to the urban center the population density increases, in most cases (Figure 4).

Similarly, analyses of population growth over several years, based on CSO data, indicate the same trend. In most cases, settlements located farther from the city have experienced population declines. The population is steadily increasing or remains at a similar level) in the units bordering the city. This phenomenon is most evident in settlements located west and south of the city, directions of urban sprawl that have been dominant for years (Figure 5). For example, the population in Giełczyn (Łomża municipality) increased by 57%, while densely populated Stare Kupiski and Konarzyce recorded increases of about a dozen percent.

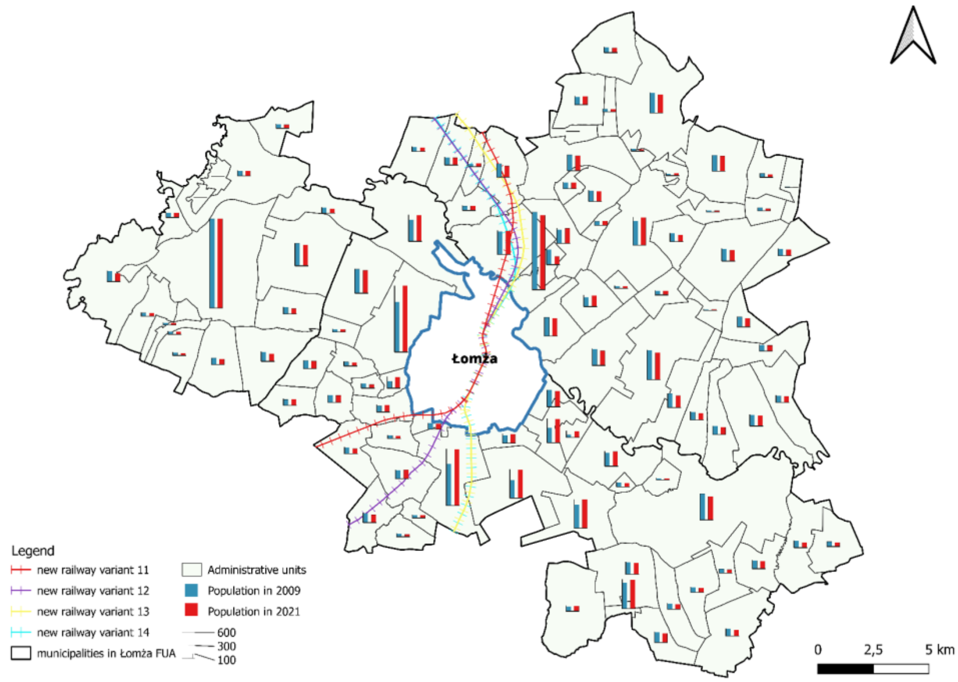


Figure 5. Changes in population of settlements in the Łomża FUA commuting zone
Source: Authors' elaboration based on National Census 2021 data (Statistics Poland, n.d.)

4.2 Spatial study

The study area has been strongly affected by suburbanization processes for many years (Wolny & Źróbek, 2008). Typical suburban development areas have formed as a result. These are islands of concentrated development and extended housing areas along major transport routes (roads). Figure 6 shows dense housing areas in both the city and surrounding municipalities compared to the existing transport system. The purpose of this compilation is to show the scale of building concentration in the commuting zone in relation to typical urban development and to identify areas where urban development tends to cross the city's borders, creating spatially continuous urban structures.

The highest development density is observed near the city borders and along secondary and tertiary roads. The planned railway line-in all variants-bypasses areas with the highest housing concentration in the municipality of Łomża. However, in two variants, the route runs in close proximity to a compact housing zone. The situation differs in the municipality of Piątnica, where all considered variants run through the high-density housing area in the western part of the municipality. In the city itself, the line also runs through the densely urbanized center; only the northern part undeveloped areas. However, in this case, variants 13 and 14 are routed adjacent to the existing disused railway, simultaneously increasing the distance from the most densely built-up areas (Figure 6).

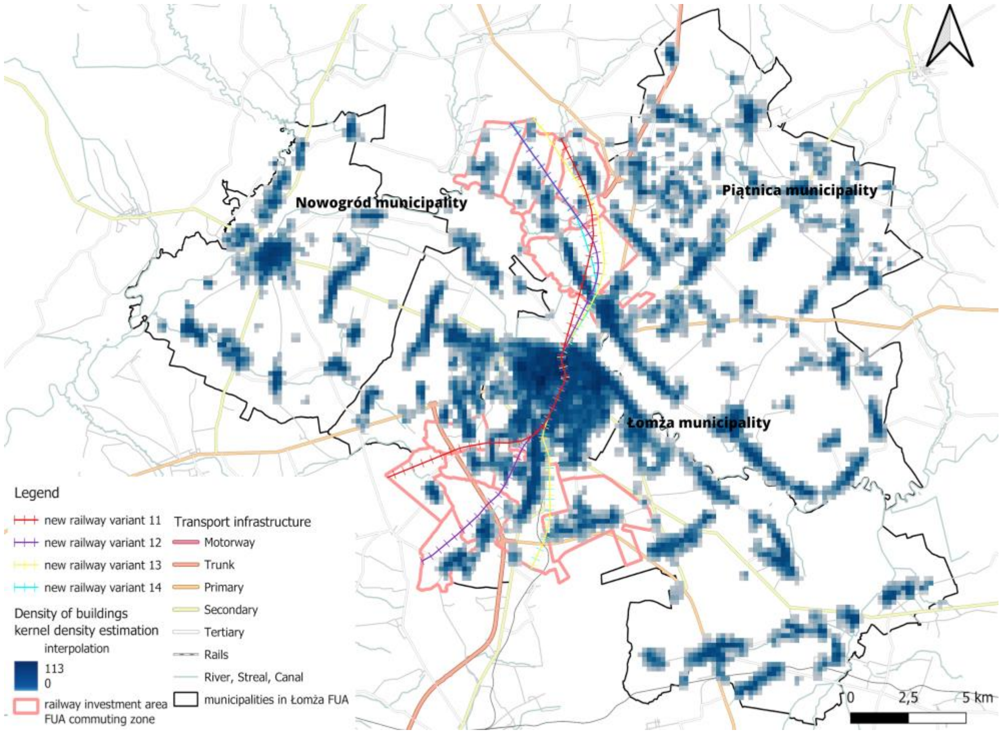


Figure 6. NIMBY background: built-up area density in Łomża FUA
Source: Authors' elaboration based on DTOk10 (Geoportal.gov.pl, 2023) and OpenStreetMap (2023) data

The next stage of the analysis was to determine the direction and intensity of development in the railway investment area, which is divided into parts located in the Piątnica and Łomża municipalities (Figures 7 and 8). The suburban development was analyzed within the timeframe of 2008-2023. The result of the calculations showed the number of buildings assigned to the homogeneous fields of the analytical grid, determined based on point data—specifically, the centroids of the buildings. Figures 7 and 8 present both the distribution of buildings and the dynamics of their development across three distinct sub-periods.

Within the Łomża municipality's investment area, Konarzyce and Giełczyn exhibit the most pronounced suburbanization effects. In Konarzyce, the largest development was recorded between 2008 and 2013, primarily to north and west (areas directly bordering the city). In this locality, variant 12 bisects the newly developed single-family housing estate in the northwest, which includes buildings constructed during two periods: 2008-2013 and 2018-2023 (the most recent buildings, as shown in Figure 7). In the analogous area in the municipality of Piątnica, the most significant building development was observed in Piątnica Poduchowna and Czarnocin, where the most buildings have been constructed in the last five years. However, all variants traverse Czarnocin, also in the area of the most recent development from 2018-2023. Meanwhile, in Piątnica Poduchowna, three variants run along the outskirts of the village with few buildings from the 2008-2013 period nearby (Figure 8).

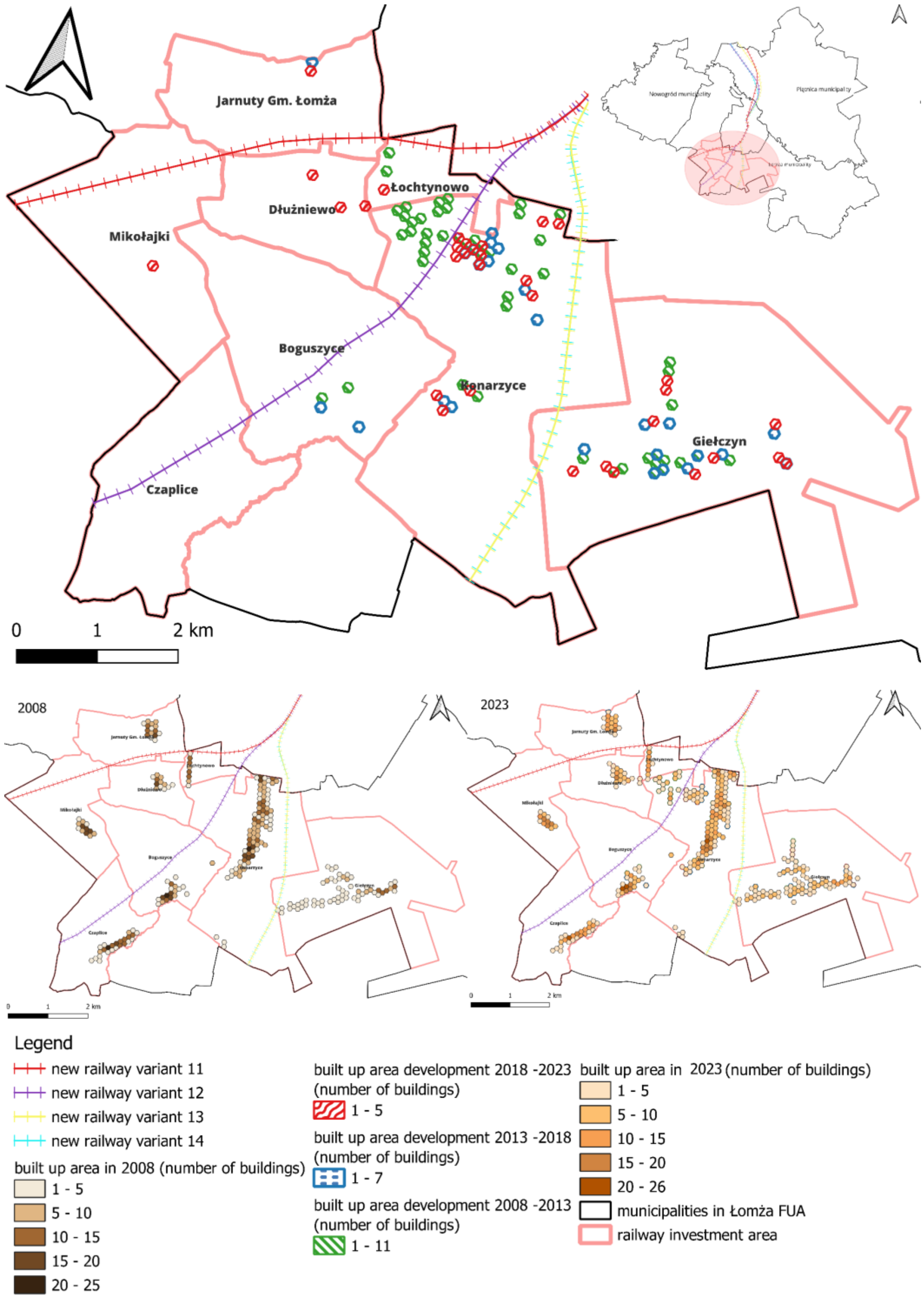


Figure 7. Built-up area development in railway investment area between 2008 and 2023 in Łomża municipality
Source: Authors' elaboration

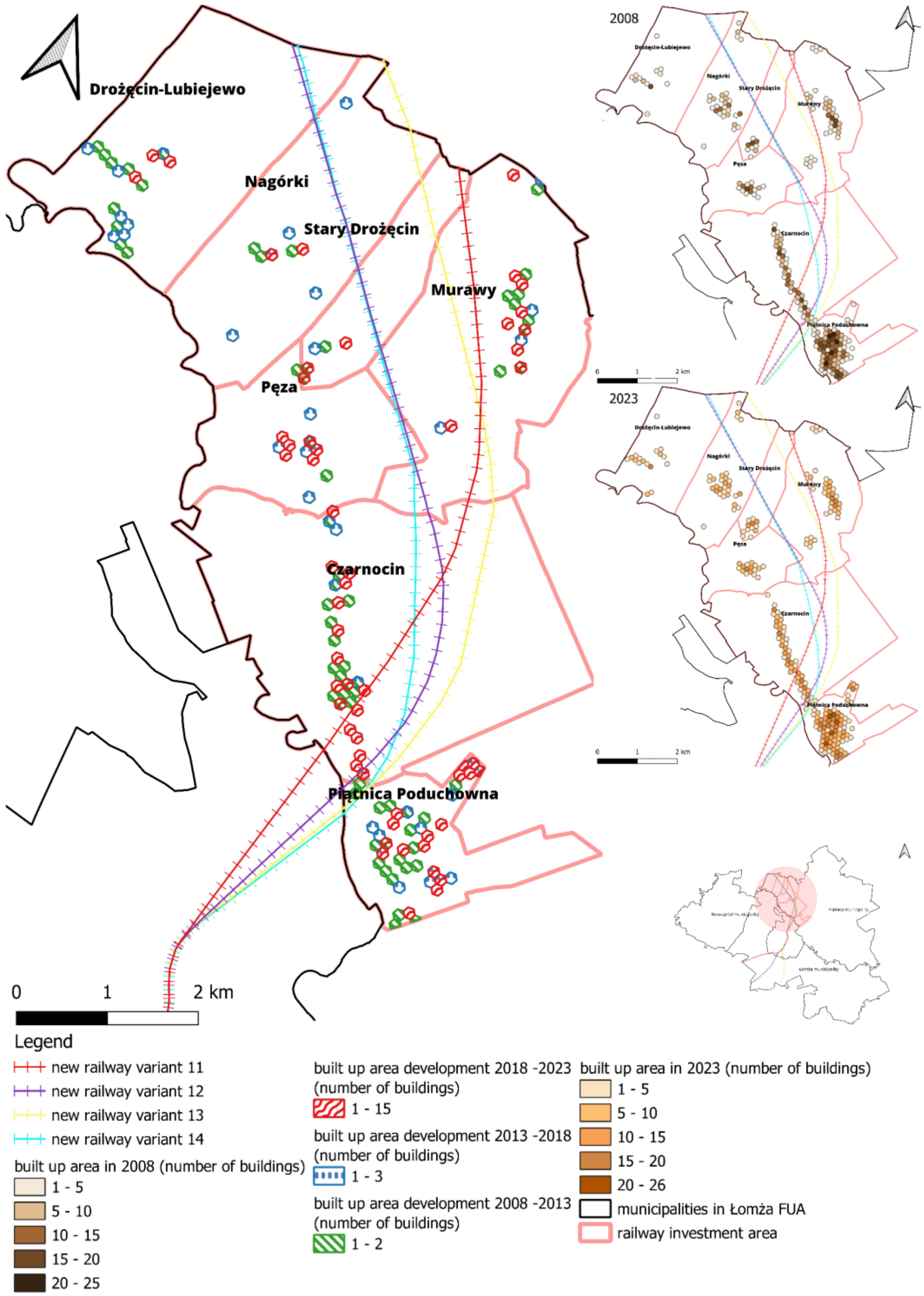


Figure 8. Built-up area development in railway investment area between 2008 and 2023 in Piątnica municipality
Source: Authors' elaboration

In the analyzed period 2008 to 2023, 263 buildings were constructed in the rail investment area within municipality of Piątnica, and 539 in the municipality of Łomża, respectively. Figure 9 illustrates the functions of the newly constructed buildings. In the municipality of Łomża, residential buildings constituted 66% of new buildings, while in the municipality of Piątnica, they constituted 63%. Additionally, a few recreational bungalows were completed in Piątnica. This is associated with the tourist and recreational character of the area, resulting, among others, from its location in the Narew River valley. Farm buildings, barns, sheds, and garages in both municipalities account for 30% of the completed buildings. A marginal share (less than 2%) is accounted for by commercial and service buildings, such as supermarkets and warehouses. Buildings whose purpose could not be determined were not included in the analysis presented in Figure 9. The total number of such cases did not exceed 1% of the identified buildings.

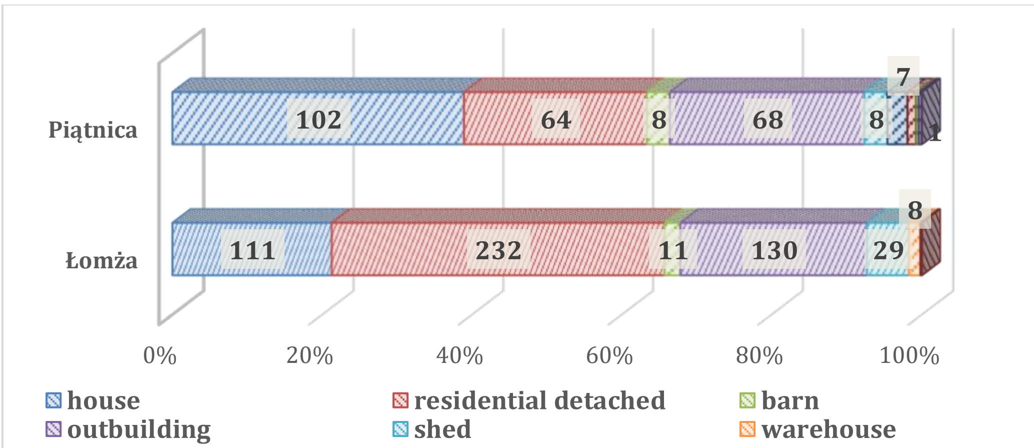
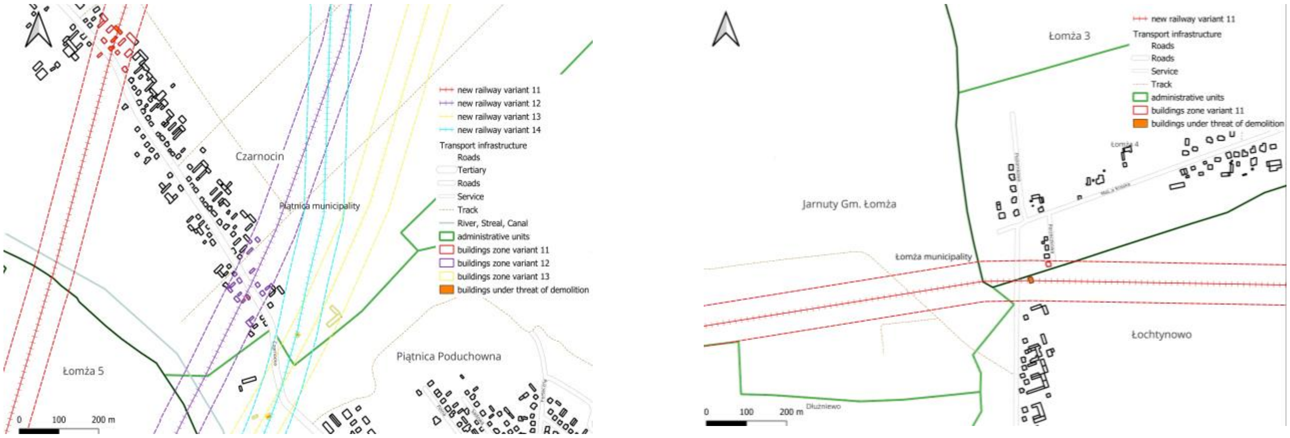


Figure 9. Destinations of buildings developed between 2008 and 2023 in the investment area
Source: Authors' elaboration based on DTOk10 (Geoportal.gov.pl, 2023) and OpenStreetMap (2023) data

The designed variants involve significant spatial conversions; the most severe of which are the demolition of buildings and landscape changes to protected areas (monuments, cultural parks, landscape parks, forest complexes). Figure 10 a and b present selected examples from the municipalities of Łomża and Piątnica, through which the various variants are planned. For the purposes of the analysis, the buildings through which the projected rail tracks pass were identified, and a 50-meter radius zone of direct rail impact was defined (Figure 10 a and b).



(**a**) (**b**)

Figure 10. Areas of significant unwanted conversions in Łomża FUA and building demolitions a) Piątnica municipality b) Łomża municipality
Source: Authors' elaboration based on CPK OST-GIZ V2 (2023), DTOk10 (Geoportal.gov.pl, 2023), and OpenStreetMap (2023) data

The highest number of buildings at risk of demolition is found in variant 11 (V11); they are located in the central part of Czarnocin (Figure 10 a). Similarly, variant 12 (V12) crosses this settlement, but the tracks pass mostly through farm buildings. In variants 13 (V13) and 14 (V14) there are two buildings to be demolished on the outskirts of Czarnocin and Piątnica Poduchowna (Figure 10a). The situation is much better in the municipality of Łomża. Only in the case of variant 11 implementation, there is a building to be demolished in Łochtynowo (Figure 10b), the other variants avoid the existing buildings.

4.3 Assessment of the NIMBY effect in railway investment areas

In the next stage of the research, the probability of the NIMBY effect was estimated for settlements located in the area of the planned investment. The values of indicators for the adopted assessment factors (Table 3) were assigned to all analyzed settlements, and the results are summarized in Table 5.

Table 5. Demographic and spatial NIMBY probability factors

Administrative units	F1 - Population per housing unit in the settlement	F2 - Increase in the number of buildings between 2008 and 2023	F3 - Share of housing in new development	F4 - Share of buildings constructed between 2018 and 2023 in the number of new buildings	F5 V11 - Share of residential buildings within the railway line's vibration impact range	F5 V12 - Share of residential buildings within the railway line's vibration impact range V12	F5 V13 - Share of residential buildings within the railway line's vibration impact range V13	F5 V14 - Share of residential buildings within the railway line's vibration impact range V14
Boguszyce	3.22	12.71%	35.00%	26.00%	0.00%	0.00%	0.00%	0.00%
Czaplice	3.45	5.83%	17.00%	50.00%	0.00%	0.00%	0.00%	0.00%
Czarnocin	3.18	11.29%	49.00%	44.00%	16.09%	9.20%	1.72%	4.60%
Dłużniewo	2.65	35.56%	9.00%	56.00%	0.00%	0.00%	0.00%	0.00%
Drożęcin-Lubiejewo	3.10	28.75%	74.00%	13.00%	0.00%	0.00%	0.00%	0.00%
Giełczyn	2.53	56.20%	68.00%	29.00%	0.00%	0.00%	0.76%	0.76%
Jarnuty	3.42	10.00%	46.00%	38.00%	0.00%	0.00%	0.00%	0.00%
Konarzyce	2.56	40.47%	61.00%	23.00%	0.00%	1.76%	0.20%	0.20%
Łochtynowo	4.52	20.00%	27.00%	40.00%	6.90%	0.00%	0.00%	0.00%
Mikołajki	2.91	6.50%	63.00%	50.00%	0.00%	0.00%	0.00%	0.00%
Murawy	3.51	10.04%	13.00%	39.00%	8.00%	0.00%	0.00%	0.00%
Nagórki	3.31	6.51%	100.0%	18.00%	0.00%	0.00%	0.00%	0.00%
Pęza	2,58	13,64%	67.00%	40.00%	0.00%	0.00%	0.00%	0.00%
Piątnica Poduchowna	3.41	10.68%	81.00%	52.00%	0.00%	0.00%	0.20%	0.20%
Stary Drożęcin	3.33	13.43%	100.0%	44.00%	8.33%	0.00%	0.00%	0.00%

Source: Authors' elaboration

Based on these, a rating of the individual railway route variants was developed (Table 6). The assessment was carried out using a three-point scale and ranks were assigned. The results allowed for the identification of the variants with the highest risk of community opposition in the various localities covered by the project.

According to Table 6, the highest probability of a NIMBY effect is associated with implementing variant 12. This variant scored highly in three settlements and its route covers several rapidly developing areas, including Czarnocin and Konarzyce, significantly increasing the risk of local protests. Variant 11 is rated as a medium risk.

Table 6. Design railway variant ratings according to NIMBY risk

Administrative units	F1 - Population per housing unit in the settlement	F2 - Increase in the number of buildings between 2008 and 2023	F3 - Share of housing in new development	F4 - Share of buildings constructed between 2018 and 2023 in the number of new buildings	F5 V11 - Share of residential buildings within the railway line's vibration impact range V11	F5 V12 - Share of residential buildings within the railway line's vibration impact range V12	F5 V13 - Share of residential buildings within the railway line's vibration impact range V13	F5 V14 - Share of residential buildings within the railway line's vibration impact range V14	V11 rate	V12 rate	V13 rate	V14 rate
	(1: 2.53-3.04, 2: 3.04-3.36, 3: 3.36-4.52)	(1: 6-11%, 2: 11-16%, 3: 16-56%)	(1: 9-42%, 2: 42-67%, 3: 67-100%)	(1: 13-27%, 2: 2-42%, 3: 42-56%)	(1: 1-3%, 2: 3-6%, 3: > 6%)				0 - if the variant skips a settlement			
Boguszyce	2	2	1	1	-	-	-	-	0	6	0	0
Czaplice	3	1	1	3	-	-	-	-	0	8	0	0
Czarnocin	2	2	2	3	3	3	1	2	15	15	11	13
Dłużniewo	1	3	1	3	-	-	-	-	8	0	0	0
Drożęcin-Lubiejewo	2	3	3	1	-	-	-	-	0	9	0	9
Giełczyn	1	3	3	2	-	-	-	-	0	0	9	9
Jarnuty	3	1	2	2	-	-	-	-	8	0	0	0
Konarzyce	1	3	2	1	-	1	-	-	0	9	7	7
Łochtynowo	3	3	1	2	3	-	-	-	15	9	0	0
Mikołajki	1	1	2	3	-	-	-	-	7	0	0	0
Murawy	3	1	1	2	3	-	-	-	13	7	7	7
Nagórki	2	1	3	1	-	-	-	-	0	7	7	7
Pęza	1	2	3	2	-	-	-	-	0	8	0	8
Piątnica Poduchowna	3	2	3	3	-	-	-	-	0	11	11	11
Stary Drożęcin	3	2	3	3	3	-	-	-	17	11	11	11
Total									**83**	**100**	**63**	**82**
NIMBY risk									**Medium**	**High**	**Low**	**Medium**

Source: Authors' elaboration

Although it crosses fewer villages, it runs directly through intensively built-up areas, meaning more buildings are in the project's impact zone. This route is likely to cause similar social conflicts and should therefore not be recommended for implementation. On the other hand, the lowest probability of NIMBY effect was recorded for variant 13 (Table 6). This is mainly due to a more favorable route through the villages in the municipality of Piątnica compared to variant 14. Covering the area of the municipality of Łomża, both variants have a similar route, but variant 13 is characterized by a lower potential for social conflict. Moreover, in this variant the settlement of Konarzyce benefit from the railway stop localized in this settlement. Among the buildings within the railway stop buffer zone of 600 m, there are 20 residential buildings, accounting for 4% of the total. Therefore, significantly more residential buildings positively than negatively affected.

4.4 Validation

The assessment results were validated during in-depth interviews with local authority representatives familiar with public attitudes toward the railway project. These participants also participated in public consultations organized by the investor. Based on the comments submitted, a list of the most frequently identified risks for each investment option was compiled (Table 7).

Table 7. Risks related to the railway line variant

Risks	V11	V12	V13	V14
Demolition of buildings in Łomża rural municipality (RM)	Yes	No	No	No
Demolition of buildings in Piątnica rural municipality (RM)	Yes	Yes	Yes	Yes
Change in functional and spatial structure of settlements - Łomża RM	Yes	Yes	No	No
Change in functional and spatial structure of settlements in Piątnica RM	Yes	Yes	No	No
Change in local transport system (including road to the city) -Łomża RM	Yes	Yes	No	No
Change in local transport system (including road to the city) -Piątnica RM	Yes	Yes	Yes	Yes
Necessity of ownership changes related to land for railway line -Łomża RM	Yes	Yes	No	No
Necessity of ownership changes related to land for railway line-Piątnica RM	Yes	Yes	Yes	Yes
Historically or culturally valuable landscape fragmentation -Łomża RM	No	No	No	No
Historically or culturally valuable landscape fragmentation -Piątnica RM	No	No	Yes	Yes
Number of indications	8	7	4	4
NIMBY Scale	**High**	**Medium**	**Low**	**Low**

Source: Authors' elaboration

The analysis made it possible to determine the NIMBY level on a scale of 1 to 10, where 8–10 meant high, 5–7 meant medium, and 1–4 meant low risk. (Table 7). Variants 13 and 14 were assessed as low risk, variant 12 as medium risk, and variant 11 as high risk, with only one point difference between variants 11 and 12. The results confirmed the validity of the recommendation to implement variant 13 and reject variants 11 and 12, as further illustrated in the comparative analysis (Figure 11).

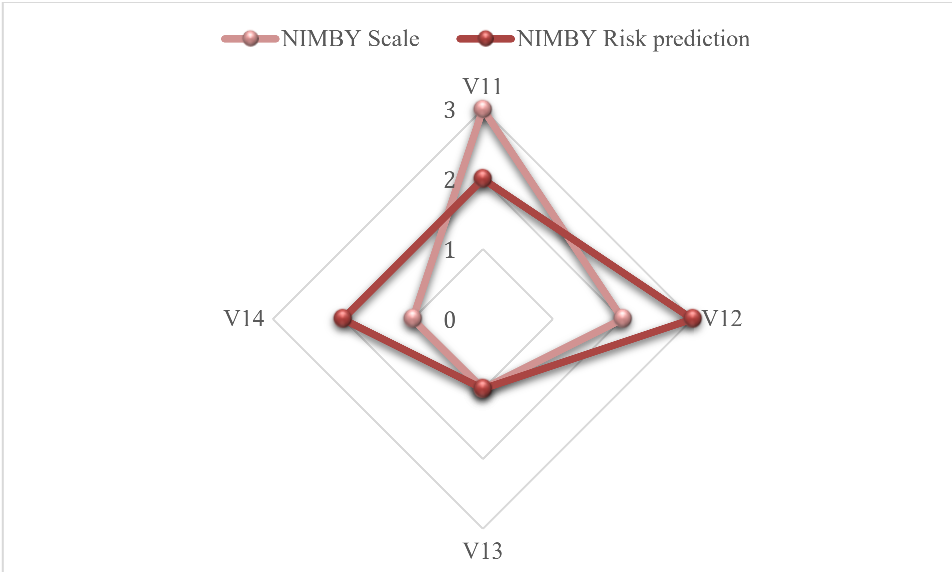


Figure 11. NIMBY scale and NIMBY assessment where 3 is high, 2 is medium, and 1 is low
Source: Authors' elaboration

5 Discussion

The validated results of the case study indicate a need to include land-use change analysis in the process of assessing the NIMBY phenomenon. Simulations of potential protest hotspots should predate the development stage of investment variants and public consultations. This will exclude vulnerable areas from further design analyses, which can translate into savings in time, cost reduction and prevention of social conflicts.

The method developed for determining the probability of a NIMBY phenomenon is an innovative approach applicable to planning processes related to infrastructure expansion in rapidly developing areas—both nationally and internationally. A novel element of the study is an assessment algorithm based on spatial data, including population densities, building densities and the age of buildings in settlements. Previously, the micro-scale approach has not been used in feasibility studies for the location of rail infrastructure; moreover in the context of NIMBY analysis, as the summary in Table 1 confirms. The method addresses the need to simplify the complex investment process associated with railway line projects. Particularly at the planning and design stage, there is a need to monitor land use and population flows in FUAs.

Empirical research conducted in the suburban area of Łomża reveals the intensive dynamics of its development in both demographic and spatial terms. It has been determined that the planned development includes many settlements characterized by high population density and new housing development. The extent to which land-use change influences the NIMBY phenomenon is a dimension that could be further explored in relation to previous findings as it appears to have limited attention in previous studies. Meanwhile, validation revealed that the dynamics of spatial conversion is a key element of the phenomenon. Main advantages of using land-use (SDI) data are wide availability, reliability and annual updates.

On the other hand, demographic statistics for smaller territorial units, such as settlements, are not subject to obligatory annual reporting, although the CSO updates them annually at the NUTS 5 level (municipalities). In practice, this means that the extent and frequency of their collection and updating of detailed demographic data depend on the individual decisions of local governments, which may impact the limited availability and quality of these data. In addition, demographic data in Poland is mainly based on registration rather than the actual place of residence. This is verified during the National Census every 10 years. This affects the assessment of actual space occupancy.

The results of the empirical research confirm the hypothesis that NIMBY is a phenomenon that increases in suburban areas under investment pressure. In turn, there is support for investment where it is less onerous and improves local accessibility. Meanwhile, in developing settlements—especially where there is a high intensity of development and dynamic growth of new buildings—crossing them by the planned railway line is associated with increased social resistance and negative attitudes among residents.

Public acceptance of the investment is stronger in localities where its impact is perceived as beneficial. Konarzyce is a case example where the planned railway stop increases local transport accessibility. Therefore, the positive effects may outweigh the negative ones. In other locations, the new railway line may be seen as a barrier hindering road traffic, especially because, in the infrastructure hierarchy, the railway takes priority over local roads.

In the design process for a linear investment, several options are considered. These are initially determined based on objective conditions such as terrain, water conditions, existing spatial barriers, the location of protected areas, or existing and planned infrastructure. These factors help demarcate alternative routes in a limited area. These variants are modified during the public consultation; a noticeable example of which is the renumbering of the alternative variants of the subject investment from 1-4 (consulted on in 2022) to 11-14 in the third quarter of 2023 (CPK OST-GIZ V2, 2023). According to the results of Łomża FUA case study, the same investment variant can elicit different attitudes in different municipalities. In one municipality, it may be accepted; in another, it may cause a strong NIMBY phenomenon. Moreover, the intensity of opposition may vary within a single municipality, depending on the local spatial context and the investment's impact on the quality of life at the micro level.

6 Conclusions

The conducted research confirmed the hypothesis that the NIMBY phenomenon in suburban areas is strongly correlated with the degree of suburbanization. Settlements with intensive spatial and demographic development show a higher level of disagreement with linear investments, especially with rail infrastructure. The NIMBY assessment algorithm, based on spatial data on building density and age, represents an innovative tool in the process of localizing infrastructure investments. Railway developments can adversely affect property values, cause buyouts and expropriations, and introduce significant changes to settlements' spatial layout. Increases in land prices and construction costs make owners of newly built properties particularly inclined to oppose these developments. Therefore, the algorithm can support the analysis of investment options in the context of the NIMBY phenomenon's and improve the planning and design phase, reducing the risk of delays caused by residents' protests.

A conducted study indicates the need to include analyses of spatial structure change in the process of assessing the occurrence of the NIMBY phenomenon, as land-use data is widely available and updated more frequently than demographic data, making it a more effective analytical tool for assessing spatial conflicts. The research findings highlight the need to enhance investment feasibility studies through micro-level consultations with local authorities. In areas where spatial conflicts have historically existed and local authorities have knowledge of them, a closer examination would be appropriate. They can also identify locations where the planned rail stop is likely to bring added value to the local community as in the case of the Konarzyce settlement.

Subsequent research should include further validation of the NIMBY assessment algorithm and extension of the analyses to other FUAs, including metropolitan areas to assess the universality of the proposed approach.

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Author contribution

The authors confirm their contribution to the paper as follows: conceptualization, methodology, writing: A. Wolny-Kucińska, A. Dawidowicz, M. Gross, M. Dudzińska; formal analysis, validation, formatting: A. Wolny-Kucińska; funding acquisition, supervision and project administration: A. Dawidowicz.

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