



A sacrifice for the greater good? On the main drivers of excessive land take and land use change in Hungary

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ABSTRACT

Despite continuous population decline or stagnation, many Central and Eastern European cities experience urban sprawl and expansion, accompanied by excessive land take and land use change. This paper investigates recent trends in land take and land use change in Hungarian cities, aiming to identify the drivers of these processes. The study utilizes the Urban Atlas (UA) databases from 2006 and 2018 to analyze land use change in selected Hungarian cities, employing QGIS software to compile the database and MS Excel to conduct the statistical analysis. A linear trajectory model is employed to project land use change by 2026, based on 2006–2018 UA data. Additionally, via the in-depth analysis of Debrecen, the study highlights the recent acceleration of land use change to compare the projected trend with the forecasted one. Local climate strategies focus on addressing environmental concerns, including changes in land use at the city level. Therefore, this study reviews the relevant documents associated with each city to assess its commitment to reducing land take. The results indicate that despite its declining population, Hungary has seen a significant expansion in artificial surfaces, primarily due to industrialization and population policies introduced by the central government, which is likely to continue in the coming years. Unfortunately, local climate strategies have been insufficient in preventing cities from experiencing urban sprawl and expansion and preserving local ecosystem services. This underscores the inability of municipalities to defend local interests against central government directives. The findings of this study indicate that the current central policies are the main drivers of land take and urban sprawl and expansion. Prioritizing the compact city model and brownfield developments could effectively mitigate these issues. Finally, the paper advocates that complete jurisdiction over land use decisions be restored to local governments, enabling them to reject investments that may jeopardize local environmental goals.

1. Introduction

By approximately 2007, the world's urban and rural populations had become equal (Ritchie and Roser, 2019). Subsequently, the urban population has rapidly increased, primarily in developing countries (United Nations, 2019). Worldwide, urbanization is accompanied by the dramatic expansion of built-up areas in cities (Bai et al., 2012; Batisani and Yarnal, 2009; Decoville and Feltgen, 2023; Luo et al., 2018). Urban sprawl, characterized by the physical expansion of urban areas, can range from scattered developments or even isolated buildings to the complete coverage of the area with built structures (European

Environment Agency, 2006; Jaeger et al., 2010). One adverse effect of this process is the transformation of agricultural and natural land into residential and industrial land as well as other artificial surfaces, such as transportation infrastructure (see, for example, Jiang et al., 2022; Li et al., 2022; Parveen et al., 2023; Seto et al., 2012). In addition, many studies have found that urban growth is associated with food risk (Abu Hatab et al., 2019; Feng et al., 2021; Szabo, 2016), global warming (Guo et al., 2022; Helbling and Meierrieks, 2023; Khanh et al., 2023), and various health problems (Kuddus et al., 2020; Leon, 2008).

Although the European Union (EU) is highly urbanized, with an average urbanization rate of around 72 % (Clark et al., 2018), and the

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EU's population has been stagnant for some time, with just 1.4 % growth in the last decade, land take remains a serious issue (Decoville and Feltgen, 2023). According to a report by the European Environment Agency (EEA), since the 1950s, the total surface area of cities in the EU has increased by 78 % while the population has grown by just 33 % (European Environment Agency, 2006). In addition, the net land take during 2012–2018 reached approximately 3000 square kilometers in functional urban areas (FUAs) in the EU and the United Kingdom (UK), resulting in a 2.6 % increase in artificial surfaces (European Environment Agency 2022). Simultaneously, these regions lost approximately 1700 square kilometers of arable land and 1300 square kilometers of pasture. Other studies have demonstrated that the most significant increases in artificial surfaces have been related to roads and the urban fabric (European Environment Agency, 2019; Schiavina et al., 2022). In 2021, the European Commission (EC) issued the “EU soil strategy for 2030,” intending to protect and restore soil and ensure its sustainable use (European Commission 2021). In this communication, the EC proposed that Member States set medium-term targets to significantly reduce land take by 2030 and long-term targets to achieve “no net land take” by 2050 (Schiavina et al., 2022).

In the Central and Eastern European (CEE) region, including the Czech Republic, Hungary, Poland, and Slovakia, artificial surfaces are rapidly expanding despite declining populations (Cegielska et al., 2018; Kovács et al., 2019; Kurowska et al., 2020; Rózycka-Czas et al., 2021; Sandu, 2023a; Solarski and Krzysztofik, 2021). For example, a study by Iváncsics and Filepné Kovács (2021) reported accelerating growth in artificial surfaces in mid-sized Hungarian cities between 1990 and 2018, primarily driven by suburbanization and related road network developments. In post-socialist CEE countries, agricultural land abandonment emerged as a significant process in the turbulent transitional and economic restructuring period between 1990 and 2000 (Alcantara et al., 2013; Kuemmerle et al., 2009; Munteanu et al., 2014). In the following years, a considerable percentage of abandoned agricultural land has been used for other purposes, such as reforestation, afforestation, and the extension of the urban fabric (Calka et al., 2022; Nalej, 2016; Wnęk et al., 2021). A recent study by Filepné Kovács et al. (2024) found that 88 %–98 % of the new artificial surfaces in urban areas in the CEE region were created by the conversion of agricultural land. In addition, according to a report by the EEA, Poland and Hungary are among the top three countries in the EU that experienced the most significant loss of arable land and permanent crops between 2000 and 2018 (i.e., 6811 ha/year and 5855 ha/year, respectively) (European Environment Agency 2020).

Although there are signs that urban sprawl has recently started to slow (Rózycka-Czas et al., 2021; Filepné Kovács et al., 2024), along with improvements in the legislative protection of land and soil and heightened environmental awareness (Hudecová and Kyseř, 2023; Stankovics et al., 2020), the excessive land take characterizing urban areas in CEE countries has only slightly eased. For example, some cities in Poland and Hungary are still experiencing a substantial increase in built-up areas (Cegielska et al., 2018 Sandu, 2023b; Werner et al., 2022). According to Sandu (2023b), the expansion in built-up areas may be due to several possible factors, including economic development, government policies, and institutional quality. Certainly, there may be overlaps and variations in the main drivers of land use changes across countries. This paper selects Hungary as a case study to illustrate the policies and national strategies driving the most recent land-use change trends in the region.

Hungary, one of the newest EU Member States, has experienced a steady and significant population decline for decades. The country's population reached 10.37 million in 1990 but by 2023 had dropped to approximately 9.60 million due to accelerated natural decrease and emigration. Accordingly, most settlements, from villages to large regional centers, have seen population declines. For example, Budapest, Hungary's capital, has experienced a population decline of 310,000 individuals over the course of three decades (Csomós et al., 2023). Since the early 2010s, the government has implemented various measures

aimed at reversing this demographic trend, which has simultaneously resulted in a significant decrease in agricultural land, as well as natural and seminatural land within urban areas (see, for example, Iváncsics and Filepné Kovács, 2021; Filepné Kovács et al., 2024). Government policies such as the (re)industrialization of the nation have only recently affected land take and land use change. Consequently, the magnitude of this effect has not yet been investigated and evaluated. However, we assume that the “business as usual” trend in terms of land take may differ significantly from the trend accelerated by government policies.

This paper aims to explore how land use has changed in major cities, identify which land-use categories have been the most affected by the changes, and project future land-use trends based on UA data. Then, we focus our attention on Debrecen, a prominent Hungarian city currently experiencing robust urban and economic developments as well as massive expansion of built-up areas. Using Debrecen as a case study, we will highlight the dramatic increase in land take compared to a “business as usual” projection. In addition, we will review the climate strategies of selected cities, as they are dedicated to demonstrating the overall commitment of local governments to address environmental issues, including land-use changes. In the Discussion section, we will delineate the government policies that have driven significant land-use changes in cities in Hungary. Finally, we will draw conclusions.

2. Data and methods

2.1. Study area

For the analysis of land-use change trends, we selected Budapest, the capital of Hungary, and six major cities in the countryside (i.e., Debrecen, Győr, Kecskemét, Miskolc, Pécs, and Szeged) that are often referred to as regional centers (Csomós, 2012; Rechnitzer et al., 2019) (Fig. 1). According to the Hungarian Central Statistical Office's census data, in 2022, the population of Budapest was 1,685,342 and the combined population of the six major cities was 881,237. The selected cities comprised 26.7 % of the country's population in 2022. However, as shown in Table 1, almost all the identified cities have experienced a steady and significant population decline over the last three decades. For example, Miskolc has lost 33 % of its population and Pécs has witnessed a 22 % population decline since 1990.

For the case study, we chose Debrecen, Hungary's second most populous city. Recently, Debrecen has witnessed significant economic growth, propelled by the influx of manufacturing companies building factories in the city's existing and newly designated industrial areas. Residential areas have also undergone significant expansion. Thus, there has been a substantial overall increase in land take over the past decade. The expansion of artificial surfaces has been associated with increased urban heat island effect in Debrecen (Bottyán et al., 2005; László et al., 2015) and the other selected cities (Dian et al., 2020; Unger, 2020), exacerbating the effects of climate change. Therefore, it is essential to assess how urban land use and management challenges are reflected in local climate strategies.

2.2. Land cover and land use data

We employed UA 2006 and 2018 databases to detect changes in land use. UA databases are updated every six years and are freely available from the Copernicus Land Monitoring Service (CLMS) website for research purposes. We analyzed the databases using the QGIS software. As we wished to limit our analysis to the central cities, we first extracted their areas from FUAs by utilizing the urban core layer provided in the UA 2018 database. Next, we recalculated the area of the polygons in the newly created database. We also calculated a transition matrix by clipping the 2006 and 2018 databases within GIS software, then recalculated the area of the resulting polygons. Subsequently, we exported the data to MS Excel to perform descriptive statistical analysis, creating descriptive tables and a cross-table for the transition matrix. Finally, a

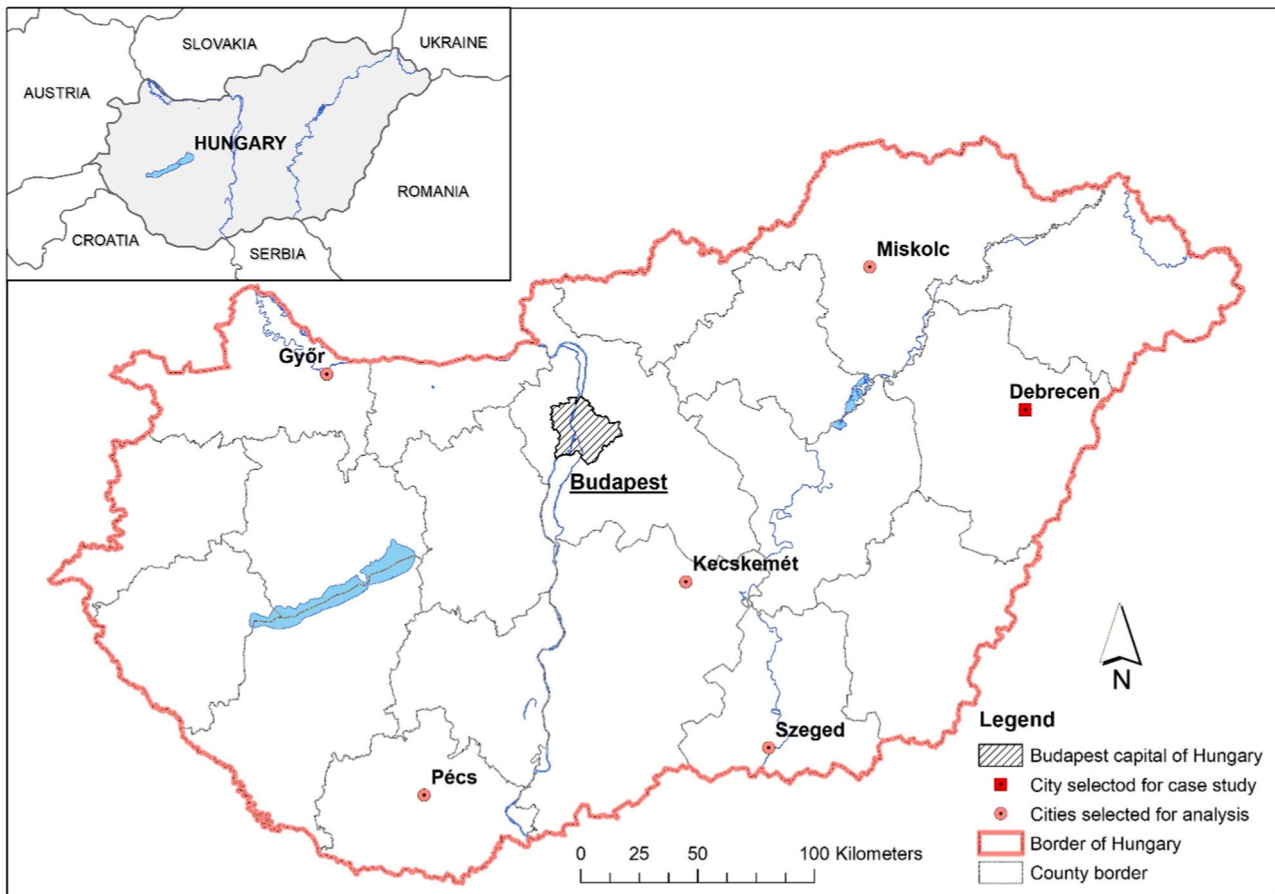


Fig. 1. The geographical locations of selected cities.

Table 1

The populations of the selected cities in 1990, 2006, 2018, and 2022.

	Population (1990)	Population (2006)	Population (2018)	Population (2022)
Budapest	2016,774	1698,106	1749,734	1685,342
Debrecen	212,235	204,083	202,214	199,858
Győr	129,338	128,279	130,094	127,599
Kecskemét	102,516	108,835	110,638	108,120
Miskolc	196,442	174,416	155,650	147,533
Pécs	170,039	156,116	144,188	139,330
Szeged	175,301	163,259	161,122	158,797

Source: Hungarian Statistical Office, Detailed Gazetteer of Hungary (http://www.ksh.hu/apps/hntr.main?p_lang=EN)

land use projection was calculated for Debrecen.

The mapping of land use changes from 2006 to 2018 was conducted using the UA Change 2006–2012 and 2012–2018 databases provided by the CLMS. A Sankey graph (Fig. 2) was created at Sankeymatic.com to visualize the transition matrix data between 2006 and 2018. The industrial areas currently under development and slated for development in the coming years were determined based on the local building codes and zoning plan for the city of Debrecen. For the mapping, we used ArcGIS 10.8.

2.3. Land use change projection and forecast

For each city, we make land use change projections by 2026 assuming changes follow a linear trajectory aligning with a business-as-usual projection (see, for example, Daba and You, 2022; Zhao et al., 2020). In this case, each land use category in a city will experience the

same annual change between 2018 and 2026, as it did between 2006 and 2018 (see Formulas 1 and 2):

$$average_annual_LUC_{i,2006-2018} = \frac{\sum PA_{i,2018} - \sum PA_{i,2006}}{12} \quad (1)$$

$$projected_LUC_{i,2026} = annualLUC_{i,2006-2018} * 8 \quad (2)$$

where, i is a land use category as defined by the UA 2006, and PA is the area of a particular polygon mapped by UA.

In the case of Debrecen, we made a further land use change forecast based on recently completed, ongoing, and announced industrial developments. To conduct this analysis, we first gathered data on developments implemented in Debrecen from the website of the Hungarian Investment Promotion Agency (HIPA) (<https://hipa.hu/>), an organization created to help investors obtain information on Hungary's economic landscape. Using this data, we identified the geographic location of industrial and other developments in the city. Most companies had publicly disclosed information on development sites, plot sizes, factory areas, investment costs, and employee numbers on their websites, but some kept this information hidden. However, using Google Earth's distance measure tool, we acquired the essential area data for each implemented development. For forthcoming developments, we examined Debrecen's local building codes and zoning plan (<https://www.debrecen.hu/hu/debreceni/kozerdeku-adatok/uj-telepulesren-dezesi-eszkozok>), allowing us to map the sizes of development land acquired by investors and the maximum built-up ratio permitted for the plots. This data enabled us to formulate and compare various future land use change outcomes for Debrecen, thereby demonstrating how significantly the current government policies will impact land use.

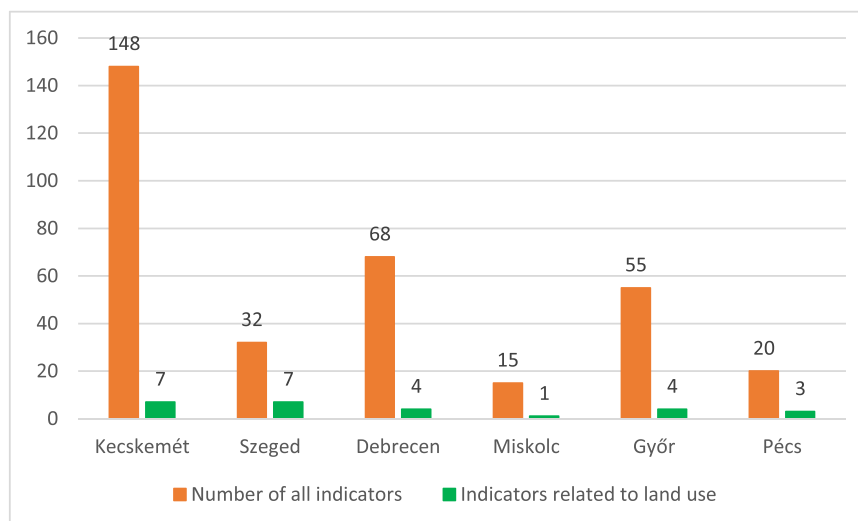


Fig. 2. The number of all and land use-related indicators in local climate strategies.

2.4. Local climate strategies

To broaden the analytical scope of the research, in addition to quantitative data analysis, selected cities' local climate strategies were also reviewed. Combining different methods to study specialized policy areas may ensure the soundness of the results (Bardach and Patashnik, 2015). Local climate strategies were chosen for further scrutiny because they are available for all cities and their time frames are roughly similar. The reason for this is that, at the time of the analysis, the local climate strategies were the only "urban strategies" available containing references to preventing land take and land use change. However, it should be noted that many cities are still preparing their sustainable urban development strategies (SUDSs), which aim to coordinate environmental goals with urban development goals. If once completed, the SUDSs are expected to be effective tools for cities to prevent land take.

Therefore, the main aim of the analysis of local climate strategies is to explore the link between the commitments and intentions of local governments regarding land use and the real-world processes on the ground. In line with the policy-purpose approach (Cardno, 2018), first, we carefully read the strategies and identified keywords or phrases referring to the strategies' purposes, main objectives, and focus areas. Then all terms related to land use were defined as well as their occurrence frequencies and locations in the text. Manually reviewing the individual strategies enabled us to obtain an overall picture of the city-specific measures and targets, how ambitious the cities' plans are, and whether land use occupies a key position among the strategies' goals. The local climate strategies are freely available via the local governments' websites.

3. Results

3.1. Land use change in Budapest and six major cities from 2006 to 2018

First, we explored the differences between land use changes in Budapest and major cities located in the countryside. Budapest is the largest settlement in Hungary, with a total area of 52,527 ha. According to UA land use data for 2018, 37.13 % (19,505.24 ha) of Budapest's area was occupied by the urban fabric, 23.48 % (12,332.49 ha) by industrial, commercial, and transportation units, and 1.51 % (793.23 ha) by mine, dump, and construction sites, and unused areas. Artificial surfaces (not including artificial nonagricultural vegetated areas like green urban areas and sports and leisure facilities) accounted for 62.12 % (32,630.96 ha) of the city's total area. In contrast, agricultural areas, natural and seminatural areas (e.g., urban forests), and water areas

occupied 29.59 % (19,895.86 ha) of the total area.

Table 2 shows that the continuous urban fabric increased by 78.16 ha (+1.03 %) between 2006 and 2018, and the discontinuous low-density and very-low-density urban fabric combined also increased by a total of 356.58 ha (+53.84 %). However, the discontinuous dense urban fabric and discontinuous medium-density urban fabric land use categories experienced a total decrease of 278.05 ha in area (-2.42 %). These changes suggest that Budapest's inhabited area is affected by two opposite urbanization trends, namely urban sprawl and densification. Urban sprawl is perhaps the most visible contemporary process in Budapest. For example, the discontinuous low-density urban fabric grew by 343.93 ha (+152.57 %) between 2006 and 2018, making it the second largest increase of artificial surfaces after land for roads. Furthermore, the discontinuous very-low-density urban fabric grew by 198.81 % (12.65 ha), which was the most dynamic growth among all land use categories.

The area of industrial and commercial units grew by 162.65 ha (+2.46 %) over 12 years, equaling the growth of the area of industrial and commercial units of Debrecen (168 ha), a city with an almost ninefold smaller population than Budapest.

Between 2006 and 2018, agricultural and seminatural areas and wetlands experienced the most significant decrease in area (518.94 ha combined). Furthermore, the forest area in Budapest grew by 112.47 ha (+2.21 %), whereas the city lost green urban areas of 4.45 ha (-0.15 %). The Budapest Climate Strategy and Sustainable Energy and Climate Action Plan (BFVT Ltd., 2021) highlights afforestation as a primary objective to increase carbon absorption capacity. Efforts invested in achieving this goal have reportedly led to the expansion of forest areas.

Overall, Budapest's artificial surfaces (not including green urban areas and sports and leisure facilities) experienced a growth of 379.84 ha, accounting for only 0.72 % of the city's total area.

Table 3 shows that artificial surfaces accounted for 22.98 % (37,601.95 ha) of the combined area of the six major cities in 2018, meaning that artificial surfaces covered an area 2.6 times smaller than in Budapest. In contrast, agricultural and seminatural areas and wetlands combined, and forests occupied areas that were 8.3 and 8.5 times larger, respectively, than in the capital.

In the six major cities, the total area of the discontinuous very-low-density urban fabric grew by 1130.59 % between 2006 and 2018, adding 267.39 ha to the existing urban fabric. This suggests that urban sprawl is a more dramatic process in large cities in the countryside than in Budapest. As Table 3 demonstrates, the continuous urban fabric grew by only 0.45 % (24.39 ha) within 12 years, reaffirming that major cities

Table 2
Land use changes in Budapest from 2006 to 2018, based on Urban Atlas data.

UA Code 2006/2018	Land use category	Total area, 2006 (ha)	Share in the cites' total area (%)	Total area, 2018 (ha)	Share in the cites' total area (%)	Change from 2006 to 2018 (ha)	Change from 2006 to 2018 (%)
11100	Continuous urban fabric (S.L.: > 80 %)	7604.88	14.48	7683.04	14.63	78.16	1.03
11210	Discontinuous dense urban fabric (S.L.: 50 %–80 %)	9973.19	18.99	9906.29	18.86	−66.90	−0.67
11220	Discontinuous medium-density urban fabric (S.L.: 30 %–50 %)	1511.15	2.88	1299.99	2.47	−211.15	−13.97
11230	Discontinuous low-density urban fabric (S.L.: 10 %–30 %)	225.42	0.43	569.36	1.08	343.93	152.57
11240	Discontinuous very-low-density urban fabric (S.L.: < 10 %)	6.36	0.01	19.01	0.04	12.65	198.81
11300	Isolated structures	26.74	0.05	27.55	0.05	0.81	3.04
12100	Industrial, commercial, public, military, and private units	6608.53	12.58	6771.18	12.89	162.65	2.46
122	Road and rail network and associated land	5195.77	9.89	5561.31	10.59	365.54	7.04
13100	Mineral extraction and dump sites	231.99	0.44	317.58	0.60	85.59	36.89
13300	Construction sites	439.12	0.84	82.83	0.16	−356.28	−81.14
13400	Land without current use	427.98	0.81	392.82	0.75	−35.16	−8.21
14100	Green urban areas	2888.12	5.50	2883.67	5.49	−4.45	−0.15
14200	Sports and leisure facilities	1236.79	2.35	1277.94	2.43	41.15	3.33
20000/2*	Agricultural, seminatural areas, wetlands	9521.46	18.13	9002.52	17.14	−518.94	−5.45
30000/ 31000	Forests	5099.33	9.71	5211.80	9.92	112.47	2.21
50000	Water	1529.92	2.91	1519.93	2.89	−9.99	−0.65
	TOTAL	52,526.75	100.00	52,526.82	100.00	0.07	0.01

* For 2018, the land use category “Agricultural areas” (UA Code 2018: 2) includes the categories “Herbaceous vegetation associations (natural grassland, moors...)” (UA Code 2018: 32000) and “Wetlands” (UA Code 2018: 40000).

Table 3
Land use changes in major cities from 2006 to 2018, based on Urban Atlas data.

UA Code 2006/2018	Land use category	Total area, 2006 (ha)	Share in the cites' total area (%)	Total area, 2018 (ha)	Share in the cites' total area (%)	Change from 2006 to 2018 (ha)	Change from 2006 to 2018 (%)
11100	Continuous urban fabric (S.L.: > 80 %)	5368.87	3.28	5393.25	3.29	24.39	0.45
11210	Discontinuous dense urban fabric (S.L.: 50 %–80 %)	9659.51	5.90	9808.83	5.99	149.32	1.55
11220	Discontinuous medium-density urban fabric (S.L.: 30 %–50 %)	3087.40	1.88	3284.42	2.01	197.02	6.38
11230	Discontinuous low-density urban fabric (S.L.: 10 %–30 %)	653.34	0.40	846.94	0.52	193.60	29.63
11240	Discontinuous very-low-density urban fabric (S.L.: < 10 %)	23.65	0.01	291.04	0.18	267.39	1130.59
11300	Isolated structures	1009.11	0.62	1073.93	0.66	64.82	6.42
12100	Industrial, commercial, public, military, and private units	7728.92	4.72	8919.70	5.45	1190.79	15.41
122	Road and rail network and associated land	5889.98	3.60	6200.93	3.79	310.95	5.28
13100	Mineral extraction and dump sites	711.38	0.43	824.10	0.50	112.72	15.85
13300	Construction sites	269.16	0.16	304.25	0.19	35.09	13.04
13400	Land without current use	708.67	0.43	654.56	0.40	−54.10	−7.63
14100	Green urban areas	2233.58	1.36	2235.31	1.36	1.73	0.08
14200	Sports and leisure facilities	1547.37	0.94	1588.92	0.97	41.55	2.68
20000/2*	Agricultural, seminatural areas, wetlands	77,775.02	47.48	75,145.31	45.88	−2629.71	−3.38
30000/ 31000	Forests	44,026.28	26.88	44,121.52	26.94	95.23	0.22
50000	Water	3107.30	1.90	3106.50	1.90	−0.79	−0.03
	TOTAL	163,799.54	100.00	163,799.51	100.00	0.00	0.00

* For 2018, the land-use category “Agricultural areas” (UA Code 2018: 2) includes the categories “Herbaceous vegetation associations (natural grassland, moors...)” (UA Code 2018: 32000) and “Wetlands” (UA Code 2018: 40000).

across the country were characterized by urban sprawl rather than densification.

Given the land use categories most affected by changes, we can conclude that agricultural and seminatural areas and wetlands experienced a dramatic loss of 2629.71 ha (−3.38 %) between 2006 and 2018.

In contrast, the combined area of industrial and commercial units produced a robust growth of 1190.79 ha (+15.41 %). For example, between 2006 and 2018, the six major cities added 7.3 times more areas to their industrial and commercial areas than did Budapest, a city with almost twice as many residents.

3.2. Projected land use changes by 2026

After exploring changes in land use between 2006 and 2018 in Budapest and six major cities in the countryside, we set a projection of land use changes up to 2026 based on UA data for 2006 and 2018. In this case, we assumed land use changes in selected cities would follow a linear trajectory.

As seen in Table 4, the discontinuous low-density urban fabric and the discontinuous very-low-density urban fabric will multiply in Budapest and the six major cities, occupying an additional 237.72 and 307.33 ha (+150 %), respectively. That is, despite experiencing population decline, urban sprawl will significantly affect Hungarian cities' spatial development. Furthermore, cities' industrial and commercial areas will experience dramatic growth, whereas agricultural areas will face a massive loss. Considering land use changes between 2006 and 2018, the six major cities will add approximately the same size of industrial and commercial areas by 2026 as the total area expansion of Budapest within the same period (i.e., 793.86 vs. 801.97 ha).

In addition, it can be assumed that the densification strategy applied in Budapest will result in the growth of the continuous urban fabric and, as an opposite trend, a slight decrease in green urban areas. Because densification will remain a relatively marginal process in cities in the countryside, urban green areas will probably not be used for development purposes.

The excessive expansion of artificial surfaces cannot be maintained long-term, and it is expected that sooner or later, measures will be taken to halt the degradation of agricultural and seminatural areas and wetlands.

3.3. Local climate strategies as tools to prevent land take

Hungarian cities' local climate strategies have been prepared based on a central guide. Because of this, they comprehensively approach the prevention of climate change's adverse effects through adaptation, mitigation, and awareness raising. On the other hand, the quality and

content of documents in terms of local specificity differ significantly from city to city.

In the strategies' situation assessment chapters, land use and land use change did not receive special attention. These two keywords were sporadically mentioned in the examined strategies compared to other sectors, such as transportation or renewable energies and energy efficiency (Table 5). In many cases, the examination of plan harmonization compliance—a chapter dedicated to investigating the fit of the local climate strategy to national strategies—contained these based on our analysis.

An exception is Kecskemét, where the increasing costs of city services and utilities are mentioned as an adverse effect of urban sprawl and expansion. In addition, the strategy points out the development of the compact city as a goal. In contrast, Miskolc's local climate strategy considers arable land a usable resource, providing space for further investments, such as projects related to adaptation objectives.

The increase of green urban areas and afforestation are always included among the mitigation measures cities plan to implement. However, based on the mandatory carbon balance calculations, the local climate strategies also reveal that carbon absorption is only a fraction of the emissions in all cities. Therefore, it appears too ambitious to achieve carbon neutrality in cities by 2050—a European and Hungarian policy goal—by solely planting forests and increasing greenery. Perhaps that is why cities defined a low number of indicator-level commitments regarding land use, for example, regarding green space developments and afforestation (Fig. 2). The only exception is Szeged, where the local government indicated it would establish 20,000 square meters of new green space by 2030 to help preserve urban biodiversity.

After analyzing cities' local climate strategies, we can conclude that local governments do not consider land take and land use change as significant concerns that could jeopardize their climate goals. Consequently, they do not perceive the need for corresponding measures. For example, cities primarily intend to electrify urban transportation, increase the share of renewable energy sources in consumption, and improve the energy efficiency of public buildings to meet climate

Table 4

Projected land use changes for selected cities by 2026, based on Urban Atlas data from 2006 and 2018.

	Projected change, 2018–2026 (ha)	Cumulative change, 2006–2026 (ha)	Cumulative change, 2006–2026 (%)	Projected change, 2018–2026 (ha)	Cumulative change, 2006–2026 (ha)	Cumulative change, 2006–2026 (%)
	Budapest			six major cities combined		
Continuous urban fabric (S.L.: > 80 %)	52.11	130.27	2.74	16.26	40.65	0.76
Discontinuous dense urban fabric (S.L.: 50 % - 80 %)	-44.60	-111.51	-1.79	99.55	248.87	2.58
Discontinuous medium-density urban fabric (S.L.: 30 % - 50 %)	-140.77	-351.92	-37.26	131.35	328.37	10.64
Discontinuous low-density urban fabric (S.L.: 10 % - 30 %)	229.29	573.22	406.86	129.07	322.67	49.39
Discontinuous very-low-density urban fabric (S.L.: < 10 %)	8.43	21.08	530.16	178.26	445.65	1884.32
Isolated structures	0.54	1.36	8.11	43.21	108.04	10.71
Industrial, commercial, public, military, and private units	108.43	271.08	6.56	793.86	1984.65	25.68
Road and rail network and associated land	243.70	609.24	18.76	207.30	518.25	8.80
Mineral extraction and dump sites	57.06	142.65	98.38	75.15	187.87	26.41
Construction sites	-237.52	-593.80	-216.36	23.39	58.48	21.73
Land without current use	-23.44	-58.59	-21.90	-36.07	-90.17	-12.72
Green urban areas	-2.97	-7.42	-0.41	1.15	2.88	0.13
Sports and leisure facilities	27.43	68.58	8.87	27.70	69.24	4.47
Agricultural, seminatural areas, wetlands	-345.96	-864.90	-14.53	-1753.14	-4382.84	-5.64
Forests	74.98	187.45	5.88	63.49	158.72	0.36
Water	-6.66	-16.65	-1.74	-0.53	-1.32	-0.04

Table 5

The result of keyword analysis of local climate strategies.

	Number of keywords by topics					
	Land use	Land use change	Transport	Public transport	Renewable energies	Energy efficiency
Kecskemét	53	0	408	91	73	100
Pécs	15	0	182	33	158	82
Szeged	7	3	76	16	27	42
Debrecen	4	0	238	42	41	36
Győr	3	0	144	24	49	73
Miskolc	1	0	148	21	46	49
Total mentions	83	3	1196	227	394	382

targets. As the latter developments are eligible for funding from the EU, the local climate strategies may be perceived more as tools to assist local governments in accessing EU funding rather than as effective guidelines for cities on achieving climate neutrality.

3.4. Examining Debrecen as a case study to map different land use change trajectories

After projecting land-use changes by 2026 based on a linear trajectory, we focus on one of the six major cities, Debrecen, to examine which land-use categories will be most affected by these changes if the city's ongoing and planned developments are completed. With this, we aim to illustrate the disparities between the magnitudes of the projected and observed land use changes.

Fig. 3 depicts a transition matrix of UA land use and land cover categories for Debrecen. Data show that between 2006 and 2018, primarily agricultural land and wetlands were converted into urban fabric and industrial areas and roads, resulting in a loss of 556.5 ha of agricultural land.

According to the land use change projection based on a linear

trajectory projection (see the previous section), Debrecen is anticipated to lose an additional 248.6 ha of agricultural land between 2018 and 2026. This indicates that the total loss of agricultural land in the 2006–2026 period could reach 805.1 ha. However, in recent years, the government has designated Debrecen as a major industrial hub of Eastern Hungary. In line with this vision, it has encouraged and supported foreign companies in choosing the city for their industrial investments.

Table 6 portrays a comprehensive picture of industrial investments whose impacts on land-use change have emerged since the publication of UA 2018. Some factories have already started operations (e.g., ThyssenKrupp and Krones), while most are under construction (e.g., BMW, CATL, and SEMCORP). Based on data regarding the plot sizes claimed by investors, the factories will need a cumulative area of 869.5 ha. According to Google Earth images and the city's zoning plan, we can conclude that almost all industrial units have been or will be built in agricultural and seminatural areas. Nevertheless, this does not imply that the city will lose a vegetated area totaling 869.5 ha. This is because, according to local building codes, a specific ratio of the plots must be covered by greenery. For example, the BMW Group is allowed to

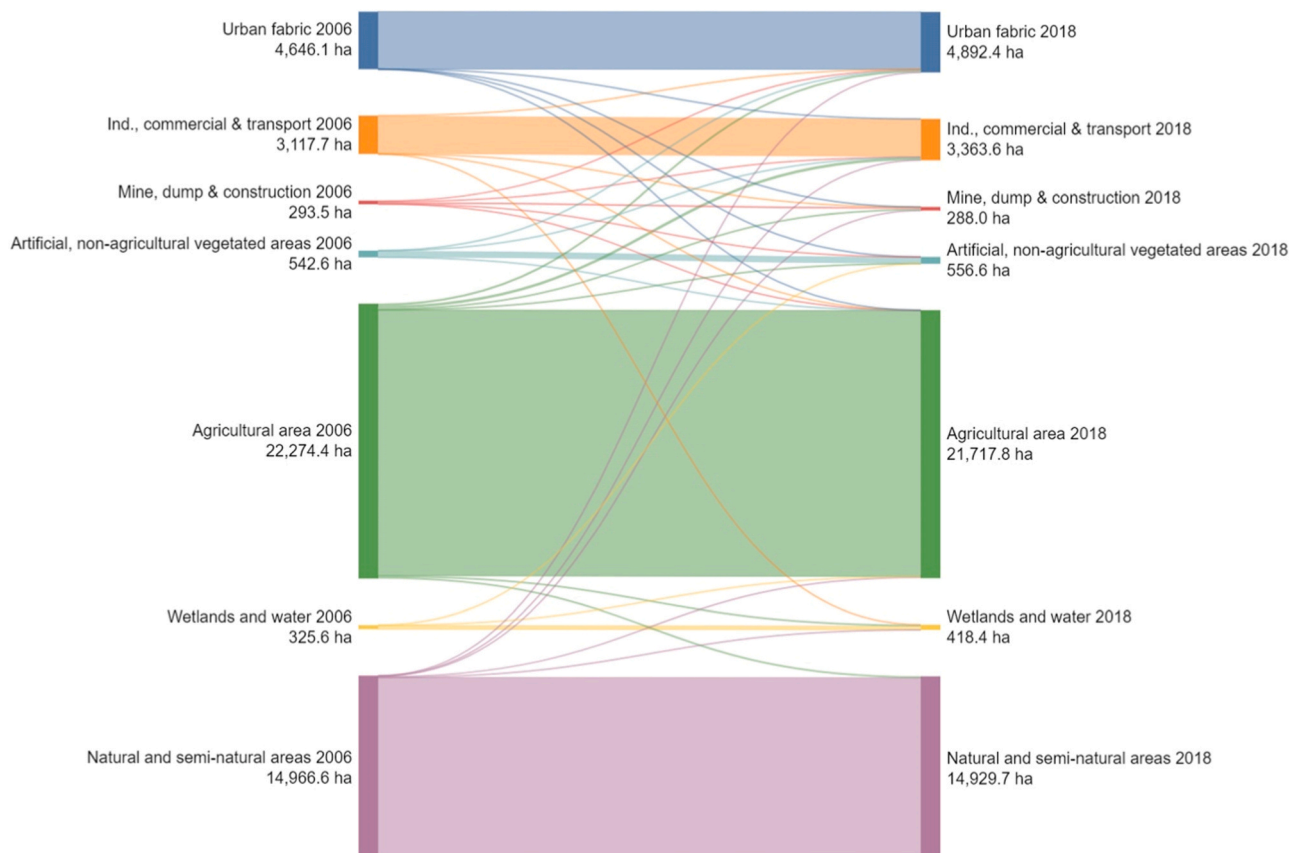


Fig. 3. Transition matrix of UA land use and land cover categories for Debrecen between 2006 and 2018.

Table 6
Summary description of recent and announced investments in Debrecen (2018–2026).

Investor	Investor's home country	Type of the investment	Investment cost (million EUR)	Number of new jobs	Factory area (m ²)	Plot area (ha)	Minimum green space ratio (%)	Projected date of the investment's completion	Industry
ThyssenKrupp	Germany	greenfield	not available	250	46,000	10	30	2018	automotive
Krones	Germany	greenfield	40	660	44,000	15	20	2019	systems engineering
Richter Gedeon	Hungary	capacity increase	48	120	3500	8.7	30	2020	pharmaceutical
Deufol	Germany	greenfield	not available	120	46,000	15	20	2020	packing
BHS Trans	Hungary	greenfield	7.9	80	19,000	4.5	30	2021	logistics
Hoffmann Neopac	Switzerland	greenfield	18	25	28,000	5.5	30	2022	packing
Vitesco Technologies	Germany	greenfield	120	450	31,000	10	20	2022	automotive
Zhejiang Huashuo Technology	China	greenfield	43	300	20,000	11.6	20	2023	automotive
SEMCORP Group	China	greenfield	184	440	97,000	19	20	2023	battery
EcoPro BM	South Korea	greenfield	728	631	264,000*	44	20	2025	battery
BMW Group	Germany	greenfield	2000	1000	2000,000*	400	30	2025	automotive
CATL	China	greenfield	7340	9000	1326,000*	221	20	2025	battery
Sensirion	Switzerland	greenfield	4	100	6200	5.2	30	2025	sensors
EVE Power	China	greenfield	1000	1000	45,000	100	20	2026	battery
TOTAL			11,533	14,176	3931,700	869.5			

Source: Hungarian Investment Promotion Agency, companies' websites, Debrecen's local building codes, Debrecen's zoning plan

*Calculated based on data about the maximum built-up ratio derived from Debrecen's local building codes

build up a maximum of 50 % of the 400 ha it owns and is required to create green spaces occupying a minimum of 30 % on the same plot of land. If the investors create only the minimum required green space ratio, as is their typical practice, the total area of green spaces on industrial development plots will be 217.29 ha. The new green spaces will most probably be lines of trees encircling the industrial sites, aiming to protect neighboring residential areas from potential emissions (e.g., noise and air pollutants). Therefore, the net loss of vegetated areas between 2018 and 2026 is expected to be 652.21 ha if no new developments are undertaken.

We can reasonably forecast the expansion of industrial areas, as information about planned industrial developments is typically disclosed publicly. However, it is more challenging to predict where and to what extent residential areas will expand. Usually, cities' zoning plans indicate areas reserved for future residential housing developments. For example, according to Debrecen's zoning plan, a total of 453.7 ha of land will be available for housing developments in the coming years, out of which 408.5 ha (i.e., 90 % of the total) will be allocated exclusively for family houses (Fig. 4). These areas mostly comprise abandoned agricultural land and seminatural areas on the city's eastern side. Therefore, it seems reasonable to designate these currently underused or inefficiently used areas for future residential housing developments. However, a significant risk is that factories situated in Debrecen's western side may cause people to prefer residing in that part of the city, thereby occupying valuable agricultural land for housing.

Overall, due to recent, ongoing, and planned industrial and residential developments, the gross loss of agricultural areas in Debrecen is expected to reach at least 1323.2 ha between 2018 and 2026, exceeding the projected loss (248.6 ha) by more than 432 %. In order to further emphasize the scale of land take and land use change in Debrecen, Fig. 5 shows the increase of the built-up area (i.e., the combined areas of the urban fabric and industrial and commercial units) per 1000 inhabitants. In 2006, the built-up area per 1000 inhabitants in Debrecen was 38.17 ha, which increased by 8 % in the following 12 years, reaching 41.24 ha per 1000 inhabitants in 2018. If this trend were to continue, the built-up area per 1000 inhabitants would be 43.41 ha in 2026. However, due to the steady population loss and the sizable expansion of industrial and residential areas, the city's built-up area will expectedly increase to 48.39 ha per 1000 inhabitants, which means a 26.8 %

increase within 20 years.

Based on lessons learned from the Debrecen case study, it is expected that the transformation of agricultural and seminatural areas and wetlands into artificial surfaces will accelerate in major cities across Hungary in the coming years.

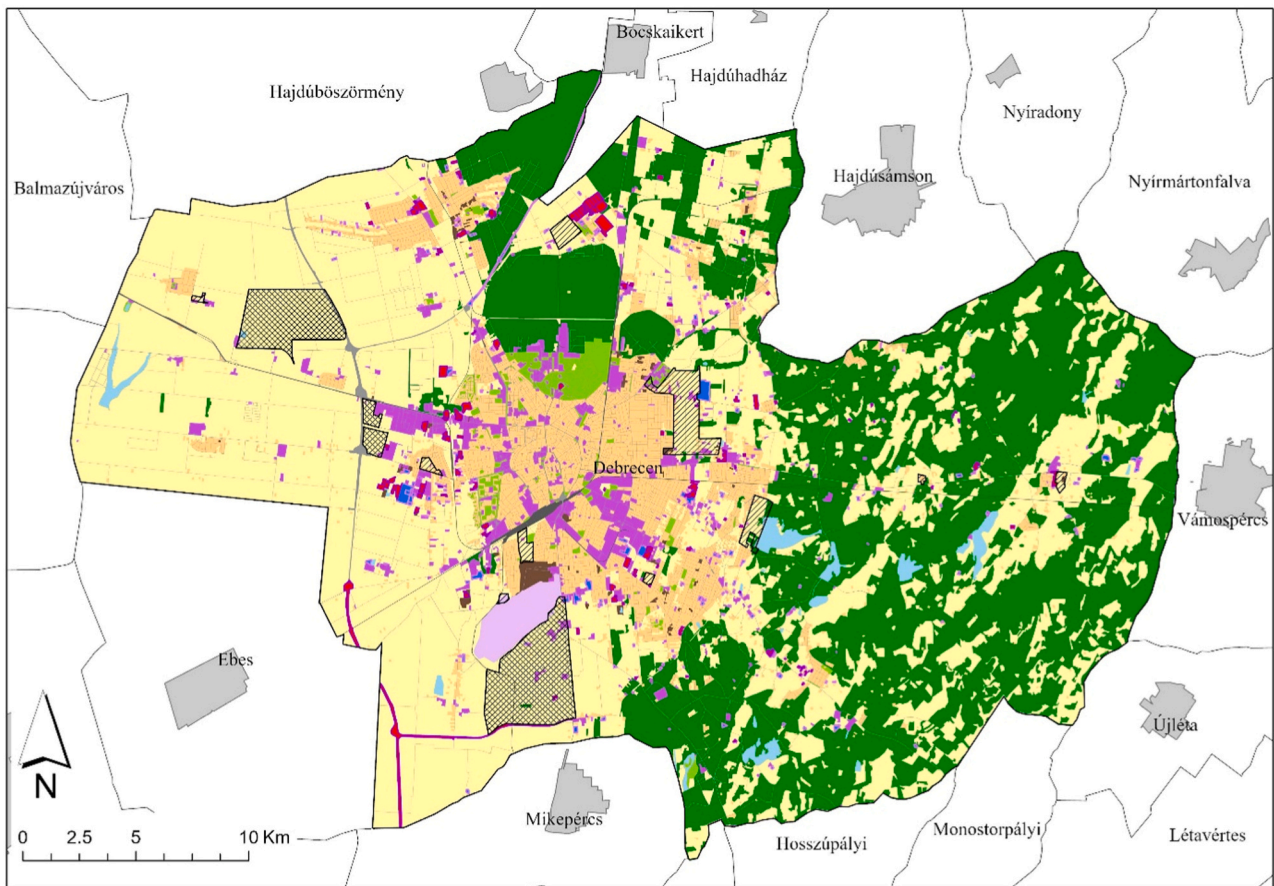
4. Discussion

In the last two decades, Hungarian cities have experienced sweeping changes in land use, and many are likely to be affected by even more dramatic changes in the coming years. These land use changes have not happened randomly but have been propelled by government policies implemented in the last 15 years. In the following section, we will discuss the impacts of these policies on land use.

4.1. The impacts of the country's (re)industrialization

Industrialization often plays a key role in the development strategies of low-income countries in Asia (Kruse et al., 2023), and it also appears to be a fundamental strategy in the CEE region (Bykova et al., 2023; Lengyel et al., 2017). The launch of Hungary's (re)industrialization can be traced back to the end of the 2000s.

As a result of the global financial crisis that hit Hungary in 2009, the unemployment rate surged, reaching a peak of 11.3 % in 2010 and remaining over 10 % until 2013. In response to the shockingly high unemployment rate, the government set two primary goals regarding the economy: the industrialization of the country and the establishment of a "work-based society" (Artner, 2016). A pivotal component of the industrialization strategy has been attracting automobile manufacturers and related industries to the country (see, for example, Geröcs, 2022). In 2022, more than 700 automotive companies, including five automobile manufacturers, were operating in Hungary. According to the HIPA, the automotive sector currently contributes 3.9 % to the GDP, a figure expected to increase to 8 %–10 % by 2025–2026. Furthermore, the sector accounts for 3.4 % of all employed persons in the country. The government provides individual firms with various incentives, including direct subsidies, to encourage them to settle in Hungary. The top beneficiaries of direct subsidies have been German automobile and auto part manufacturers (e.g., Audi, Mercedes-Benz, BMW, and Bosch). These



Legend

- Area reserved for housing developments
- Area of industrial developments 2018-2026
- New artificial surfaces 2012-2018
- New artificial surfaces 2006-2012
- Continuous and discontinuous urban fabric
- Industrial, commercial, public, military and private units
- Fast transit roads and other roads
- Railways and associated land
- Airports
- Mine, dumps sites, construction land
- Green urban areas, sports and leisure facilities
- Agricultural land
- Natural and semi-natural vegetation
- Wetlands and water
- Settlement area
- Borders of settlements

Fig. 4. Forecasted land take in Debrecen for industrial and housing purposes based on recent, ongoing, and planned developments (2018–2026).

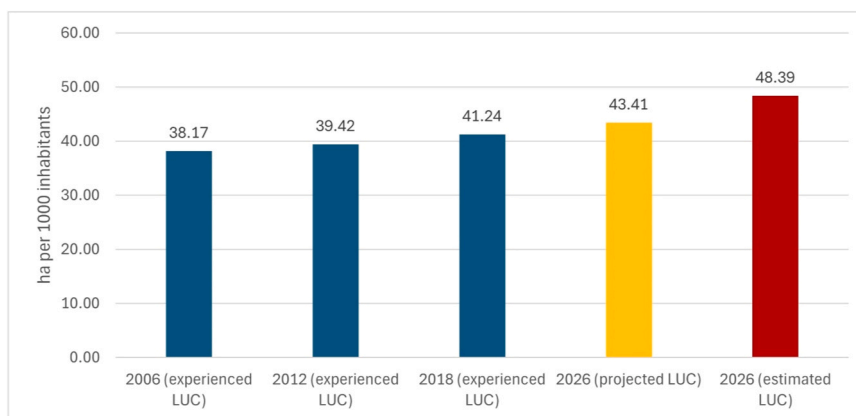


Fig. 5. The projected and forecasted increase of the built-up area in hectares per 1000 inhabitants in Debrecen.

companies tend to establish factories in major cities in the countryside (e.g., Győr, Kecskemét, Debrecen, and Miskolc), where a lot of “free” space is available to accommodate large industrial developments.

Recently, South Korean and Chinese companies specializing in lithium-ion battery manufacturing have replaced German automotive companies as the top investors in Hungary. This development is due to a radical shift in the government’s industrialization strategy, triggered by the global electric vehicle revolution. Because the top lithium-ion battery suppliers of Hungary-based German automobile makers are Chinese and South Korean technology companies, the government has taken measures to attract these battery manufacturers to Hungary. In 2022, the Ministry of Innovation and Technology issued the National Battery Industry Strategy 2030, the main goal of which is to facilitate the establishment of an “internationally competitive national industry.” The government has declared that it will make the country an interface between the West (i.e., automobile manufacturing) and the East (i.e., battery manufacturing). In addition, by establishing lithium-ion battery factories in the country, the government aims to position Hungary as a pivotal actor in the European electric vehicle supply chain. In 2022, 73 % of the FDI was directed toward the battery and automotive industries (Györffy, 2023), with a focus on cities in the countryside where ample agricultural land and seminatural areas were available for industrial and related infrastructural developments. For example, it was recently announced that large tracts of agricultural land will be acquired and expropriated in Győr (400 ha), Szeged (300 ha), and the Budapest Agglomeration (500–800 ha) to convert them into industrial areas.

Therefore, it is evident that one of the main drivers of the land take and land use change currently being experienced by major cities in the countryside is due to Hungary’s forced industrialization. Outside of the CEE region, this strategy is also widely used in low-income developing countries to boost economic growth and is often followed by excessive land take and massive destruction of agricultural land and natural and seminatural areas (see, for example, Debela et al., 2020; Dorninger et al., 2021; Kuang et al., 2016; Tian, 2015).

4.2. The impacts of family policies and the improving household incomes

Since the collapse of the communist regime in 1989/1990, post-socialist CEE countries have experienced substantial population declines (UNFPA 2022), primarily due to significant drops in fertility rates (Eurostat 2023) and increases in emigration (Ilahi et al., 2016). The emigration of the working-age population undermines the economic potential of CEE countries, while the rapid aging of the population puts pressure on the social security system. Therefore, governments in the region have introduced various measures to attempt to increase fertility rates (Cook et al., 2023; Michoń, 2021). For example, Poland has launched the Family 500+ program to financially support approximately 4 million children under the age of 18 and 2.6 million families.

In Hungary, the government launched a Family Housing Allowance Program (FHAP) in 2015 to address worrying demographic trends (i.e., to halt the steady population decline), offering up to 20 million Hungarian forints of assistance per family for building or buying a new home. Only families with three or more children, or those who pledge to have at least three children, are eligible for a nonrefundable allowance and favorable interest rates. The amount was recently increased to 50 million Hungarian forints.

In addition, as a result of the nationwide industrialization program, numerous manufacturing and other job opportunities have been established in the country, pushing the unemployment rate below 4% in 2023. Although cheap labor has historically been a significant incentive for multinational companies to establish operations in Hungary, there has been a substantial increase in the average gross annual wage per full-time employee, rising by 155% between 2010 and 2022 (https://www.ksh.hu/stadat_files/mun/hu/mun0070.html). Higher household incomes and the FHAP’s support programs have made it possible for families to buy bigger apartments and build bigger houses. For example,

since the inception of the FHAP in 2016, there has been a notable increase in the number of family houses built annually: in the six major cities and Budapest, 2638 family houses were built in 2020, 165 % more than in 2015.

Nevertheless, it should be noted that there appears to be a slight difference between the housing development trends of Budapest and major cities in the countryside. In Budapest, the number of family houses built in 2020 increased by 51 % compared to those built in 2015. However, cities in the countryside such as Kecskemét, Debrecen, and Szeged, witnessed a far more substantial increase in new family houses, with growth rates of 643 %, 575 %, and 457 %, respectively. In Budapest, several neighborhoods have been gentrified (e.g., the Corvin Quarter), offering an attractive environment for more affluent people. For example, between 2006 and 2018, the expansion of the continuous urban fabric was three times greater in Budapest than in the six major cities combined. In addition, since the beginning of the 1980s, a massive agglomeration, officially known as the Budapest Agglomeration (BA), has developed around Budapest. This agglomeration comprises more than 80 cities, towns, and villages and accommodates approximately 800,000 people (excluding the population of Budapest). In recent decades, settlements in the BA have experienced an influx of people from Budapest. Many find that villages within the BA offer a more pleasant and affordable environment compared to the outskirts of Budapest. In contrast, major cities in the countryside do not have highly developed agglomerations like Budapest but instead have “free” lands available to expand the outskirts within the city’s perimeter. For example, between 2006 and 2018, Miskolc lost 12 % of its population, while the city’s residential areas grew by 10 %. Overall, new housing developments, primarily in cities in the countryside, tend to occupy agricultural and seminatural areas surrounding existing built-up areas.

In sum, despite their declining populations, major cities across Hungary are undergoing significant urban sprawl and expansion. This trend is primarily fueled by the overall increase in people’s incomes and the government’s financial incentives for young families to build or buy new homes. Similar patterns have also been observed in other CEE countries, including the Czech Republic (Sýkora and Ourednek, 2007) Poland (Rózycka-Czas et al., 2021; Wiatkowska et al., 2021), and Slovakia (Hajduková and Sopiřová, 2021).

4.3. The role of local climate strategies in mitigating the impacts of government policies

In Hungary, the strategies and plans formulated at different territorial levels often contain conflicting goals and measures. For example, while the 2nd National Climate Change Strategy (NÉS-2 in Hungarian) set ambitious decarbonization goals by 2050 at the national level, various industrialization and battery strategies have opposing goals. The primary reason for this situation is rooted in economic interests. The automotive industry, which is the primary recipient of FDI and a key driver of economic development in CEE countries like Hungary, is undergoing a transformation toward electromobility (Török, 2022). As a result, automobile manufacturers in the region are under increasing pressure to boost electric car production (Szalavetz, 2022). Therefore, countries in the CEE region are witnessing the establishment of battery factories and associated industries to support this transition (Czifrusz, 2023), which they must accommodate to avoid the risk of automobile manufacturers relocating their factories elsewhere. These new factories require sizable plots of land for their operations.

Furthermore, in Hungary, this process is not only tolerated but also facilitated by the government. For example, the Hungarian Parliament accepted “Act LIII of 2006 on accelerating and simplifying the implementation of investments of national economic priority,” which serves as a legal mechanism allowing the government to implement any investments it deems crucial, even when they provoke fierce public debate, as with the battery factories. If the government declares an investment vital for the national economy, it has the authority to designate

the location of the investment through a government decree. In such cases, the chosen local government is obligated to assist in the project's implementation, including providing the necessary infrastructure, utilities, and plots of land. For example, the China-based automotive company BYD announced plans to construct a giant factory for manufacturing electric buses in Szeged, a city located in the south-eastern region of Hungary with a population of approximately 160,000. The government classified the investment as a national economic priority to facilitate the project's implementation. Additionally, it has offered financial support to the local government, enabling it to expropriate 300 ha of arable land for conversion into an industrial zone. Consequently, while promoting economic development, such initiatives negatively impact environmental and climate goals (Buzogány and Cotta, 2022; Haring et al., 2019; Óvári et al., 2023).

In Hungary, local governments utilize building authorities and zoning plans to regulate the growth of residential areas. However, a permissive approach is often adopted in daily practice, reflecting the influence of neoliberal urban planning and governance strategies that became widespread after the regime change (Taşan-Kok, 2011). The change in building regulations also supports this practice. Since 2016, for example, individuals can build a residential house up to 300 square meters, while companies can build up to six apartments and 1000 square meters, and either can expand an existing structure, with a simple notification process, eliminating the need for a permit procedure. Furthermore, illegally constructed buildings can also obtain a permit to legitimize their ongoing existence. As a result, the proliferation of urban residential areas is a defining feature of large cities in Hungary (Kovács et al., 2019; Vasárus et al., 2018). Similar causal factors and development trajectories have also been described in other CEE countries (Hardi, 2022; Schmidt et al., 2014).

In summary, cities have tools to control the land taken for industrial investments and residential construction; however, these can be circumvented under certain conditions. Local zoning plans, which regulate urban land use in Hungary, primarily serve as technical and engineering documents. These documents are long-term in nature, and as such, their updates do not coincide with the seven-year fiscal cycles of the EU. Therefore, they are only occasionally aligned with the strategies prepared for these periods. Moreover, when zoning plans are renewed, cities tend to focus on updating them to reflect existing conditions, with a primary emphasis on strategic goals for economic and transport development. Thus, urban climate strategies do not directly shape zoning plans and urban land use because the mainstreaming process—the integration of climate protection into sectoral documents and plans—is still in its early stages (Aylett, 2015). As a result, climate protection is not integrated into the daily decision-making of local governments.

The lack of weight of climate strategies is vividly demonstrated by a recent case where local activists revealed that the Kecskemét municipality intended to permit a local company to build a new office building, parking garage, and shopping center complex in the city center, partly on the site of an urban park. The protestors cited the adopted climate strategy, pointing out that the investment contradicted several of its objectives, including the prohibition of new traffic-attracting developments in the city center and the protection of urban green spaces. The case ended with a public hearing, and no construction has started. While this case illustrates the potential influence of climate strategies on local governance, it remains an isolated instance, highlighting the necessity for a significant shift in mindset among local authorities regarding climate protection.

Generally speaking, municipalities do not typically deal with the broader effects of forced industrialization and urban sprawl and expansion. This is partly due to government policies that have weakened the decision-making autonomy of local governments in favor of prioritizing investors' interests. Additionally, cities are eager to attract investors and satisfy people's housing demands. Thus, local climate strategies struggle to fulfill their role of curbing urban sprawl and

expansion and excessive land take.

4.4. Limitations

Although we made efforts to carefully select the data and methods used for this analysis, some limitations must be reported. First, the most recent data provided by the UA is five years old, with the newest UA edition expected to be published in 2024. Therefore, we will soon have current data on land use change in selected cities, making our projection obsolete. Second, we only managed to acquire data on the most significant industrial investments in Debrecen; it is possible that some small-scale developments went unannounced or that data on them was not disclosed publicly. Furthermore, there is a possibility that as-yet-unknown developments will occur during the period we examined. While these developments would alter the final figures, the land use change trend would remain the same. Moreover, not all announced developments may be implemented due to rapidly changing economic conditions. Finally, this study focused on investigating cities' local climate strategies, because currently they are the only "urban strategies" available containing references to preventing land take and land use change. However, local governments of large cities are currently preparing their sustainable urban development strategies (SUDSs) for the period of 2021–2027, which aim to directly incorporate many of the local climate strategy's goals into the medium-term urban development. After reviewing some SUDSs' publicly available working versions, we expect that land take and land use change will be more prominent among the environmental issues to be addressed. Based on this, we can investigate the SUDSs impact on land use change around 2028–2029 at the earliest.

5. Conclusions

Urban sprawl is one of the most critical and complex contemporary challenges for cities in both developing and developed countries. However, the primary drivers of this process vary between different countries and cities. Globally, in most cases, rapid urban population growth and the associated economic development result in excessive land use changes. In contrast, in Hungary, the expansion of cities' built-up areas is occurring simultaneously with a steady population decline. Urban sprawl and expansion are primarily driven by two government policies aimed at (re)industrializing the country and boosting population growth. Since the early 2010s, the implementation of these policies has put significant pressure on land use and has resulted in massive land take in cities, primarily those in the countryside. Because the government has repeatedly announced its unwillingness to replace these policies, this trend will most likely continue. In addition, the findings demonstrate that local climate strategies dedicated to providing guidelines for cities to meet national and European climate goals are ineffective in addressing urban sprawl and expansion and preserving local ecosystems. Finally, if measures are not taken to halt the unreasonable land use change, Hungary will not be able to meet the EU's mid- and long-term land take targets (if they are national priorities at all).

The central and local governments have various options to tackle this issue. Prioritizing the compact city model and investing in brownfield redevelopment within these policies could significantly mitigate residential and industrial land take. In addition, a shift in the economic development paradigm is necessary, transitioning from excessive industrialization to a knowledge-driven economic development model that prioritizes the sustainable use of natural resources. Finally, restoring full jurisdiction over land use decisions to local governments is crucial, empowering them to reject investments that may jeopardize local environmental goals. Since industrial developments, especially battery factories, involve significant environmental risks, protecting local interests is impossible without strong local autonomy.

The findings demonstrate that local governments are currently unable to protect local interests. Thus, civil initiatives have emerged across

Hungary in response to planned industrial developments. These initiatives underscore a growing environmental consciousness among the population and a heightened sensitivity to environmental injustices. We aim to explore these dynamics further in follow-up research endeavors.

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Declaration of Competing Interest

The authors report there are no competing interests to declare.

Data availability

No data was used for the research described in the article.

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