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Modelling school capacity demand under rapid suburbanization: A case study of the Košice urban region following a major industrial investment

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Abstract

Population redistribution and changes in age structure pose persistent challenges to the efficient and sustainable provision of public services. This study aims to support evidence-based and spatially targeted investment decisions in public services, with a specific focus on pre-primary and primary school capacity planning. The paper applies demographic modelling of population development, with particular attention to child age categories relevant to pre-primary and primary education, to assess how suburbanization processes and major industrial investments may reshape future demand for educational infrastructure. A cohort-component population forecast is combined with an investment-adjusted scenario that captures potential demographic responses associated with large-scale industrial development. Spatial differentiation is introduced through a zonation framework that integrates demographic trends, residential capacity, and empirical analogies from a comparable investment-driven regional transformation. The approach is demonstrated using the Košice urban region, a rapidly suburbanizing area where a major automotive investment is expected to further intensify population redistribution. The results reveal that investment-related demographic dynamics can substantially alter the spatial distribution of future school capacity demand, mitigating population decline in the urban core while concentrating growing needs in suburban zones. Beyond the specific case study, the proposed modelling framework offers a transferable methodology applicable to other regions facing suburbanization and investment-driven demographic change, providing a robust basis for strategic and timely planning of educational infrastructure.

Key words:
population, forecasting, investment, analogy, spatial zonation, child population, educational infrastructure

1 INTRODUCTION

As a consequence of the second demographic transition, Western societies are facing unprecedented changes in population age structures, with far-reaching implications for economic development, labour markets, and the efficient, equitable, and sustainable provision of public services. Persistently low fertility, delayed childbearing, increasing life expectancy (cf. Mládek, 1998), and intensified spatial mobility are reshaping demographic profiles across regions (Kačerová et al., 2014; Šidlo et al., 2020; Sobotka & Fürnkranz-Prskawetz, 2020) and generating new pressures on public service systems. These demographic transformations are increasingly reflected in pressures on public service provision (Marešová et al., 2015; Lopreite & Mauro, 2017; Carbonaro et al., 2018; Wiśniewski et al., 2021; Nagarajan & Sixsmith, 2023), where education systems in particular must adapt to both declining and spatially redistributing child populations.

These challenges are further shaped by development strategies aimed at enhancing regional competitiveness through large-scale industrial investments, which can reinforce spatial population redistribution among and within urban areas. Education systems, and particularly school capacity provision, are among the most affected public services, needing to respond not only to changing demographic patterns in the child population but also to its shifting spatial distribution. Addressing these dynamics requires a systematic, evidence-based approach to anticipate future demand and guide the allocation and design of educational infrastructure. Population forecasting is essential for anticipating future changes in the number of children, pupils and students and thus for evidence-based planning of educational capacity, staffing and infrastructure (Tran, 2017; Markova et al., 2020; Yang et al., 2020; Chaves e Silva et al., 2025).

The Košice urban region (KUR) provides a suitable case for examining how changing population patterns and major industrial investment may reshape future demand for educational infrastructure. While the core city of Košice has been experiencing a significant population decline, the surrounding Košice-okolie district, which encompasses the city's suburban zone, has been undergoing population growth (Pregi

& Novotný, 2022). In 2026, Volvo is expected to launch production in the immediate suburban vicinity of Košice (MH SR, 2022). This represents the largest investment in the region in decades and is likely to increase its attractiveness as a destination for migration. Consequently, it may contribute to population growth and increase demand for public services, particularly educational facilities such as kindergartens and primary schools.

At the national level, however, demographic trends remain less favourable. The continuously increasing age of mothers at childbirth, the phenomenon of delayed fertility recuperation, and the declining number of women of reproductive age (Potančoková, 2011; Šprocha & Fitalová, 2022; Nestorová Dická & Lipták, 2024) are contributing to the shrinkage of the school-age population. As a result, the concurrent influence of demographic processes at multiple spatial scales is expected to reshape patterns of educational demand, potentially creating a mismatch between regional population dynamics and existing educational infrastructure, thereby requiring a systematic reassessment and redistribution of educational infrastructure in the KUR.

Significant economic investments can support territorial development and attract productive population groups. Yet, their demographic effects usually arise with a time lag and remain conditioned by structural factors, including human capital composition, mobility patterns and housing availability. Forecasting population responses to large-scale projects, therefore, requires demographic modelling of potential trajectories and their spatial implications.

This study aims to model future population development in the Košice urban region up to 2050, focusing on the implications of planned industrial investment for educational infrastructure. It assesses how population dynamics and age structure may change and uses a cohort-component model to generate alternative demographic scenarios. The resulting forecasts provide a basis for anticipating shifts in the school-age population and for strategic planning of educational infrastructure and related services at the regional level.

2 THEORETICAL BACKGROUND

A typical phenomenon in postsocialist cities was the shift from population centralization to decentralization, characterized by population growth in suburban hinterlands at the expense of shrinking central urban areas (Turok & Mykhnenko, 2007; Mykhnenko & Turok, 2008). In Slovakia, this process manifested as rapid suburban development, affecting not only the largest cities but often also small regional and subregional centers (Pregi & Novotný, 2019). While Bratislava, as the capital of Slovakia, was also affected by suburbanization, its stronger economic performance and migration attractiveness made its demographic trajectory more favourable than that of Košice (Novotný, 2016; Pregi & Novotný, 2019; Šveda et al., 2021). However, the development of the IT sector and knowledge-intensive services in Košice has likely contributed to a migration increase in the KUR over the past decade. Within Slovakia, Košice now performs as a complementary metropolitan region attracting migration from across the entire Eastern Slovak regional subsystem (Novotný et al., 2024).

Changes and spatial variability of demographic trends were also affected by substantial postsocialist economic transformation. Investment flows and industrial–service localisation patterns became decisive drivers of regional growth and population redistribution (cf. He et al., 2016). Understanding the linkages between investments, job creation and demographic dynamics is therefore crucial for interpreting current urban and suburban trends, including those in the Košice metropolitan region.

Lower production costs in Eastern Europe generated opportunities for above-average profits, reshaping the geography of job creation and employment relocation within the European automotive sector (Domański & Gwosdz, 2018; Pavlínek, 2018, 2020; Mytna Kureková, 2018; Németh, 2024). The concentration of jobs in several Eastern European countries illustrates a spatio-temporal mechanism in which initial locational advantages attract further producers seeking to benefit from the same conditions. This pattern has been reinforced by investment incentives, the consolidation of supplier networks and technological solutions supported by modern infrastructure. Similar effects may be anticipated in the KUR.

Historically, the construction of the metallurgical complex (now U. S. Steel Košice) in the 1950s constituted the dominant development impulse for Košice and eastern Slovakia. It triggered substantial labour demand and a significant influx of migrants from rural areas of east and central Slovakia (Korec, 2009; Górka & Kušnírová, 2021). The city's population almost tripled between 1950 and 1970, from about 60,000 to more than 150,000 inhabitants (Jirsová et al., 1978). This expansion occurred in a specific post-war context defined by a labour surplus, low capital mobility, and centralised planning, in which labour availability was a key locational determinant. Population growth thus reflected state-directed industrialisation rather than market-based responses (Kline & Moretti, 2013).

In sharp contrast, the planned Volvo Cars investment near Valaliky, a suburban village of Košice, represents a market-driven, globally competitive model of regional development. Capital mobility, innovation and labour availability are now central determinants. The new plant is expected to create several thousand jobs and induce secondary demand in housing, services and infrastructure (Pavlínek, 2018; Agnew & Lyons, 2018), potentially mitigating population decline in Košice and stimulating growth in its suburban hinterland. Long-term demographic impacts will depend on labour mobility, housing capacity and overall regional attractiveness (Camagni & Capello, 2013).

Economic and demographic transformation has also led to changes in the demand for public services and has called into question their effectiveness. The development of educational infrastructure in Slovakia has closely followed demographic developments. During the population boom in the post-war period and the pro-natalist measures in the 1970s (Šprocha & Tišliar, 2016), the school network and their capacities have expanded significantly. The subsequent demographic change, characterized by a declining number of births since the early 1980s and accelerating after 1990, has reduced the size of preschool and school cohorts. These shifts decreased demand for educational capacities and placed pressure on municipalities to restructure school networks under market conditions and decentralised governance (Nestorová Dická, 2011, 2013; Nestorová Dická & Jacková, 2022; Križan et al., 2022; Kačerová et al., 2024; Švecová & Tolmači, 2025). Many Slovak regions continue to experience shrinking child populations, resulting in surplus

educational capacities and intensified efforts to optimise school networks (Šiškovič et al., 2016). Yet the alignment of such rationalisation with spatially differentiated demographic trends remains uncertain. Historically, educational infrastructure was often planned under assumptions of population growth, despite projections indicating otherwise (Buček & Bleha, 2013). The sustainability of educational facilities depends directly on the number of children and pupils; their decline reduces municipal revenues and amplifies pressure to reorganise school networks.

3 DATA AND METHODS

The study uses databases from the Statistical Office of the Slovak Republic (SO SR, 2011–2024) and the Slovak Centre of Scientific and Technical Information (SCSTI, 2011–2024). The base demographic input dataset comprises time series on mortality, live births, and migration, disaggregated by age and sex. Data on the region's educational infrastructure, including the number of children, age structure, school attendance, and schools, classes, and capacity units, were obtained from SCSTI databases. Information about planned residential capacity was extracted from spatial planning documents of the Košice Self-Governing Region (KSGR, 2024). In this study, planned residential capacity refers to the estimated potential of a municipality to accommodate new residents, based on approved local spatial planning documents (master plans) and the availability and development readiness of residential building plots.

This research focuses on the KUR, an urban region consisting of the city of Košice as the urban core and its hinterland, defined as the Košice-okolie district at the LAU 1 level. The urban region defined in this way spatially corresponds to the approximated functional region as delineated by Halás and Klapka (2024), and to the Functional Urban Area as defined by the EU-OECD methodology (Dijkstra et al., 2019). The urban core is represented in this context by the four urban districts of Košice I-IV. Population modelling at the LAU 2 level (municipalities, neighbourhoods) was carried out with the awareness of the increased uncertainty associated with projections of small population sets; however, these outlooks served exclusively for the purposes of the KUR spatial zonation. Subsequent modelling of population potentials relevant for educational infrastructure was carried out at the level of population sets created by aggregating municipalities into particular analytical zones, thus eliminating the prognostic risk resulting from the small population size (Fig.1).

The study's methodological framework comprises two interlinked parts. In the first phase, complementary

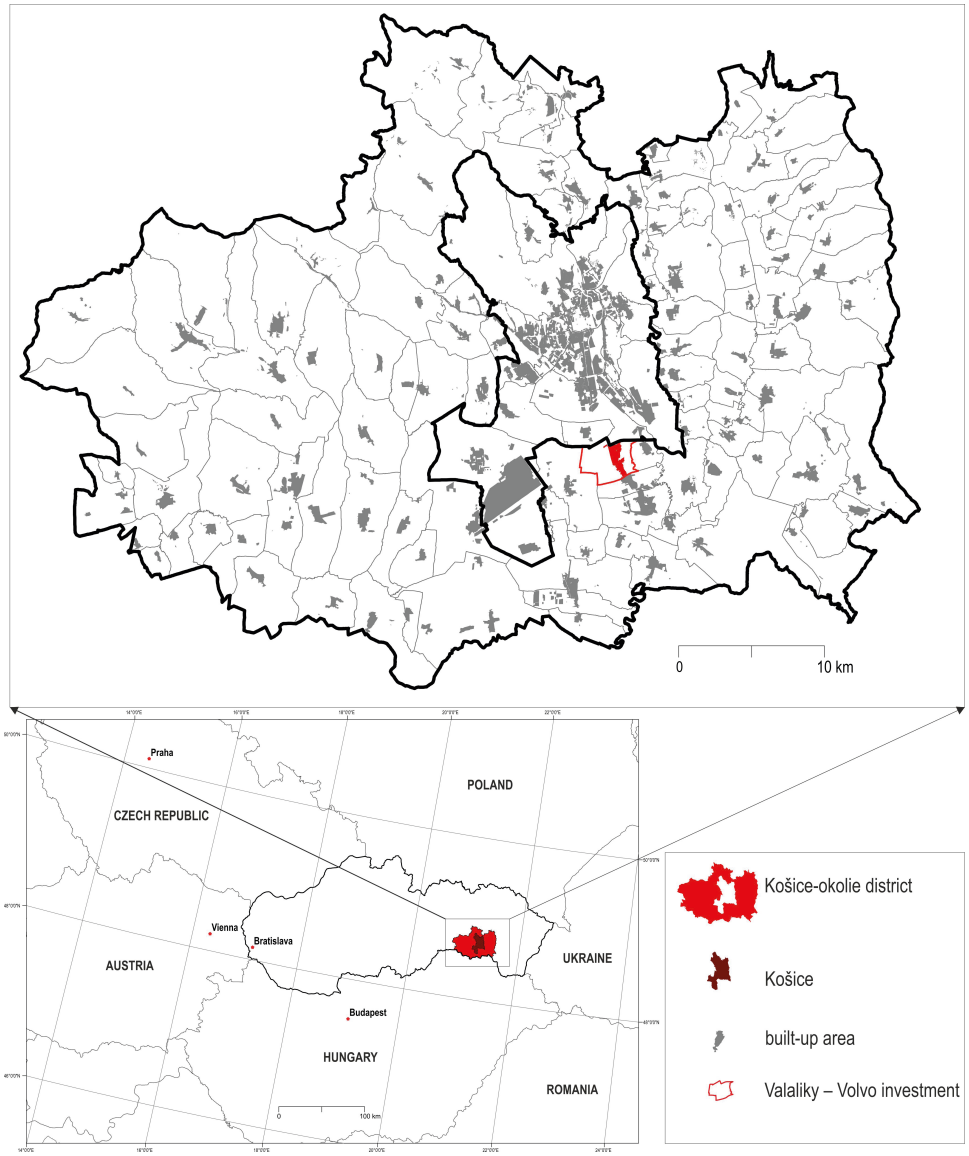


Fig. 1. Košice urban region as a spatial framework of the research

analytical and modelling approaches were applied to identify possible trajectories of population development in the KUR, which served as the basis for delineating spatial zones according to the expected intensity of investment-induced demographic change. The second phase of the research subsequently focused on modelling population projections for the individual zones to quantify the demographic impacts of the industrial investment, with particular emphasis on cohort-specific migration processes. The analytical procedure consisted of the following sequential steps. First, municipalities in the Košice urban region were evaluated based on baseline demographic development; the expected investment-related demographic effect was assessed by analogy with Žilina; and the municipalities' residential development capacity was evaluated based on planned housing development. Second, these three analytical components were combined into a rule-based typology of municipalities. Third, the municipality typology was aggregated into three functionally interpretable and spatially compact zones. Fourth, zone-specific cohort-component forecasts were prepared under the baseline and analogy-based scenarios. Finally, the projected child population was translated into demand for educational capacity under two enrolment regimes. The framework is transferable at the level of analytical procedure rather than case-specific parameters; while the individual thresholds, migration adjustments, and residential-capacity assumptions must be calibrated to local conditions, the sequence of analytical steps can be applied in other metropolitan regions exposed to suburbanisation and investment-driven demographic change. Figure 2 summarises this sequence of analytical steps and distinguishes the municipality typology and functional-spatial aggregation as intermediate stages between the initial analytical inputs and the final zonal forecasts.

Because the demographic response to major economic investments is strongly conditioned by the specific characteristics of both the territory and the investment itself, it cannot be reliably inferred solely from existing demographic trends. The study therefore applies a combination of alternative modelling approaches based on: (i) population dynamics, used to capture the spatial differentiation of demographic development within the KUR and to identify areas with distinct trajectories of population processes; (ii) a prognostic analogy method, which derives the direction and intensity of population change from comparable regions that have previously undergone similar investment impulses; and (iii) a residential-capacity modelling approach, which evaluates the ability of municipalities to absorb future population growth by translating planned residential development capacities into feasible cohort-specific migration gains.

Analogical reasoning is grounded in transferring verified mechanisms of population dynamics between regions that exhibit comparable functional and spatial structures and a similar investment-induced labour-market shock (cf. Štědroň et al., 2012). The research used a predictive analogy method, based on Kia Motors' investment in the city of Žilina's suburban zone, to identify the intensity of population changes triggered by the investment, with particular emphasis on their dependence on distance from the investment core. The selection of the Žilina region as the reference territory is methodologically justified by: (i) the comparable sectoral type and scale of the automotive foreign direct investment, and (ii) its location in the hinterland of a major regional centre outside the dominant gravitational influence of Bratislava. By comparing shifts in migration patterns and population increments in municipalities surrounding the KIA plant, observed before and after the start of production, and in comparison, with national-wide trends, we derived an 'investment effect' parameterised by road distance. This spatially differentiated effect was subsequently applied analogically to the KUR.

Municipality-level population development in the KIA analogue region was assessed across four analytical periods: (i) 2003–2006, representing the four-year period before production began, (ii) 2007–2010, corresponding to the early production phase, (iii) 2011–2020, corresponding to the later operational phase, and (iv) 2003–2020 as the entire observation period. To evaluate the spatial concentration of growth in relation to the investment site, alternative distance thresholds of 10 km, 15 km, and 20 km from the KIA were tested by comparing population growth inside and outside the threshold using the Mann-Whitney-test (Tab. 1).

The testing showed that shorter thresholds captured the strongest inner concentration of growth, particularly in the immediate and near suburban hinterland. However, the 20 km threshold provided the most

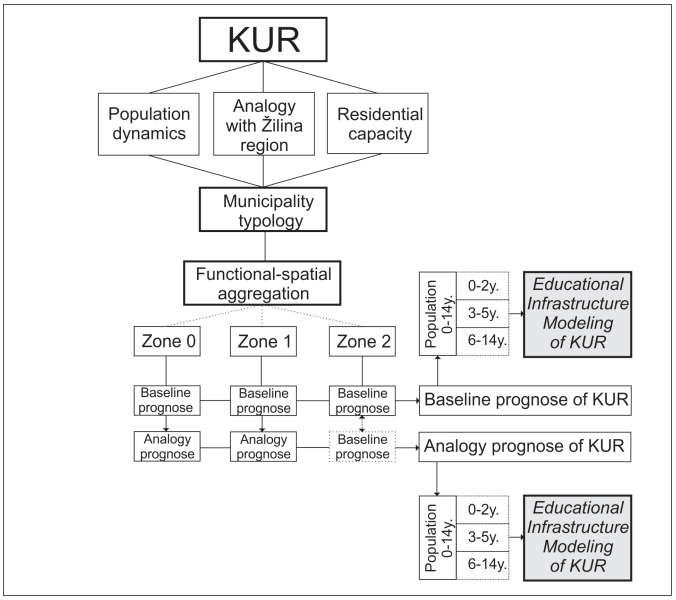


Fig. 2. Methodological framework for the educational infrastructure modelling in the Košice urban region (KUR)

Tab. 1. Testing alternative distance thresholds of investment-related population growth in the KIA analogy region

distance	period	n inside	n outside	median annual growth inside (%)	median annual growth outside (%)	p-value
10 km	2003–2006	15	56	0.14	0.18	0.98
	2007–2010	15	56	0.69	0.25	0.17
	2011–2020	15	56	0.78	0.22	0.02
	2003–2020	15	56	0.59	0.21	0.10
15 km	2003–2006	32	39	0.21	0.17	0.79
	2007–2010	32	39	0.60	0.10	0.03
	2011–2020	32	39	0.62	0.09	0.00
	2003–2020	32	39	0.52	0.12	0.01
20 km	2003–2006	51	20	0.22	0.00	0.05
	2007–2010	51	20	0.45	-0.02	0.05
	2011–2020	51	20	0.51	-0.07	0.00
	2003–2020	51	20	0.42	0.00	0.01

Note: Distance thresholds were tested using the Mann-Whitney-test

suitable broader operational delimitation for zonation purposes, as it captured a stable pattern of differentiated population growth across the examined periods.

The authors' analysis of the Žilina analogue region further showed that municipality-level population dynamics were shaped not only by road distance from the investment site, but also by residential development capacity, reflected in the readiness of land-use planning documentation and housing projects. Based on these insights, a planned residential capacity model was integrated into the subsequent analytical modelling framework for the KUR. The residential outlooks provided essential information on the potential scale of future residential development. Expected population increases were derived from the number of planned housing units and converted into estimated population figures using previously documented suburbanization patterns in the Košice hinterland (Dická, 2006; Novotný, 2012, 2013, 2014).

Planned residential capacity was differentiated according to two basic forms of housing development: (i) individual housing construction (family houses), and (ii) collective housing construction (apartment units). To convert planned residential capacity into expected population growth, we applied explicit occupancy assumptions that reflect the prevailing suburbanisation patterns in the KUR. For family housing construction, a house was assumed to generate an inflow of 2 adults and 1.5 children. For flat housing construction, a flat was assumed to generate an inflow of 1.5 adults and 0.5 children. In this way, planned housing capacity was translated not only into total expected population growth, but also into its basic age structure.

The assumption that the demographic response will occur within the existing suburban migration system is well-founded, given that the Volvo investment is located within the immediate suburban zone of Košice, which has long exhibited a rapid population growth and intensive residential development. The resulting residential outlooks therefore establish a realistic framework for quantifying future population growth and simultaneously verify the spatial capacity of the territory to accommodate further demographic development, potentially driven by the combined effect of the industrial investment and continuing suburbanization processes.

The results of the three analytical approaches were used to classify municipalities according to their expected development potential. The typology differentiates municipalities into categories ranging from very high to very low development potential, drawing on an integrated assessment of population trends, analogies with the Žilina region, planned residential capacity, and the locational advantages of individual territories. These factors simultaneously constitute the methodological basis for the subsequent spatial zonation of the region. The final municipality type was then determined by combining these three partial scenario-based assessments according to an explicit rule-based classification scheme (Tab. 2). The resulting typology expresses different combinations of demographic potential, investment-related spatial advantage, and residential absorption capacity.

The municipality typology and the final spatial zonation represented two consecutive analytical steps. The eight-type municipality classification served as a synthetic layer capturing different combinations of demographic trajectory, analogy-based investment effect, and residential development capacity. The subsequent zonation into three spatial units was not based solely on the mechanical aggregation of municipality types but also on their functional interpretation with respect to the purpose of the demographic forecasting model. The city of Košice was treated separately as zone 0, representing the region‘s urban core. This was justified by its specific demographic dynamics, its dominant role within the metropolitan system, and the distinct nature of the expected investment effect, which was assumed to mitigate shrinkage. Zone 1 was defined as the spatially contiguous belt of municipalities with a strong expected investment-related demographic response, i.e. the municipalities linked to the investment-affected suburban hinterland. Zone 2 comprised municipalities with low or very low development potential, as well as moderate-potential municipalities whose future development was expected to remain predominantly shaped by demographic processes, without a direct investment-related effect or residential capacity. The final zonation distinguished municipalities based on the expected intensity of the investment-related demographic effect. Functional linkage to the investment area and spatial coherence were implicitly embedded in this procedure through the analogy-based delimitation of the broader 20-km zone of anticipated influence.

The final spatial zonation delineates the territory into three subregions relevant for the spatial differentiation of educational-capacity demand at the regional level: (i) zone 0, representing the city of Košice; (ii) zone 1, comprising areas where a substantial investment-induced migratory response is expected; and (iii) zone 2, encompassing areas where future development is expected to be shaped predominantly by demographic processes, with only limited direct investment-related effects. The delimited zones represent the final framework of the spatial

Tab. 2. Rule-based logic of municipality typology based on development potential in the context of the Valaliky investment

Type	Baseline demographic trajectory	Analogy-based investment effect	Residential development capacity	Name	Interpretation
1	Favourable	Favourable	Favourable	Very high development potential	The municipality combines favourable demographic development, favourable position within the investment-affected area, and sufficient residential development capacity. A very strong population increase may be expected.
2	Unfavourable	Favourable	Favourable	High development potential	The municipality benefits from investment-related spatial advantage and residential preparedness despite an unfavourable baseline demographic trajectory. A substantial population increase may still be expected.
3	Favourable	Favourable	Unfavourable	High potential with residential constraints	The municipality combines favourable demographic conditions with an investment-friendly location, but its growth potential is limited by planned residential development.
4	Favourable	Unfavourable	Favourable	Moderate potential with demographic and residential support	The municipality has favourable demographic trajectory and residential development capacity, but it does not directly benefit from a strong investment-related spatial effect.
5	Unfavourable	Favourable	Unfavourable	Moderate potential based on investment-related location	Growth may occur due to a favourable position relative to the investment, but it is constrained by a weak baseline demographic trajectory and limited residential capacity.
6	Unfavourable	Unfavourable	Favourable	Moderate potential based on residential capacity	Growth may occur primarily because the municipality has residential development capacity, but it lacks both favourable demographic dynamics and direct investment-related spatial advantage.
7	Favourable	Unfavourable	Unfavourable	Low development potential	Only limited growth may be expected, mainly due to demographic conditions. The municipality lacks both direct investment-related advantage and meaningful residential capacity.
8	Unfavourable	Unfavourable	Unfavourable	Very low development potential	Population growth is not expected, as the municipality lacks favourable demographic conditions, investment-related spatial advantage, and residential development capacity.

Note: "Favourable" indicates the presence of a positive condition in the respective analytical dimension, whereas "unfavourable" indicates its absence.

zonation and serve as the basis for constructing population forecasts within the individual subregions employing the cohort-component method. This enables differentiated modelling of future demographic developments by age cohorts and migration scenarios. Although this well-established population forecasting model is considered reliable, it has limitations in the context of unpredictable circumstances such as political conflicts, pandemics, or economic investments. Nonetheless, it provides a solid foundation for the subsequent development of alternative demographic scenarios in the context of anticipated changes.

In the second phase of the research, we model future population development within the spatially defined zones to create demographic scenarios that also account for the potential impact of the industrial investment. Projected demand for school capacity is derived on a cohort-specific basis, with particular emphasis on pre-primary and primary education. Capacity calculations are carried out at the level of already aggregated demographic units within each zone, while the final interpretation is presented for the region as a functional whole. This aggregated approach is necessary because of significant commuting flows between zones, and because the practical implementation of the 2025 amendment to the School Act, particularly the regime of mandatory school districts, is not yet known, and its real effects on the spatial distribution of pupils cannot currently be reliably estimated.

Based on the identified spatial zonation and the expected development of demographic processes, two demographic scenarios were constructed: (i) the baseline scenario, which represents the initial population forecast and assumes the continuation of recently observed demographic trends, and (ii) the analogy-based scenario of investment-induced migration, which draws on a modified application of analogy prognostic modelling and aims to sensitively adjust the migration coefficients of the child and working-age population. Both population outlooks are modelled using a cohort-component population forecast based on the 2022 age- and sex-structure of the population and projected to 2050. The age groups 0-2, 3-5 and 6-14 used in the subsequent analysis do not represent internal projection intervals, but analytically defined output categories relevant to educational infrastructure planning. More specifically, the 0-2 age group was used as category relevant to future pre-primary demand; the 3-5 age group corresponds to the core pre-primary school population; and the 6-14 age group represents the population relevant to primary education.

Deviations in migration rates are derived from observed changes in the age structure of migration flows in the Žilina region before the implementation of the Kia investment and after the commencement

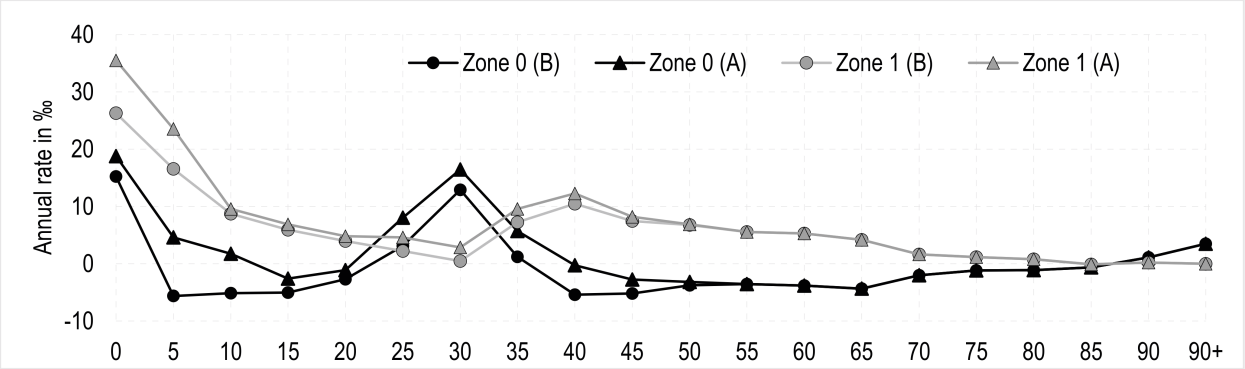


Fig. 3. Net migration age profile in the baseline and analogy-based scenario for Zone 0 and Zone 1

of production, with these differences subsequently applied to the Košice region (Fig. 3). This modification was based on the transfer of empirically observed migration tendencies from the Žilina analogue region. More specifically, age-specific net migration coefficients were first identified for two analytical spatial units in the reference region: (i) the city of Žilina, and (ii) the zone within approximately 20 km of the KIA plant. The differences recorded in these coefficients across the analysed periods were interpreted as the migration response associated with the investment. These differences were subsequently transferred to the corresponding spatial units of the KUR. The migration differences observed for the city of Žilina were applied to the city of Košice (zone 0), while the migration differences observed in the 20 km hinterland of the KIA plant were applied to zone 1 of the KUR. In zone 2, the baseline migration coefficients were retained, as no direct investment-related effect was assumed there. In this way, the analogy-based scenario did not replace the original cohort-component forecast, but adjusted its migration component by incorporating empirically derived spatially differentiated migration tendencies from the Žilina region. Fertility and mortality assumptions remained unchanged.

The analogy-based scenario builds on the extensive empirical and analytical research base on population dynamics and socioeconomic processes in Slovakia's regional context (e.g. Egyedy et al., 2015; Novotný & Pregi, 2019; Nestorová Dická et al., 2019; Nestorová Dická & Lipták, 2024). A systematic examination of migration flows, fertility rates, suburbanisation and redistribution trends, as well as the regional consequences of industrial investments (Pavlínek, 2022, 2023), provides a solid theoretical and analytical basis for interpreting the mechanisms influencing the demographic development of the KUR.

4 RESULTS

Long-term regional population dynamics

The first analytical-model approach reflects the population dynamics of the region's municipalities, based on the average annual population growth rates for the periods 2003–2012 and 2013–2022, and defines areas with a growing, stagnant, or declining population trajectory (Fig. 4). The results point to a significant spatial differentiation of population dynamics, with the greatest growth tendency being shown by municipalities in the immediate western, north and south hinterland of the city, which is in line with Dická (2006, 2007), Novotný (2013, 2014) and Trembošová et al. (2022). Population registration data indicate that population growth in these municipalities is driven primarily by the in-migration of young, economically active households from the regional core. At the same time, a higher concentration of the Roma population (cf. Kandračová, 2007), characterised by distinct reproductive patterns, substantially contributes to local demographic dynamics. These parallel mechanisms jointly underpin the differentiated yet persistently positive population trajectories. However, as the distance from Košice increases, the proportion of municipalities with stagnating or declining populations increases. Significant population redistribution is also recorded in the intra-urban structure of Košice (cf. Dická, 2006; Nestorová Dická, 2014; Novotný, 2014; Hudec & Tóth, 2014). While the central parts, the inner city and especially the socialist housing estates have been experiencing population losses for a long time, the peripheral parts of the city with available development areas and individual housing construction are growing in population. There is thus a significant internal polarisation of demographic trends within the city, while population growth in the peripheral parts is unable to compensate for the decline in the central and housing estate parts. Therefore, the metropolis is shrinking in population. The polarisation of demographic trends will also be reflected in the suburban hinterland, where the simultaneous action of endogenous demographic processes and exogenous investment-related impulses will form population growth areas.

Spatial Gradient of Population Change Induced by Strategic Investment: The Kia–Volvo Analogy

The regional pattern revealed by the second analytical approach is consistent with empirical evidence from the Žilina region, where population growth was concentrated primarily in the suburban hinterland of Žilina. These areas already had strong potential for suburbanisation. In contrast, the city itself and the more peripheral parts of the region had long experienced population decline. In the context of the analogy, it can be assumed that even an investment in Košice is unlikely to lead to a fundamental turnaround in the city's negative migration trends but may rather mitigate them. By contrast, the immediate hinterland of Košice is expected to experience more pronounced population growth. The applied analytical procedure, based on the empirically identified link between population increases and distance from the investment, reproduces the observed distance-decay pattern and confirms the existence of a distance gradient in demographic response. The highest population increases are expected in municipalities in direct contact with the Valaliky location, where the accumulation of new job opportunities and convenient

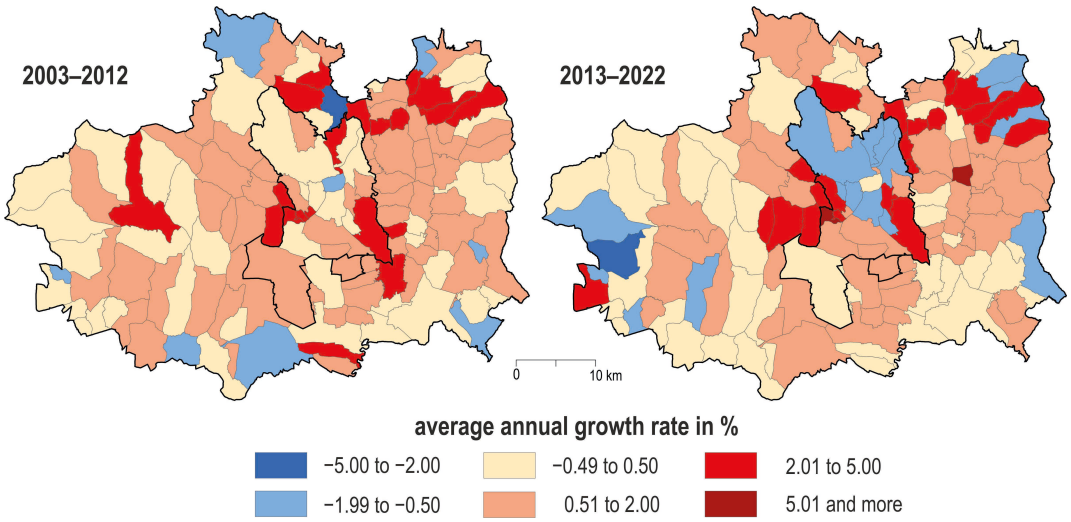


Fig. 4. Population dynamics in the Košice urban region, 2003–2022

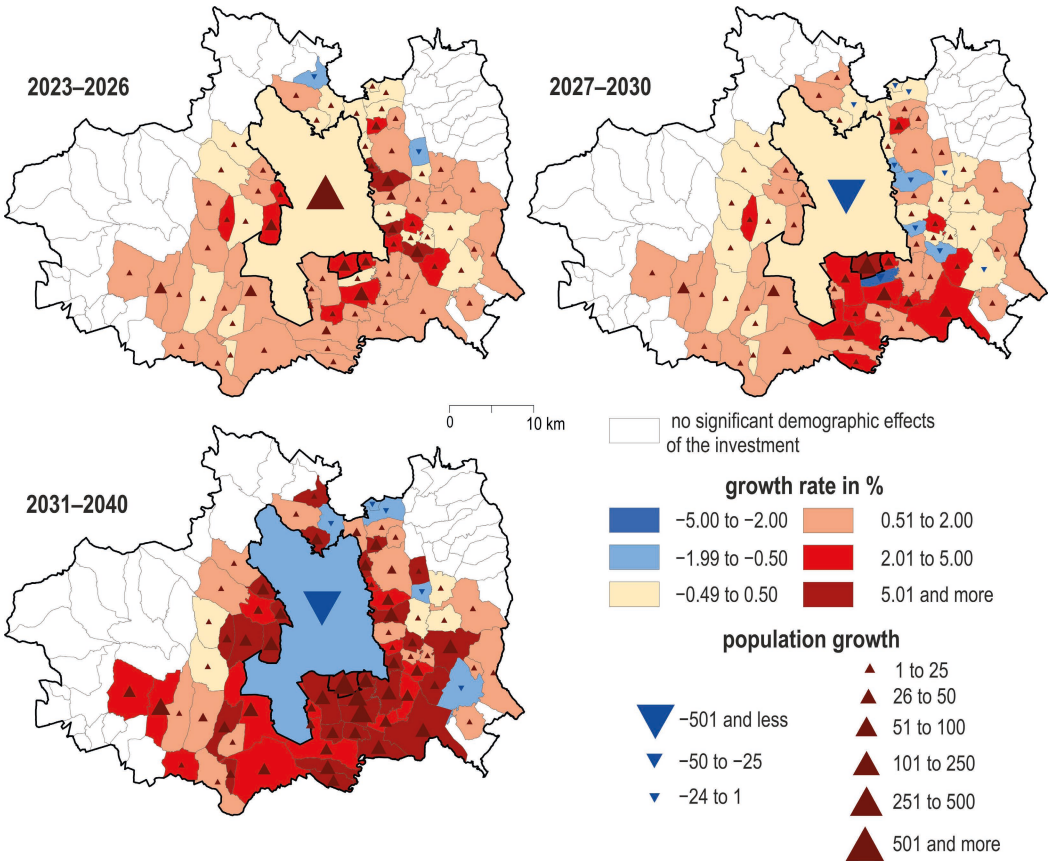


Fig. 5. Analogy-based spatial pattern of projected population change in the investment-affected zone of the Košice Urban Region, derived from the KIA Žilina case

Note: The analogy includes three periods: (2023–2026) four years before the start of production, (2027–2030) four years after its start, and (2031–2040) the subsequent decade of production operation; the figure displays only municipalities located within the approximately 20-km zone around the investment site

transport accessibility is anticipated. The analysis indicates that municipalities within an approximate 20 km radius display more pronounced positive population increments, while beyond this threshold the demographic response weakens considerably Figure 5 illustrates only the intermediate analogy-based transfer of the investment effect up to 2040. The analogy with the Žilina region suggests that the investment near Košice will primarily strengthen existing suburbanization trends, with the highest expected increases in municipalities south of Košice, several of which already showed positive population dynamics in the previous period. It is likely that the city of Košice will continue to experience population decline; however, the magnitude of this decline may be more moderate than suggested by the original reference projections. This development is fully analogous to the experience in the Žilina region, where the launch of the KIA investment did not lead to the restoration of growth in the region‘s core, but, on the contrary, strengthened population growth in its hinterland. This development is fully analogous to the experience in the Žilina region, where the launch of the KIA investment did not lead to the restoration of growth in the region‘s core, but, on the contrary, strengthened population growth in its hinterland.

Spatial Potential for Investment-Induced Population Growth

An analogy with the Žilina Region showed that population growth was not determined solely by distance from the investment but also by municipalities' readiness for land-use planning documentation. The largest increases were recorded in municipalities with existing residential reserves, which were able to absorb investment-related migration demand immediately before and after the start of production. In contrast, municipalities without planned residential capacity did not benefit from this effect, even in a favourable location. The approach analyses investment-driven population growth while accounting for planned residential capacity, thereby ensuring methodological control over the population risk of systemic overestimation. The integration of both dimensions reflects the spatial, legislative, and planning assumptions that determine future residential development. Areas with high residential potential thus create a compact zone of potential rapid growth around the region's core (Fig. 6). Conversely, municipalities without approved residential capacities are expected to contribute to future growth only to a limited extent. With the residential projects currently underway, the city of Košice has the potential to slow negative demographic trends while also expecting slight population increases. However, it should be emphasised that residential construction in the metropolis alone is not a guarantee of population growth. Košice recorded an increase of more than 10,000 housing units during the 21st century (SO SR, 2011–2024; SO SR, 2001–2024), but this was accompanied by a population decline. This paradox reflects long-term suburbanisation population shifts and selective migration processes that weaken the demographic effect of housing construction in the core. In contrast, the hinterland of Košice, with an increase of approximately 9,000 apartments, saw a population increase of almost 27,000 inhabitants, confirming the significantly different migration and reproductive dynamics in urban and suburban areas. A further factor reinforcing this pattern is the long-term transformation of household structures, specifically the steady decline in average household size and the rising share of one- and two-person households. These shifts are particularly pronounced in urban environments, where demographic ageing, delayed family formation, and changing lifestyle preferences contribute to a growing prevalence of small households (cf. Pilinská et al., 2024).

Integrated perspective on population potential and investment-driven spatial zonation

The spatial distribution of municipalities with varying levels of projected population growth was identified by integrating all three analytical approaches. Building on this integrated analytical framework, we developed a classification scheme capturing different levels of expected population potential. Each municipality was subsequently assigned to one of eight categories, ranging from "very high" to "very low" development potential (Tab. 2, Fig. 7). The municipalities with the highest expected population growth are concentrated within an optimal commuting distance of Košice and, at the same time, have planned residential capacities, favourable migration trends, and positive population growth. Municipalities that did not show population growth prospects under any of the applied model approaches, whether due to long-term demographic decline, weak migration attractiveness, limited planned residential capacity, or greater distance from Košice, were classified as areas with low population potential. The classification of municipalities provided the analytical foundation for delineating the spatial zonation of the KUR, yielding three spatially compact zones: (i) a zone with a strong expected investment impact, comprising primarily suburban municipalities in the immediate vicinity of

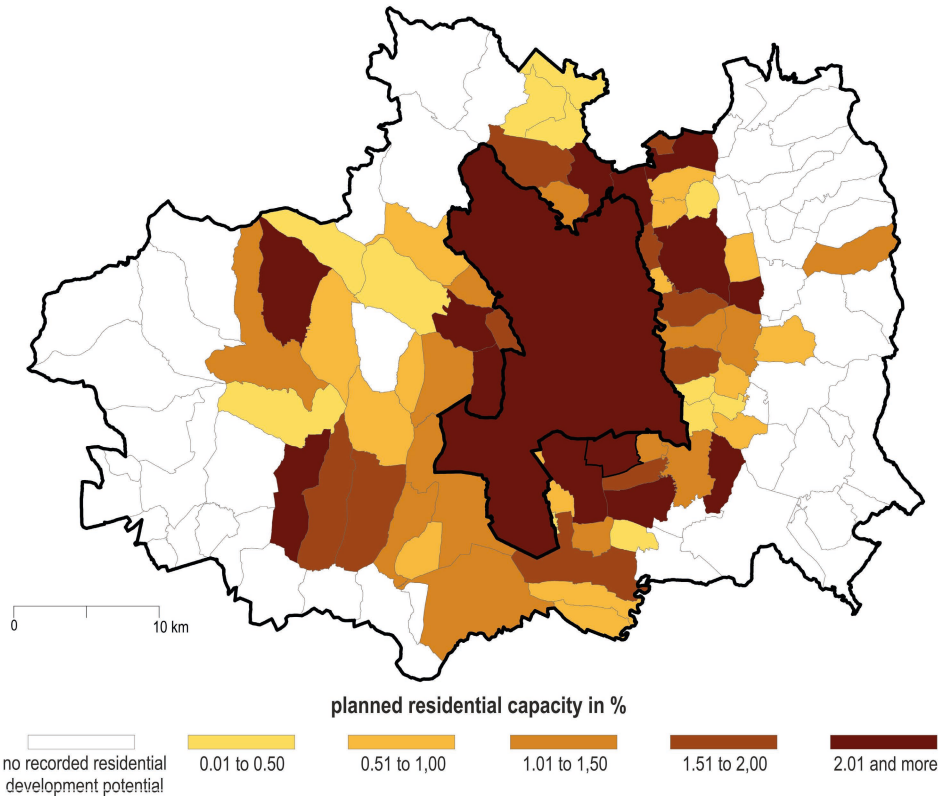


Fig. 6. Share of individual municipalities in the total planned residential capacity of the Košice urban region at the baseline year of the population projection (2024)
Source: KSGR (2024)

the investment, where the most intensive population inflow, driven by labour migration and residential development, is anticipated (zone 1); (ii) a zone with negligible investment impact, covering municipalities where demographic trajectories are expected to follow long-term endogenous trends rather than being significantly shaped by the investment (zone 2); (iii) the urban core, representing the city of Košice, where the investment is expected to slow, but not fully reverse, the ongoing population decline (zone 0, Fig. 7).

The identified spatial zonality of the region provides a platform for subsequent analyses of population impacts to assess future needs of the school network and the capacity of the region's educational infrastructure.

The future population trajectories of the individual zones differ significantly. The city of Košice (zone 0) has been experiencing annual population losses for a long time, driven primarily by a negative migration balance and declining natural growth. The baseline scenario thus reflects the continuation of the underlying demographic processes, resulting in a projected population decline of approximately 3.5% by 2030. Over the following forecast decade, an 8% reduction is anticipated, followed by a further decrease of up to 9.5% in the final projection period (Fig. 8). The investment-modified scenario indicates a moderation of population losses. The zone situated in the city's immediate hinterland has shown long-term population growth already in the baseline scenario, while the investment-modified scenario suggests the possibility of a markedly stronger demographic expansion. Zone 1 is projected to grow by 2050 23.0% in the baseline scenario and 33.8% in the analogy-based scenario. The forecasted population trajectories in peripheral zone 2 remain positive, albeit with lower growth intensity, with observed increases driven primarily by the internal demographic structure of the population (Novotný, 2012, 2015; Nestorová Dická, 2021). In zone 2, the population is expected to increase by 16.8% by 2050. The analogy with the Žilina region does not indicate any clear direct investment-related effect in this zone.

Demographic Shifts and Capacity Dynamics in Educational Infrastructure (2012–2022)

Spatial differentiation of population trajectories is also consistently reflected in age categories relevant to educational infrastructure. In the last decade, the child population aged 0-14 years in the core of the metropolitan region has declined by more than 4%, whereas in its hinterland it has increased by more than 8%. This contrast reflects the cumulative effect of the selective migration of young households in zone 1 and a more favourable age structure in zone 2, leading to higher natural increase. The 3-5-year age group, a key age group for pre-primary education, is recording a decline of approximately 6% in the core metropolitan region, in line with the long-term decline in fertility and birth rates in Slovakia (Nestorová Dická & Lipták, 2024). The hinterland in this category maintains a population growth of approximately 9%. In the region as a whole, the number of children of a given age has not changed significantly. The regional size of the 3-5-year-old age group remains relatively stable due to the counterbalancing of decline in the core and growth in the hinterland.

In the metropolitan core, the population of primary-school-aged children has declined only marginally, by less than one per cent, whereas the suburban hinterland has recorded an increase of roughly 10% over the same period (SO SR, 2011–2024). These spatial differences must also be interpreted within the broader context of Slovakia's post-socialist development, in which urban areas have generally experienced long-term population losses due to the reversal of migration flows that, under the previous political regime, were directed predominantly toward urban centres. This trend has been further reinforced by a more pronounced decline in fertility and birth rates in urban populations, except in the capital region (Bleha et al., 2020).

Shifts in the age structure have been directly reflected in the spatial and capacity arrangement of the educational infrastructure. In the KUR, pre-primary education capacities expanded by approximately 29%,

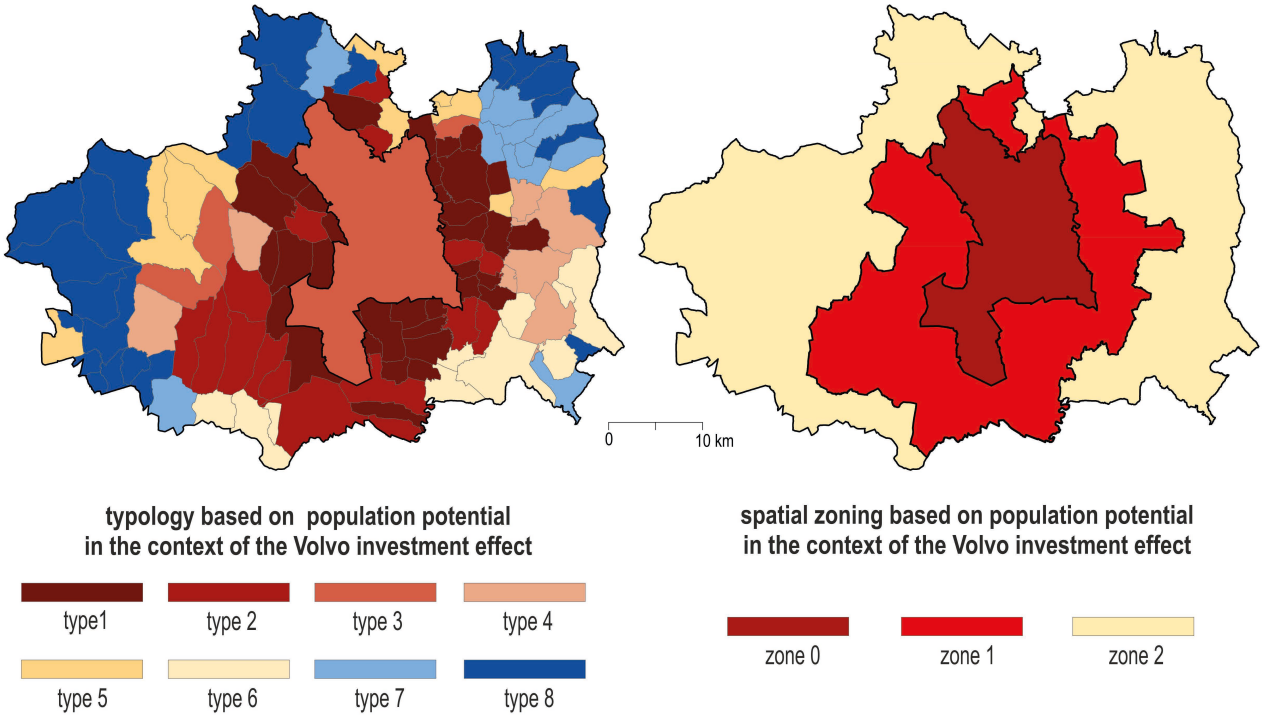


Fig. 7. Categorisation of municipalities in the Košice urban region and its spatial zoning according to population potential with the projected of investment effect
Source: KSGR (2024)

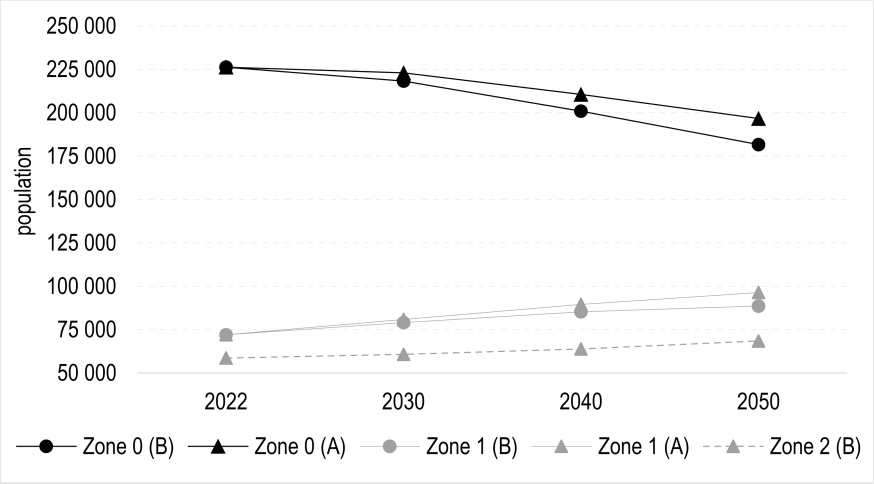


Fig. 8. Potential population trajectories in the Košice Urban Region, 2022–2050
Source: KSGR (2024)
Note: B (baseline scenario), A (analogy-based scenario)

despite the regional growth of the 3-5 age group in the reference population being less than 10%. This discrepancy between population growth and capacity expansion is explained by the rising enrolment rate, which increased by 10% during the monitored period (SCSTI, 2012–2022), with the entry into force of compulsory pre-primary education for preschool-age children being a significant factor. As a result of this legislative change, the enrolment rate of the 5-year-old age group increased by approximately 18 percentage points. The increase in the number of primary-school-age children in the region was matched by a corresponding expansion of primary school capacity, amounting to approximately 8%. However, the spatial dynamics of the pupil population within the KUR were far from homogeneous. In the hinterland, capacity expanded by 11%. In the core, capacity increased by approximately 5%, despite a 0.6% decrease in the population of the relevant age, indicating increased attendance at schools from hinterland.

Population Development Scenarios and Modelling of Educational Infrastructure Requirements

The modelling of educational infrastructure requirements is anchored in the context of the planned Volvo Cars investment near Valaliky, which is expected to generate several thousand jobs and may therefore intensify migration, suburban residential development, and the spatial redistribution of the child population within the KUR. The analysis relates these demographic scenarios to the existing educational system recorded in the SCSTI database, which includes information on the number of children and pupils, schools, classes and capacity units in pre-primary and primary education across the region. This makes it possible to interpret projected changes not only in terms of future child cohorts, but also in relation to the current institutional capacity of educational facilities.

Building on the combined methodological approach, population scenarios were developed that integrate both the baseline trend and the analogy-based scenario, thereby enabling an estimation of future pre-primary and primary education needs in the context of the investment impulse (Fig. 9). The forecast of the child population (0–14 years) in the baseline scenario, which reflects current demographic trends, indicates a substantial decline, particularly in the core of the metropolitan region, where the number of children could decrease by approximately one-third by 2050 compared to the 2022 baseline. In contrast, the hinterland is expected to experience a 12% increase in the child population, assuming continued favourable demographic trajectories. Across all child cohorts, a consistent spatial pattern emerges: while the metropolitan core continues to exhibit population decline, the hinterland shows a stable to moderately growing trend, which becomes further amplified in the investment-modified (analogy-based) scenario. For the KUR as a whole, the baseline scenario projects a decline in the 0-14 population from approximately 56.0 thousand in 2022 to 48.6 thousand by 2050, while the analogy-based scenario increases the 2050 estimate to about 52.4 thousand; however, even this adjusted trajectory remains below the 2022 level. The projected development of the youngest age groups (0-2 and 3-5 years) reflects the combined influence of fertility patterns and age-selective migration. At the regional scale, the divergent trajectories of the core and the suburban hinterland consolidate into a relatively moderate overall decline in the child population, which is partially mitigated under the analogy-based scenario. The population aged 0–2 is expected to decrease from approximately 7.5 thousand in 2022 to 6.6 thousand in the baseline scenario, while the analogy-based scenario raises the 2050 estimate to about 7.3 thousand. Similarly, the population aged 3–5 is projected to decline from approximately 12.4 thousand in 2022 to 10.4 thousand in the baseline scenario and to 11.2 thousand in the analogy-based scenario. In the suburban hinterland, the expected development of the school-age population (6-14 years) under the analogy-based scenario is shaped by a combination of intensified migration of families with school-aged children and more favourable fertility conditions. At the regional level, these dynamics translate into an aggregated outlook of relative population stability up to 2030 in the baseline scenario, whereas the analogy-based scenario anticipates an expansion of the potential primary-school population, driven primarily by projected migration flows. However, a long-term decline in fertility drives the projected population decline in the horizons of 2040 and 2050, the negative effects of which are likely to exceed the compensatory potential of migration. As a result, the 6-14 population is projected to decline from approximately 36.1 thousand in 2022 to 31.6 thousand by 2050 in the baseline scenario, whereas the analogy-based scenario moderates this trend and raises the 2050 estimate to about 33.9 thousand.

Although the 0-2-year age group does not represent the main reference group for kindergartens, its development is strategically important for capacity planning. Demographic changes in the youngest population determine future enrolments in pre-primary education, which is key to estimating demand for kindergarten services. This importance is also growing in the context of the legislatively enabled admission of children under three years of age. In the region, this legislative framework is reflected in the increasing rate of school enrolment of children under three years of age, which, already in 2024, constituted approximately 20% of the population of two-year-olds and represented 6.5% of the occupied kindergarten capacities (SCSTI, 2011–2024a).

The assessment of the future development of pre-primary education capacities in the Košice region is prepared in two variants, given the changing legal framework of obligations in the field of pre-primary education resulting from the amendment to the Education Act approved in 2025 (Act No. 323/2025 Coll.). The projection of the necessary capacities is carried out separately for the baseline and investment-modified population development scenarios. When estimating kindergarten capacity demand, derived rates of schooling for children in the region's population, monitored during 2017–2021, were applied (Fig. 10). The first variant preserves the historically observed age-specific enrolment rates recorded in 2017–2021 and is therefore treated as a pre-reform reference scenario. The second variant models an increase in line with the expanded requirement for compulsory pre-primary education introduced by the amended Education Act. The modelling of capacity needs incorporates a 5% reserve for children expected to fulfil compulsory pre-primary education through individual (home) instruction, in accordance with the applicable school legislation.

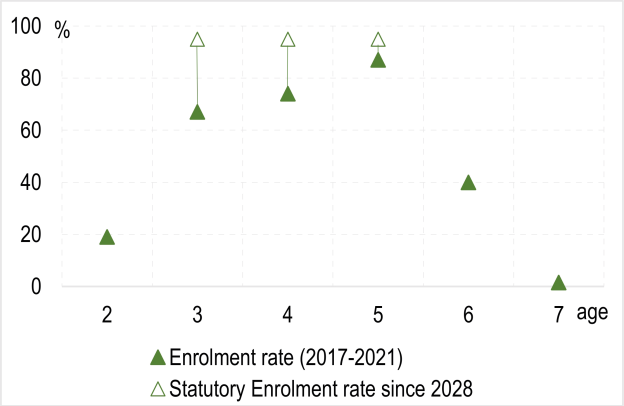


Fig. 10. Age-specific kindergarten enrolment rates under the historically observed regime (2017–2021) and under the post-reform statutory regime following Education Act No. 323/2025 Coll.

Projections of pre-primary education capacity needs for the period 2022–2050 reveal a marked divergence between the baseline and the analogy-based scenarios. In both scenarios, assuming the continuation of historically observed age-specific enrolment rates, the required capacities are expected to decline substantially relative to 2022 (Fig. 11A). In the baseline variant, a gradual decrease in required capacity is expected, whereas the analogy-based scenario indicates stabilisation or a slight increase in capacity requirements in the medium and long term. At the same time, however, increasing school enrolment rates due to the expanded compulsory pre-primary education increase capacity requirements, with a tendency for further gradual growth until the end of the projection period (Fig. 11B).

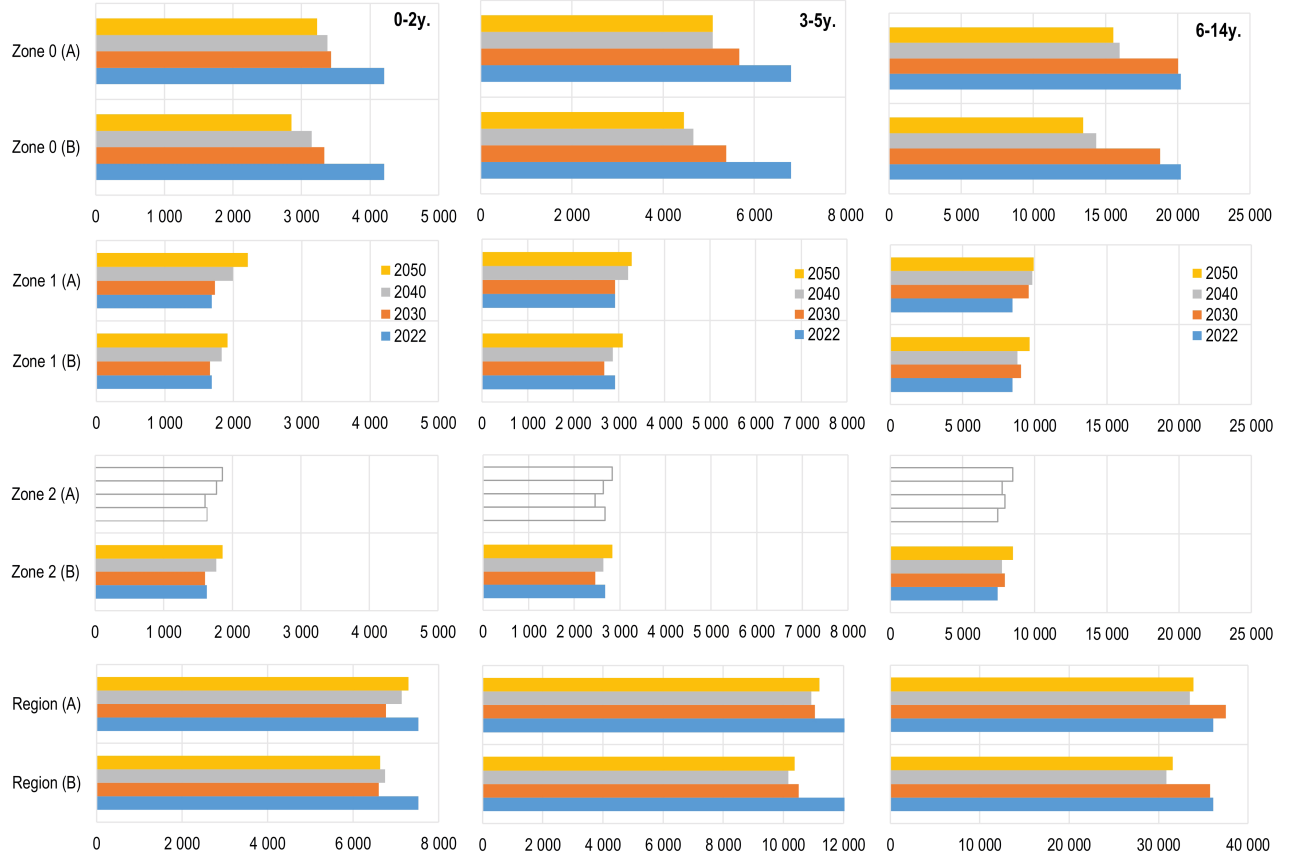


Fig. 9. Population development scenarios relevant for pre-primary and primary education in Košice urban region, 2022–2050
Note: B (baseline scenario), A (analogy-based scenario); Zone 0, 1, 2 see fig. 7.

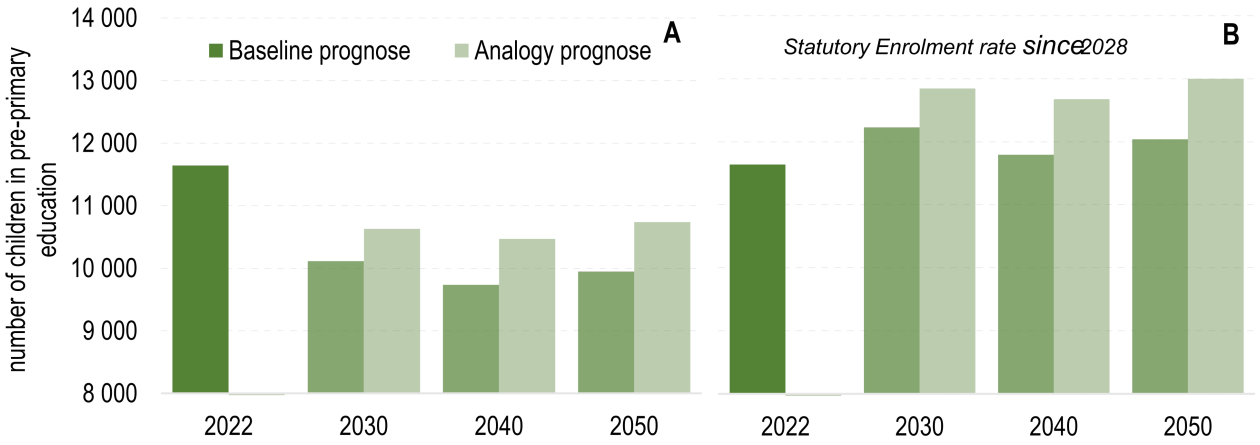


Fig. 11. Future capacity needs in pre-primary education in the Košice Urban Region, 2022–2050

Note: On the left (A), estimate based on the historically observed enrolment regime (2017–2021); on the right (B), estimate based on the post-reform statutory enrolment regime valid from 2028.

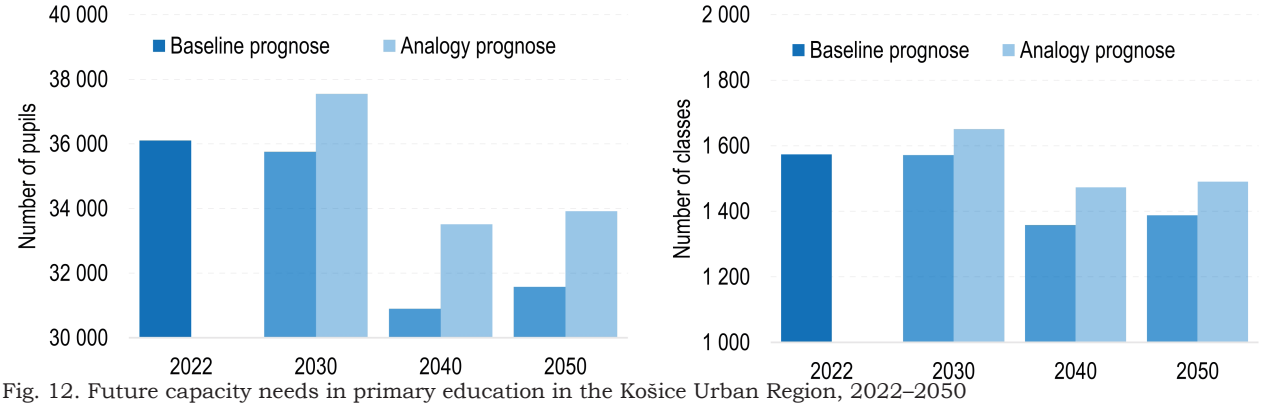


Fig. 12. Future capacity needs in primary education in the Košice Urban Region, 2022–2050

The baseline scenario for the primary-school population indicates a gradual decline in capacity needs, particularly after 2030, reflecting the expected decrease in the number of children aged 6-14. By contrast, the analogy-based scenario anticipates a substantial increase in capacity requirements up to 2030. Although a decline is projected by 2040, it remains less pronounced than in the baseline scenario. By 2050, the projection again suggests a slight rise in demand for school capacities (Fig. 12). Under the assumption of maintaining the average class size in primary education (SCSTI, 2011–2024b), the projected development of the pupil population is directly translated into the expected number of required classes, capturing not only demographic shifts but also the organisational and capacity implications for the school infrastructure.

5 DISCUSSION

The research results confirm the long-term divergent trajectory of population development between the core and hinterland of the Košice region. The demographic dynamics align with patterns observed in the broader urban system of Slovakia, where population polarisation between shrinking urban centres and expanding suburbanisation zones is deepening (Buček & Bleha, 2013; Novotný, 2016; Pregi & Novotný, 2019; Trembošová et al., 2022; Novotný et al., 2024), a trend that mirrors the generally observed redistribution of population from cities to their hinterland (e.g. Bleha & Šprocha, 2013; Ouředníček et al., 2019; Tamás, 2022; Vasárus et al., 2024). The dynamics of this development reflect ongoing suburbanisation, which involves the spatially selective migration of the younger population. This process leads to population redistribution, weakening the reproductive base in Košice and strengthening population dynamics in its hinterland. Spatially differentiated demographic processes are also captured in the baseline scenario of the population forecast, which assumes the continuation of existing trends without a fundamental change in migration or reproductive behaviour. The baseline scenario serves as a stable analytical framework within which the ongoing suburbanisation dynamics and the spatial polarisation of population potential generated by it (e.g. Dická, 2006; Hudec & Tóth, 2014; Novotný, 2015) between the urban core and its hinterland are consistently reflected in medium- and long-term projections.

The existing empirical knowledge base on the spatial structure of the population, age-selective mobility, and economic impulses in the environment of post-socialist urban regions (Štědroň et al., 2012; Stanilov & Sýkora, 2014; Novotný & Kulla, 2014; Pregi & Novotný, 2019; Pavlínek, 2022, 2023) enables a methodologically consistent projection of the investment effect onto population trajectories. The analogy-based scenario is thus not an intuitive extrapolation but a model variant grounded in substantial empirical evidence and knowledge of the regional context (Nestorová Dická, 2011, 2013; Novotný, 2013, 2014; Nestorová & Jacková, 2022; Novotný et al., 2024; Stražovec, 2024), which is crucial for assessing the demographic impacts of large industrial interventions. At the same time, this scenario also respects current demographic limits, especially the sharp decline in birth rates and fertility (Šprocha & Bačík, 2021; Šprocha et al., 2022), which

is reflected not only at the national level but also in the KUR. For this reason, the analogy-based scenario is intentionally conservative: age-specific fertility rates remain unchanged relative to the baseline scenario, and the investment effect is projected solely through migration processes. The size of the future population thus depends primarily on the size and age profile of the reproductive population.

The proposed combination of several complementary modelling approaches captures the multidimensional nature of the population response to a large industrial investment. The inclusion of planned residential capacities derived from spatial planning documents also ensures that the model reflects the real capacity limits of individual municipalities‘ growth and the spatial possibilities of residential expansion. The cohort-component prognose provides a stable baseline scenario for population development, while the analogy-based scenario allows the integration of empirical knowledge from a comparable industrial investment.

The population trajectories of the baseline scenario confirm the region‘s long-term spatial divergence, reflecting the confluence of contrasting population trends, in which the growth of the hinterland only partially offsets the decline in the core. The analogy-based scenario assumes mitigating population losses in the metropolis and strengthening migration flows, without a fundamental change in the long-term trend, which is determined by the region‘s spatial and demographic structures. Spatially differentiated population outlooks are also reflected in the age groups relevant to pre-primary and primary education. However, regional demand for kindergarten capacity is increasing despite only marginal changes in cohort size, primarily due to higher participation in pre-primary education following legislative changes and the growing enrolment of children under three. Projections clearly indicate that the most significant pressure on school capacity is concentrated in the population growth zone, where the analogy-based scenario is reflected in increased demand for educational infrastructure (Sládeková Madajová et al., 2021; Švecová & Tolmáči, 2025). Due to the shrinkage of the school-age population groups, the population projections indicated decreasing demand for educational capacities in Košice as a core of the region. However, increasing commuting may mitigate population decrease in the core and keep the pressure on capacities high. However, the amendment to the Education Act No. 323/2025 Coll. strengthens the system of preferential admission for pupils with permanent or usual residence within a public school district, while continuing to allow parents to choose another primary school with the consent of its director. Thus, although the amendment reinforces the regulatory framework governing public school districts, it does not introduce any obligation for pupils to attend the school in their designated district.

Although the study‘s combined methodological approach provides a broader, contextually anchored view of possible population development trajectories, the results should be interpreted with several limitations in mind. First, the new Building Act No. 25/2025 Coll., introduces an integrated system of building permits through a single procedure. This mechanism can shorten investment and residential development cycles, accelerating the spatial expansion of housing and thereby altering the intensity of migration flows and, subsequently, influencing population dynamics in the region.

Future population developments relevant to educational infrastructure may be significantly modified by legislative interventions that go beyond demographic processes and alter the spatial distribution of demand for school capacity. The new Act No. 323/2025 Coll., fundamentally revises the rules governing compulsory school attendance, strengthens the binding nature of school catchment areas, and introduces the concept of ‘habitual residence’ as a new principle for determining school catchment boundaries. The reform also gradually introduces compulsory pre-primary education from the age of three and adjusts the admission process for children to kindergartens and primary schools. These changes significantly affect the spatial distribution of demand for capacity.

The spatial mobility of pupils and children to Košice for education represents a specific regional factor that can significantly influence the demand for local educational capacities. Commuting from suburban zone to schools in Košice has been intensive for a long time. It largely reflects the daily commuting of parents to work in the city, which leads to disproportions between the “potential” and “actual” school population in the urban core. According to the Population census 2021, about as many as 22% of all children up to 14 years in the Košice-okolie district commuted daily to the schools in Košice (SO SR, 2021). The new City Master Plan (2025) similarly explicitly assumes higher capacity demands for kindergartens and primary schools despite the stagnation or decline in the residential child population. Institutional tightening of school district rules can partially transform local capacity needs.

Another source of uncertainty arises from the scope of home-based education, particularly in pre-primary schooling. For this reason, a conservative 5% reserve was incorporated into the estimation of pre-primary capacity requirements to account for the potential parental preference for home education. As noted by Mazur et al. (2019), parents in Central Europe have shown a long-term, growing interest in home-based education, accompanied by a gradual increase in awareness of homeschooling. This trend is frequently associated with value-based preferences and parental dissatisfaction with institutional education, suggesting that the actual demand may exceed the officially recorded numbers of children educated at home. According to Rochovská and Mazur (2019), home education may continue to expand due to curricular liberalisation, increased parental awareness, and digitalisation. Švecová and Tolmáči (2025) highlight the persistent mismatch between the demand for pre-primary education and the available institutional capacity. This capacity deficit places additional pressure on alternative forms of childcare, including informal, family-based, and home-based early education. In such circumstances, regional shortages in institutional care may lead to a relatively higher share of home-based care than national averages suggest. At the same time, Kostelecká et al. (2023) point out that the segment of parents considering home education is considerably larger than the segment that ultimately adopts it.

Transforming transport infrastructure can also be a source of uncertainty, potentially fundamentally influencing future spatial patterns of mobility and residential behaviour. The commissioning of the Košice southeast bypass in the second half of 2025 has already led to a measurable reduction in commuting times from the eastern part of the metropolitan region. Transport infrastructure interventions can expand

the areas of suburbanization, increase the spatial mobility of reproductively active cohorts, and thus induce population growth in localities that fall into zone 2 in the current model typology, but may acquire the character of an expanding suburban hinterland in the medium term.

An additional limitation concerns the sensitivity of model outputs to selected parameter assumptions. Although the research incorporates several quality elements, including testing alternative distance thresholds (10, 15, and 20 km), comparing baseline and analogy-based demographic scenarios, and evaluating alternative enrolment regimes for pre-primary demand, a formal, comprehensive sensitivity analysis across all model parameters was not carried out. The projected demand for educational capacity may therefore vary depending on the assumed intensity of the transferred investment-related migration effect, the occupancy assumptions applied to planned housing development, the final spatial delimitation of the investment-affected zone, and the future evolution of enrolment behaviour in pre-primary education. Alternative parameter settings could thus produce lower or higher scenarios of future demand in the KUR. The present results should therefore be interpreted primarily as a scenario-based strategic planning framework indicating the likely direction and spatial differentiation of change.

Municipality-level observed demographic trends were used as analytical inputs, together with the analogy-based investment effect and residential development capacity, in order to construct the municipality typology and the subsequent three-zone framework. The actual cohort-component population projections and the modelling of educational-capacity demand were then carried out at the analytical-zone level. This choice represents a deliberate compromise between territorial detail and forecast robustness. While municipality-level information was essential for identifying spatial differentiation within the region, using aggregated zones reduced the instability associated with very small population units and avoided an overly precise interpretation of educational-capacity demand. At the same time, this aggregation may conceal important within-zone heterogeneity, and the results should therefore be interpreted primarily as a strategic regional planning framework rather than as a direct operational basis for municipality-level or school-district decisions.

6 CONCLUSION

The long-term demographic trajectory of the KUR, reflected in the results of the reference population forecast, points to a deepening divergence between the population-shrinking urban core and the expanding suburban hinterland. The expected industrial investment has the potential to disrupt these stable trajectories partially: in the core, it can help slow population decline, and in suburban zones, it can further strengthen growth. Different population responses are also reflected in the expected demand for pre-primary and primary educational infrastructure, which, in the analogy-based scenario, shows significantly higher capacity requirements, especially in the region‘s dynamically expanding hinterland.

However, it should be emphasised that the ongoing implementation of reforms in the Slovak education system may fundamentally affect the modelling of future requirements for educational infrastructure. For this reason, the projected school capacities were not differentiated at the level of individual zones, as intensive commuting from suburban zones to the city persists, and the new rules may affect the allocation of students between schools and thus the spatial demand. The resulting models therefore operate within an aggregated regional framework, which reduces the sensitivity of the outlooks and, at the same time, provides a realistic estimate of capacity needs in a dynamically changing environment influenced by investments.

From a policy perspective, the results primarily highlight the need for differentiated and adaptive educational planning across the KUR. Given the scenario-based nature of the model and the sensitivity of its outputs to selected assumptions, the findings should be understood as indicating broad spatial tendencies in future demand rather than as a direct prescription for specific municipal-level investment decisions. Rather, they indicate that in the suburban growth zone, local authorities should monitor capacity pressures and assess whether the expansion of existing infrastructure will be sufficient or whether new facilities may eventually be needed; in the metropolitan core, projected demographic decline should not automatically be translated into school closure, as actual enrolment may continue to be influenced by commuting from the hinterland; and in the more peripheral parts of the region, selective adjustment of the existing network may be more appropriate than extensive new construction.

For the strategic planning of educational infrastructure, this research also provides a relevant basis for research on urban overheating processes. The Košice urban region is among the most climatically exposed areas of Slovakia. (cf. Hofierka & Fedor, 2025; Fedor & Hofierka, 2025). Given the increasing frequency of temperature extremes that also affect school days (Pecho et al., 2025), the need for strategic planning of educational infrastructure is increasingly urgent. At the same time, the increase in children‘s school commuting into the metropolitan core of the KUR increases the concentration of vulnerable population groups in microclimatically sensitive urban zones. Therefore, integrating adaptation and mitigation measures into the location, development and modernisation of school infrastructure is desirable to ensure its long-term functionality and resilience to climate change.

Ultimately, integrating evidence-based demographic modelling with territorial and infrastructural characteristics provides decision-makers with a solid evidence base, enabling more resilient, equitable and strategically coordinated development of the KUR, while also presenting a methodological framework that can be applied to other regions with different population dynamics.

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