

## Article

# National Level Land-Use Changes in Functional Urban Areas in Poland, Slovakia, and Czechia

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**Abstract:** Land-use and cover change (LUCC) impacts global environmental changes. Therefore, it is crucial to obtain cross-national level LUCC data that represents past and actual LUCC. As urban areas exhibit the most significant dynamics of the changes, accompanied by such processes as urban sprawl, it seems desirable to take into account LUCC information from such areas to acquire national level information. The paper analyses land-use changes (LUCs) in urban areas in Czechia, Poland, and Slovakia. The analysis is based on functional urban area (FUA) data from the European Urban Atlas project for 2006 and 2012. The area of urbanised land grew at the expense of agricultural areas, semi-natural areas, and wetlands over the investigated period in all three countries. The authors determined LUC direction models in urban areas based on the identified land-use change. The proposed LUC direction models for the investigated period and area should offer national level LUC data for such purposes as modelling of future changes or can be the point of reference for planning analyses. The paper proposes the following models: mean model, median model, weighted mean model where the weight is the urbanised to vegetated area ratio, and weighted mean model where the weight is the share of urbanised areas. According to the proposed LUC models, areas considered as urbanised grow in FUAs on average in six years by 5.5900‰ in Czechia, 7.5936‰ in Poland, and 4.0769‰ in Slovakia. Additionally, the change models facilitated determination of a LUC dynamics ratio in each country. It reached the highest values in Poland and the lowest in Slovakia.

**Keywords:** land use; land-use change; Urban Atlas; functional urban areas



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## 1. Introduction

The urbanisation trend has existed for several centuries. It involves an increase in the share of the population living in urban areas. The Population Division of the Department of Economic and Social Affairs of the United Nations (UN) estimates that more people have lived in urban areas than in rural areas since 2007 [1]. However, estimates of the populations living in urban areas vary because of the vague definition of urban areas. For example, according to the UN, in 2015, 54% of the world's population lived in urban areas [1]. According to the European Commission, it was about 85% (52% in urban centres and 33% in urban clusters) [2]; and Angel et al. [3] set that number at about 60%. According to forecasts by the UN, over 68% of the global population will live in urban areas by the end of 2050 [1]. Urban areas are particularly interesting in the research domain because of their dynamic changes, functions, and population densities. Population structure and dynamics are important factors shaping land use, i.e., in Europe [4]. According to the UN [5], urban growth associated with an increase in the absolute number of the population living in urban areas consist of rural to urban migration, an increase in the natural urban population, and the conversion of rural to urban areas. In Europe, there is an upward trend in growth of urban areas, despite a lower or constant population growth rate [6].

Additionally, residential and industrial areas are moved to rural areas (the surroundings of cities). Therefore, there is land-use and land-cover changes, especially from agricultural to urbanised.

Today, qualitative and quantitative classification of land use or cover types at the global, regional, and local scale have become basic tools for monitoring changes on the surface of the Earth. The actual cover of the surface of the Earth is referred to as land cover (LC) [7] while the way the surface is used by people, or its state caused by man, is called land use (LU) [8]. Land-use changes (LUC) and land-cover changes (LCC) are often investigated together as changes in land use and land cover (LUCC). LUCC most often results from individual and collective human activities driven by demographics, socioeconomic systems, politics, economies, and institutions [4,9–12], as well as nature, technology, and culture [13,14]. Because of the abundance of these factors, LUCC does not follow strict models and is non-deterministic [15]. In addition to the diversity of drivers, its spatial range plays an important role. It can be considered at the local, regional, national, and international level. Researchers most often investigate the effects of various factors on LUCC at the local level, as it is believed to be the key to understanding ongoing changes [16,17]. The most commonly discussed factor affecting local LUCC is local law [18] (such as the impact of spatial planning on LUCC through demarcation of zones at risk of floods in urban areas, where new housing development restrictions apply [19]; industrial areas [20]), past local land use, and the number of households [21–23]. Local changes can be associated with functional urban areas (FUAs), meaning a metropolis or urban agglomeration. The FUA consists of a city and its commuting zone. FUAs therefore consist of densely inhabited cities and less densely populated commuting zones whose labour markets are highly integrated with the city [24]. LUCC in urban areas are additionally affected by the significant population density and residential preferences [4]. Hence, when looking into LUCC, one should consider not only changes in agricultural, green, and forest areas, but also those related to intensive urbanisation in urban areas [25–27]. Nevertheless, the research to date has paid limited attention to analyses and modelling of land-use changes in urbanised areas and cities. An explanation (and a definition) of driving forces of LUCC in urban areas is a relevant aspect as well. From this point of view, several theoretical approaches can be considered, e.g., bid-rent theory [11,28] or urban growth machines [29,30]. Land rent (simply understood as profit from land) is a factor influencing spatial patterns of urban and suburban areas. The geographical location of land (e.g., distance from the market or from the central business district, transport costs, etc.) influences the structure and intensity of the local land use [11]. Modern theories understand the geographical location to be socially and economically valued land [29]. The urban growth machine theory stresses a role of the coalitions of actors and organizations—that all share an interest in local growth and its effects on land values and land use [30].

The impact of various factors on LUCC and their relation with the place and time are evident when considering political transformations and ensuing socioeconomic changes in a group of central- and eastern-European countries, after 1989, and after most of them joined the EU in 2004. Land-use changes in Europe are greatly diversified across space [31]. The least common conversion among broad land-use categories in the EU between 1990 and 2006 was urban expansion (~16,820 km<sup>2</sup>) [31]. Moreover, research on LUCC dynamics shows significant dynamics of the changes from 1990 to 2006 in Western Europe and a clear division into western and eastern parts of Europe [31]. The division is believed to originate from the breakdown of socialism in 1989, which contributed to such trends as the abandonment of agriculture and reduction of capital-intensive farming practices [32,33]. Central and Eastern Europe has seen land abandonment and significant conversion of land into permanent grassland and forests since the 1990s, which was confirmed by numerous case studies or regional research [9,31,34–37]. The eastward expansion of the EU in 2004 and 2007 resulted in eastern European countries being covered by many aid systems, such as the EU's Common Agricultural Policy (CAP), European Regional Development Fund, the European Social Fund, and the EU Cohesion Policy. Subsidies from these funds from

2007 to 2013 were aimed at equalising economic and social conditions in all regions of the EU, including in cities. The impact of transformations in Central and Eastern European countries in the recent thirty years on LUCC was investigated under numerous projects, in particular in such countries as Poland [38–40], Czechia [8,9], Slovakia [41,42], and Hungary [39,40,43,44].

This paper looks into LUC in Czechia, Poland, and Slovakia. Because of their location, history, and similar socioeconomic characteristics over the last three decades, the EU groups these countries as Northeastern Europe. According to national estimates, urban areas in Poland, Slovakia, and Czechia were inhabited from 2006 to 2012 by 61% [45], 55% [46], and 73% [1] of their respective populations. In the same period, urban areas occupied 6.83–6.90% of Poland [45], 14.63–14.70% of Slovakia [46], and 10.42–10.60% of Czechia [47]. These countries have different numbers of tiers of the territorial subdivision. It is important for the spatial policy as each local government at all levels has different spatial planning competencies, which affects LUCC. Poland has four levels of government (national, regional, intermediate, and local), while Slovakia and Czechia have three levels (national, regional, and local). They have hierarchical systems of spatial plans. Poland and Czechia have the planning systems, with plans at the three levels (national, regional, and local) and in Slovakia, on four levels (national, regional, and two local levels) [48]. According to the Organisation for Economic Co-operation and Development (OECD) [48], Poland and Czechia have relevant powers concerning land use at the national, regional, and local level. Moreover, in Slovakia at the local level, two land use plans exist (local plans and zoning plans). Local plans must be adopted by municipalities with more than 2000 inhabitants, if important infrastructure or public buildings exist, or are planned within their territory. The creation of zoning plans is mandatory only if it is required by local plans or when a public building is planned in the area, therefore zoning plans exist mostly in larger cities and for areas where large public developments occur, or are environmentally sensitive [48]. Information about the territorial subdivision, spatial planning, and land-use changes from 2000 to 2012 in these countries can be found in the report Land-Use Planning Systems in the OECD: Country Fact Sheets [48].

LU and LC models are developed to determine and assess the dynamics of LUCC and forecast the changes [49–52]. These are stochastic models, optimisation models, dynamic simulation models based on processes, or empirical models that undergo numerous usability evaluations [53–56]. Empirical fit models involve fitting temporal trends and spatial models into a set of predictive variables, which may impact LUCC [57]. Empirical models can be classified into spatially explicit models and aspatial models [58,59]. Spatially explicit models aim at explaining and forecasting the occurrence of LUCC while aspatial models are used mainly to forecast the size of LUCC in aggregated geographical regions. Models of dynamic processes use algorithms to describe interactions among objects in the land-cover and use system. Regardless of the method, when building LUCC models, one has to consider two aspects. One of them is the scale of the data describing LUCC. The other is to differentiate between quantitative forecasts and location of changes [60]. When analysing the location of LUCC in urban areas, one has to pay attention to the concentration of developments near the functional–historical core of the city, and such phenomena as urban sprawl and suburbanisation near roads leading to the city and around city limits [61–63]. In the case of qualitative LUCC modelling, researchers often use quantitative data on the areas of LU and LC classes within the investigated administrative regions collected by authorities. When fed to statistic tests, the data determine LUCC trends [53].

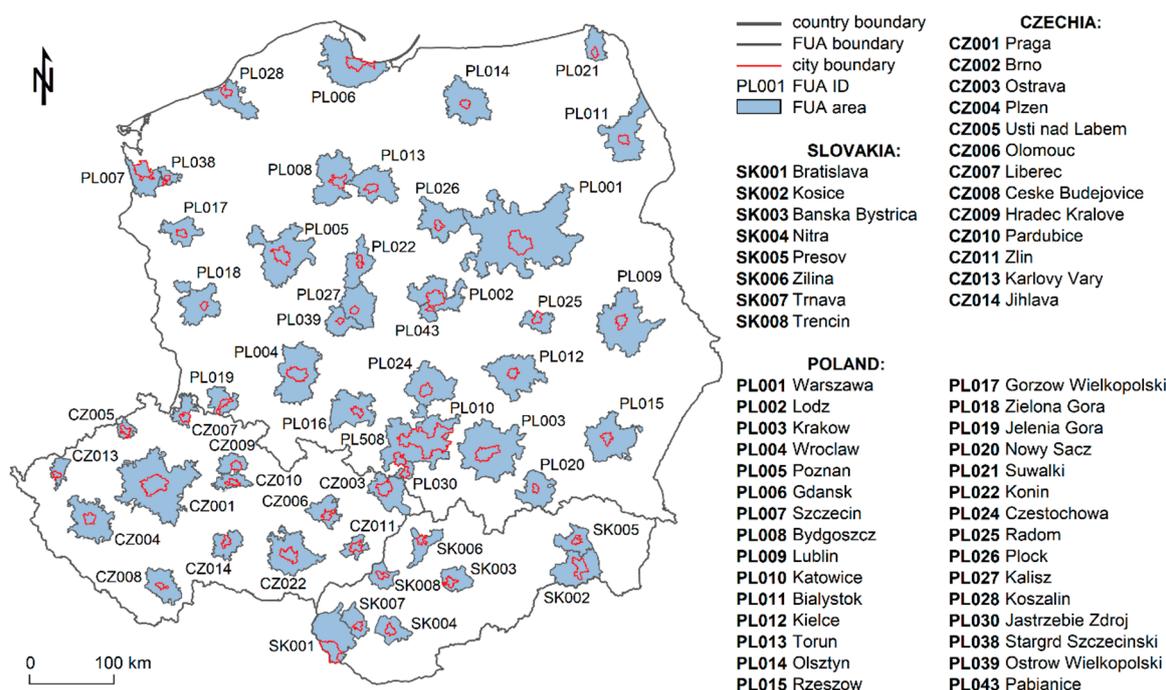
Such quantitative data illustrating the outcome of LUC drivers in urban areas can be data from the European project Urban Atlas (UA). The UA was first published in 2006 and then updated in 2012. It offers high-resolution, reliable local data on LU for urban areas. UA 2006 provide information for FUA, relating to cities with more than 100,000 inhabitants, meanwhile UA 2012 data are referred to FUA, and their surroundings with more than 50,000 inhabitants [64]. Furthermore, it can be noticed that FUA boundary may change in time as result of obtaining new information about population density, commuting, and

changes of boundaries of local administrative units. The UA was developed under the Copernicus programme, focusing on land monitoring. It is supported by the European Environment Agency (EEA) and the European Space Agency (ESA). LU data in the 2006 UA have been grouped into four basic classes: (1) artificial surface; (2) agricultural areas, semi-natural areas, and wetlands; (3) forests; (4) water. Data in the 2012 UA have been grouped into five basic classes: (1) artificial surfaces; (2) agricultural areas; (3) natural and semi-natural areas; (4) wetlands; (5) water. LU data are grouped into 22 classes in the UA 2006 and 28 classes in the UA 2012 on four-tiers of hierarchical classification. The fourth level of classification was set apart for artificial surface to differentiate between sub-categories. The division and names of the classes in the UA conform to those used in Coordination of Information on the Environment (CORINE) land cover (CLC). The minimum mapping unit (MMU) for the UA is 0.25 ha for surface objects for class 1 and 1 ha for classes 2 to 5. It means it has a 100 times greater resolution compared to CLC data, where the MMU is 25 ha for surface objects and 100 m for linear phenomena [65].

The significant impact of local factors on LUC, together with their diversity, encourage research to focus on the local level. Nevertheless, economic and regional policy, national spatial planning legislation, which affects local documents, including the shaping of the national policy for prevention of exclusion of FUAs, or for ecological stability assessments [66], need general regional and national level information about the dynamics of LUC in urban areas. It is important for sustainable development to build LUC models for FUA with a relatively high population density compared to other areas of the country. Moreover, the literature does not offer coherent models of changes in urban areas that are similar in size and functions that could be reference points for local changes in local administrative divisions. Therefore, the objective of the paper is to build LUC direction original models for urban areas from 2006 to 2012 in Czechia, Poland, and Slovakia using LUC data from the UA. The models have been built using changes in land cover of areas assigned to LU classes at the fourth level of detail, following aggregation of surfaces with LUC down to the first level of detail. The models were built based on selected FUAs representative of all FUAs in the investigated countries. They provide insight into the LUC direction for the investigated period. Therefore, they can be used at the initial stage of building of forecast models for future changes, and as reference points for local analyses in these countries. The models can be implemented easily and provide information about actual urban LUC as they take into account all factors, even if they are not explicitly known in detail.

## 2. Materials and Methods

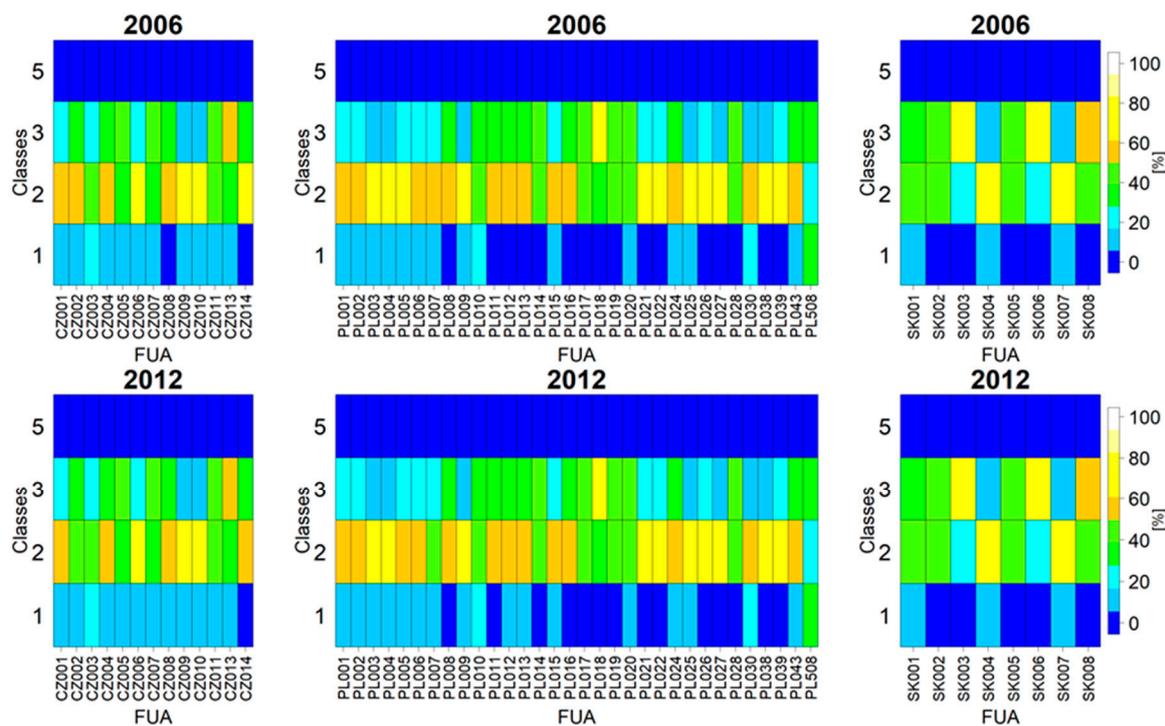
The paper uses UA data on LU for Polish, Czech, and Slovak FUAs for 2006 [67] and 2012 [68]. Compared to CLC data, UA data offer better spatial resolution and focus on FUAs, which are urbanised areas. Fifty-three FUAs were used in total; 32 from Poland, 13 from Czechia, and 8 from Slovakia (Figure 1). The number of selected FUA in particular countries resulted from their classification as functional urban areas and, thus, the availability of land-use data in the UA in 2006 and 2012. If FUA limits changed from 2006 to 2012, the research used areas of intersections of the FUA limits from 2006 and 2012 (layer intersect). Areas of FUAs classified as “no LU data” (class 91000 and 92000) were not analysed. As the number of LU classes in 2006 and 2012 differs, the research used 2006 LU classes by grouping the classes from UA 2012 as recommended by the UA [69]. LUC analyses involved basic classes 1, 2, 3, and 5, following aggregation of LU classes at fourth level of detail (sub-classes 11100, 11210, 11220, 11230, 11240, 11300, 12100, 12210, 12220, 12230, 12300, 12400, 13100, 13300, 13400, 14100, 14200, 20000, 30000, and 50000). This way, the spatial accuracy of sub-classes was retained. The list and details of all classes can be found in the UA guide [69]. The total area of the investigated Polish FUAs was 6,035,823 ha (FUA<sub>PL</sub>), which is 19.30% of the total area of Poland. For Czechia, it was 1,627,346 ha (FUA<sub>CZ</sub>), and for Slovakia, 867,346 ha (FUA<sub>SK</sub>), which was 20.63% and 17.69% of their respective total areas.



**Figure 1.** Locations and codes of the investigated functional urban areas (FUAs) in Poland, Czechia, and Slovakia.

The smallest share in FUAs, in 2006 and 2012, had class 5 (water). It did not exceed 10% of each FUA. The percentage of class 1 in FUA area in Czechia and Poland was between 10% and 20% and remains similar; in Slovakia, it ranged from 6% to 13% (Figure 2). In Czechia, the smallest share of class 1 was found in CZ008 (České Budějovice) and CZ009 (Hradec Králové), the largest, in CZ003 (Ostrava). In Poland, outliers of class 1 could be found in PL010 (Katowice), PL030 (Jastrzębie Zdrój), and PL508 (Rybnik), where the percentage of class 1 exceeded 20%. The share of class 2 in the FUA area in Czechia and Poland was similar and ranged from 26% to 70%. The maximum value for Czechia was found for CZ009 (Hradec Králové). In Poland, the lowest shares of class 2 were in PL018 (Zielona Góra), and PL508 (Rybnik), and the largest were found in PL009 (Lublin), PL025 (Radom), PL027 (Kalisz), and PL038 (Stargard Szczeciński). The greatest range of class 2 share in the FUA area was identified in Slovakia: from 25% to 77%. The lowest values were found for SK003 (Banská Bystrica) and SK006 (Zilina) while the largest, for SK004 (Nitra). The share of class 3 was similar in all the analysed countries. For Czech FUAs, the share of class 3 ranged from 17% (CZ009—Hradec Králové and CZ010—Pardubice) to 50% (CZ008—České Budějovice and CZ013—Karlovy Vary). Class 3 in Polish FUAs ranged from 13% (PL009—Lublin, PL025—Radom, PL038—Stargard Szczeciński) to 60% (PL018—Zielona Góra), while for Slovak FUAs, it was from 11% (SK002—Košice and SK004—Nitra) to 68% (SK003—Banská Bystrica).

The share of LU class 1 in areas of FUAs was similar in regards to individual FUAs in a country and among the investigated countries. Classes 2 and 3 were slightly more diversified. The mean range of the percentage share among FUAs was 45%.



**Figure 2.** The shares of land- use (LU) classes 1, 2, 3, and 5 in the analysed FUAs in 2006 and 2012.

Using the value of percentage shares of LU classes 1, 2, 3, and 5 in the area of each FUA in 2006 and 2012, the authors determined the share of the change area of each LU class in the FUA area, which was then used to build change models for each country. The shares of LUC areas in the areas of FUAs at the fourth level of detail were very small; hence, the authors refrained from building models at this level. Still, if the need for detailed data arises, the models can be calculated for changes at the fourth level of detail as well. Moreover, the authors assumed an equal impact of all FUAs on the national LUC models, and so they used the share of class area changes in the FUA area. Hence, LUC models are affected not by the surface of FUAs but the share of areas of changes within them. This solved the issue related to different sizes of a country's FUAs. Therefore, changes in class areas in two different FUAs were considered identical if the ratios of their areas to their respective FUAs were similar.

Outliers were defined to facilitate the development of models that would (statistically) reliably describe the direction and dynamics of LUC within each set. It was achieved with an outlier criterion based on the Mahalanobis distance, which is a measure of dissimilarity of multi-attribute objects and a metric commonly used in cluster analysis [70,71]. The literature offers many modifications of the Mahalanobis distance [72] that can be used to identify outliers [73]. The Mahalanobis distance enables the researcher to compare objects described with inter-correlated attributes, and prevents variables exhibiting greater deviations of value ranges from exerting a greater impact on the distance than the other variables; thus, rendering variable standardisation/normalisation unnecessary. When object attributes are not correlated, the Mahalanobis distance becomes the Euclidean distance. The Mahalanobis distance ranges from 0.38 to 11.78 for all sets of the FUAs. The outlier criterion was set to the value of Mahalanobis distance above 5. Outliers were identified in a three-dimensional space defined by the share of change areas in LU class 1, 2, and 3 in the areas of the FUAs. The LUC models were built for basic classes 1, 2, and 3. Class 5 (water) was excluded from the analysis as it had the smallest share in the area of the investigated FUAs, and the literature does not seem to justify the determination of the model for this class.

Four LUC models were proposed by authors: mean ( $W_{MN}$ ), median ( $W_{MD}$ ), weighted mean ( $W_{U/B}$ ), with a separate weight for each FUA equal to the ratio of the urbanised area to vegetated area, and weighted mean ( $W_U$ ), with a separate weight for each FUA equal to the share of the urbanised area in the FUA (Equations (1)–(4)). In  $W_{U/B}$  model, the urbanised area corresponds to the basic class 1 (artificial surfaces with dominant human influence and without agricultural land use, e.g., buildings, roads, construction of infrastructure, other artificially sealed or paved areas, as well as urban parks or leisure parks [69]). The vegetated area consists of the classes, classified to classes other than class 1, according to nomenclature of UA 2006 (agricultural areas, natural and semi-natural areas, forests, water and wetlands). In this context, the vegetated area can be understood as biologically active surface (non-sealed).

1. Mean LUC model ( $W_{MN}$ ):

$$W_{MN}^c = \frac{\sum_{i=1}^n \frac{x_i^c}{a_i}}{n} \cdot 1000\% \quad (1)$$

2. Median LUC model ( $W_{MD}$ ):

$$W_{MD}^c = \text{median} \left\{ \frac{x_i^c}{a_i}, i \in \{1, 2, 3, \dots, n\} \right\} \cdot 1000\% \quad (2)$$

3. LUC model weighted with the ratio of urbanised areas to vegetated areas in FUA ( $W_{U/B}$ ):

$$W_{U/B}^c = \frac{\sum_{i=1}^n \left[ \frac{x_i^c}{a_i} \cdot \frac{au_i}{ab_i} \right]}{\sum_{i=1}^n \frac{au_i}{ab_i}} \cdot 1000\% \quad (3)$$

4. LUC model weighted with the area of urbanised land in FUA ( $W_U$ ):

$$W_U^c = \frac{\sum_{i=1}^n \left[ \frac{x_i^c}{a_i} \cdot au_i \right]}{\sum_{i=1}^n au_i} \cdot 1000\% \quad (4)$$

where:

$i \in \{1, 2, 3, \dots, n\}$ —consecutive FUAs in the country;

$n$ —the number of FUAs in the country;

$c$ —LU class  $c \in \{1, 2, 3\}$ ;

$x_i^c$ —the aggregate area of changes in class  $c$  and FUA $_i$ ;

$a_i$ —the area of the FUA $_i$ ;

$au_i$ —the aggregate urbanised area in the FUA $_i$ ;

$ab_i$ —the aggregate vegetated area in the FUA $_i$ .

The fit of the proposed models for the relevant country was verified by determination of the cosine distance between actual LUC values in FUAs and LUC calculated with  $W_{MN}$ ,  $W_{MD}$ ,  $W_{U/B}$ ,  $W_U$ .

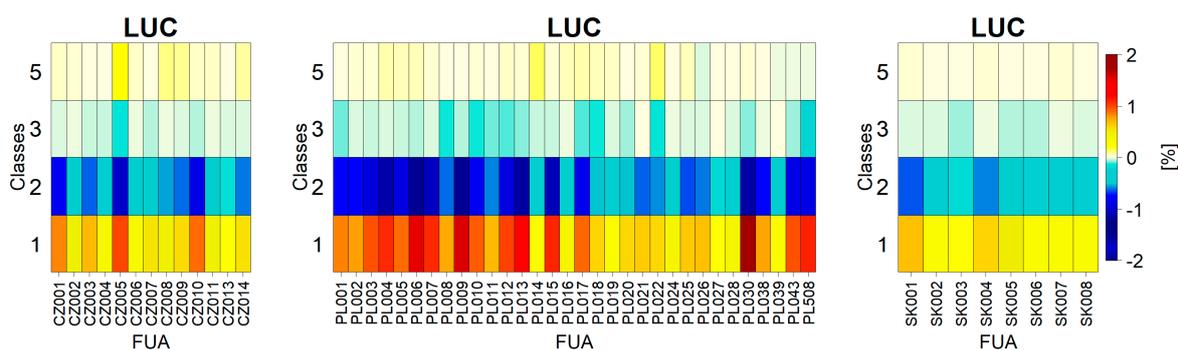
The LUC models can also be used to determine the dynamics of LUC as the length of a vector with change models for a specific LU class ( $W_c$ ) as its components:

$$D_W^{LUC} = \sqrt{\sum_{i=1}^c (W^c)^2} \quad (5)$$

The analyses were conducted in R-project [74] using the fields [75] and philyentropy [76] libraries.

### 3. Results

The direction and dynamics of LUC in Czechia, Poland, and Slovakia were determined by analysing the differences in areas of basic LU classes for data from 2006 and 2012 within a given FUA. Values of differences in areas of individual basic LU classes were then expressed as their share in the area of a given FUA (Figure 3). The most significant LUC between 2006 and 2012 in the investigated countries were identified between LU class 1 and 2. Urbanised areas grew at the expense of agricultural areas, semi-natural areas, and wetlands over the selected time frame in the investigated countries. The coefficient of correlation for LUC in class 1 and 2 was high and statistically significant. In each country and each FUA, it was  $-0.98$ .



**Figure 3.** LUC in basic classes between 2006 and 2012 in Czechia, Poland, and Slovakia.

The largest growth of urbanised areas at the expense of agricultural areas, semi-natural areas, and wetlands were identified in Czechia in CZ005 (Ústí nad Labem), in Poland for PL006 (Gdańsk), PL009 (Lublin), and PL030 (Jastrzębie Zdrój), and in Slovakia for SK001 (Bratislava). Capitals of Poland and Czechia also saw a significant increase in urbanised areas. Prague grew more urbanised by 0.82% (3928 ha), and Warsaw, by 0.81% (6616 ha). For Czech FUAs, class 1 areas on average grew by 0.57% of  $FUA_{CZ}$  (9276 ha) in total, and class 2 on average shrunk by 0.57% of  $FUA_{CZ}$  (9276 ha) (see Table 1). The most significant changes in class 1 and 2 areas took place in Poland. The area of class 1 on average grew by 0.81% of  $FUA_{PL}$  (48,890 ha), and class 2 was on average reduced by 0.77% of  $FUA_{PL}$  (46,476 ha) (see Table 1). The smallest changes in class 1 and 2 areas took place in Slovakia. The area of class 1 on average grew by 0.40% of  $FUA_{SK}$  (3469 ha), and class 2 was on average reduced by 0.37% of  $FUA_{SK}$  (3209 ha) (see Table 1). Moreover, the area of class 3, forest, grew smaller in Czechia by 0.03% of  $FUA_{CZ}$  (514 ha), in Poland by 0.06% of  $FUA_{PL}$  (3811 ha), and in Slovakia by 0.03% of  $FUA_{SK}$  (280 ha).

**Table 1.** Mean values of LUC in basic classes between 2006 and 2012 in Czechia, Poland, and Slovakia.

Classes	Country		
	Czechia	Poland	Slovakia
(% LUC in the Class)			
1	0.57	0.81	0.40
2	−0.57	−0.77	−0.37
3	−0.04	−0.06	−0.03
5	0.04	0.02	0.00

To provide a precise image of LUC classification, the authors presented changes by sub-classes (fourth level of detail) of class 1, Artificial Surface (Figure 4). The most intensive LUC in sub-classes of class 1 from 2006 to 2012 were identified for: 11240—discontinuous very low-density urban fabric, 12100—industrial, commercial, public, military, and private units, and 13300—construction sites (Figure 4). For Czechia FUAs, class 11240 areas on

average grew by 0.19%, meanwhile for Poland and Slovakia FUAs it was 0.28% and 0.08% respectively (Table 2). In the case of class 12100 its areas on average grew by 0.15% for Czechia FUAs, 0.13% for Poland and Slovakia FUAs (see Table 2). Aggregate changes in classes 11240, 12100, and 13300 were for Czechia 0.34% of FUA<sub>CZ</sub> (5509 ha), for Poland 0.51% of FUA<sub>PL</sub> (31,165 ha), and for Slovakia 0.15% of FUA<sub>SK</sub> (1280 ha).

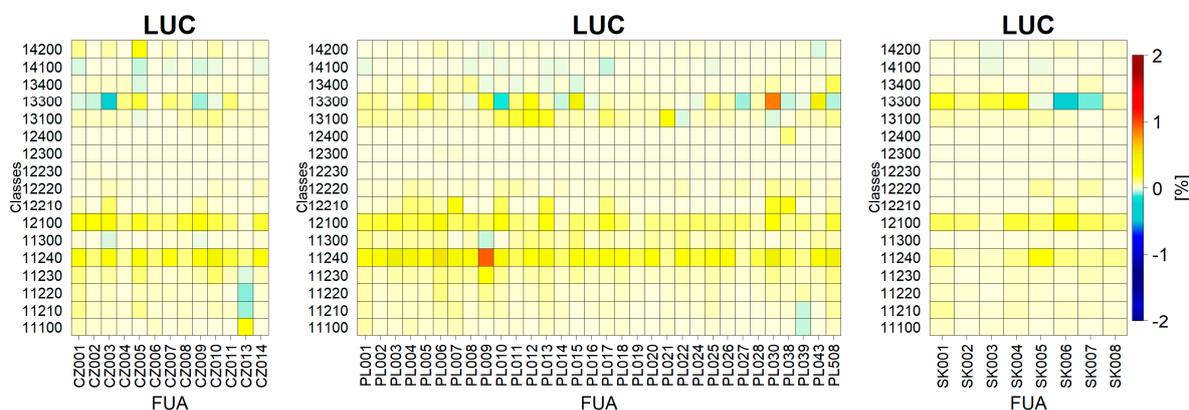


Figure 4. LUC in sub-classes of basic class 1—artificial surface between 2006 and 2012 in Czechia, Poland, and Slovakia.

Table 2. Mean values of LUC in sub-classes of basic class 1—artificial surface between 2006 and 2012 in Czechia, Poland, and Slovakia.

Classes	Country		
	Czechia	Poland	Slovakia
(% ) LUC in the Class			
11100	0.02	0.01	0.01
11210	0.02	0.02	0.03
11220	0.01	0.03	0.02
11230	0.05	0.05	0.02
11240	0.19	0.28	0.08
11300	0.00	0.04	0.01
12100	0.15	0.13	0.13
12210	0.02	0.05	0.01
12220	0.01	0.02	0.02
12230	0.00	0.00	0.00
12300	0.00	0.00	0.00
12400	0.00	0.00	0.00
13100	0.03	0.06	0.03
13300	0.01	0.08	0.03
13400	0.01	0.02	0.01
14100	−0.01	0.00	0.00
14200	0.04	0.01	0.01

The LUC values were then used to build models. The authors decided to reject those FUAs for which LUC values were outliers in the context of the country based on the Mahalanobis distance. Four FUAs were rejected in Poland, PL014 (Olsztyn), PL022 (Konin), PL030 (Jastrzębie Zdrój), and PL508 (Rybnik). One FUA was rejected for Czechia CZ005 (Ústí nad Labem) and one for Slovakia, SK007 (Trnava). Having removed the outliers, the authors built LUC models using equations 1–4 separately for each country with their respective FUAs (Table 3). The biggest per mille share of the area was noted for Czechia and Slovakia for model  $W_U$ , for Poland the largest values were obtained for  $W_{U/B}$ , which is well apparent for classes 1 and 2. All of the proposed models indicate that the LU changed from vegetated area to urbanised area in FUAs of the investigated countries. The value of the LUC dynamics ratio, according to Equation (5), was different for each of the countries.

The largest LUC dynamics ratio was found for Poland, and the smallest, for Slovakia. These findings are consistent with results of LU analyses in individual FUAs of the countries.

**Table 3.** Values of models and LUC dynamics at the national level in per mille for each country.

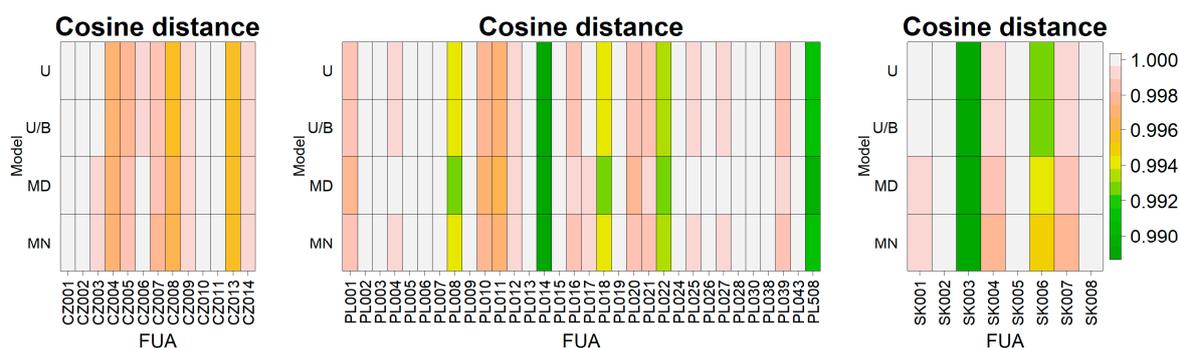
Country	Model	(%o) LUC in the Class			LUC Dynamics (%o)
		Class 1	Class 2	Class 3	
Czechia	$W_{MN}$	5.3111	−5.3306	−0.2951	7.5306
	$W_{MD}$	5.1642	−5.1762	−0.2894	7.3175
	$W_{U/B}$	5.5916	−5.5304	−0.3164	7.8709
	$W_U$	6.2935	−6.2314	−0.3066	8.8619
Poland	$W_{MN}$	7.8758	−7.5254	−0.5091	10.9050
	$W_{MD}$	7.5953	−7.4274	−0.3814	10.6302
	$W_{U/B}$	7.9744	−7.6279	−0.5229	11.0477
	$W_U$	6.9290	−6.6227	−0.4878	9.5974
Slovakia	$W_{MN}$	4.1752	−3.8478	−0.3769	5.6904
	$W_{MD}$	3.1920	−2.9896	−0.2966	4.3834
	$W_{U/B}$	4.1107	−3.7311	−0.4262	5.5679
	$W_U$	4.8297	−4.5449	−0.3515	6.6412

Moreover, the LUC dynamics ratio varies depending on the model used to determine it. In Czechia and Slovakia, the largest value of the LUC dynamics ratio was calculated for model  $W_U$ . In Poland, it reached the lowest value, while the highest was recorded for model  $W_{U/B}$ .

The similarity of the LUC models to the actual changes in all FUAs was determined with the cosine distance. The cosine distance will help verify the extent to which the proposed LUC models are representative of the actual LUC in the country for urban areas.

The cosine distance between all LUC models and the actual LUC was above 0.979 (Figure 5), which is indicative of a high similarity of the compared data. For Czechia, the proposed models best describe CZ001 (Prague), CZ002 (Brno), CZ010 (Pardubice), and CZ011 (Zlin). The worst fit was achieved for CZ008 (České Budějovice) and CZ013 (Karlovy Vary). The cosine distance between LUC models and the actual LUC was above 0.995 for all FUAs. According to the cosine distance between the LUC models and actual LUC in Polish FUAs, the models were best fitted for 84% of the FUAs with the cosine value exceeding 0.995. For the other 16% of FUAs in Poland, the cosine distance value was between 0.987 and 0.995. In Slovakia, the worst model fit was identified for SK003 (Banská Bystrica). For other FUAs, the cosine distance was above 0.995.

In regards to the fit of LUC models to FUAs that were considered outliers, and, thus, rejected during model estimation, the cosine distance did not reach the lowest values for the rejected FUAs in Czechia and Slovakia (CZ005 and SK007). Still, in Poland, three out of four rejected FUAs belonged to the set of the 16% FUAs with the lowest cosine distance values. Models with the best fit are those that are the closest to the percentage values of changes in the country in classes 1 and 2. In Poland, the most similar values were noted for model  $W_{U/B}$ , in Czechia,  $W_U$ , and in Slovakia,  $W_{MN}$  and  $W_{U/B}$ .



**Figure 5.** The cosine distance between the LUC models and actual LUC in individual FUAs in Czechia, Poland, and Slovakia.

#### 4. Discussion

This paper looked into LUC of the FUAs in Czechia, Poland, and Slovakia. For this reason, LUC direction original models for urban areas from 2006 to 2012 in Czechia, Poland, and Slovakia, using LUC data from the UA were built. The models were built using changes in land cover of areas assigned to LU classes, at the fourth level of detail, following aggregation of surfaces with LUC, down to the first level of detail. The analyses of LUC from 2006 to 2012 indicate that the LUC trend towards an increase in urbanised areas in FUAs continues. Moreover, the share of areas undergoing urbanisation in FUAs Czechia, Poland, and Slovakia varies from 0.43% to 0.85%. According to the existing research, the share of the area undergoing urbanisation in the total area of Czechia, Poland, and Slovakia is lower, about 0.1 to 0.2% [26]. Hence, urbanisation in FUAs seems to be four times more dynamic and the increase in urbanised areas at the expense of agricultural areas can be expected to continue in the future. Furthermore, changes in land use at a similar level can also be expected in other European countries, especially in Central and Eastern Europe, which have similar socioeconomic characteristics.

Bičík et al. [9] noted that, according to cadastral data, the area of agricultural land shrunk and the percentage of developed/urbanised land grew in Czechia in the 1990s. For Slovakia, Pazúr and Bolliger [42] noted a decrease in agricultural areas and an increase in urbanised areas from 1980 to 2012 using national level CLC data, among other things. In their analyses of 1990 to 2006 CLC data for Poland, Łowicki and Mizgajski [77] noted an increase in forest and urbanised areas at the expense of agricultural areas. Moreover, Nalej [78] identified the largest LUC for Poland from 2000 to 2006 in the conversion of agricultural land into urbanised areas, mainly in the outskirts of metropolises. Having analysed quantitative data for the years 2002 to 2016, Noszczyk et al. [53] noted positive trends for urbanised and forest areas and reduction of agricultural land and wasteland in eastern Poland. In light of the above, the results of the work seem to be consistent with the existing research in the field, and suggest that the direction of LUC continued from 2006 to 2012 also in functional urban areas.

Currently, landscapes are becoming more urbanised, which in turn results from local changes on a global scale. Moreover, landscape changes should be monitored to ensure proper landscape decision-making [79]. Therefore, the research also demonstrated the possibility of building LUC models at the national level that reliably represent local changes. Moreover, the national LUC models built from the analyses of LU of all the available FUAs in the countries can be the point of reference for positioning LUC in urban areas identified using a complex, multi-attribute local LUC analysis. The mean model, median model, or weighted mean model taking into account the share of urbanised and vegetated areas in the FUA area turned out to represent well LUC in FUAs of individual countries.

The proposed models were built based on the data from the UA. Using the proposed methodology and data from the CLC, it is possible to develop the models describing the LUC in the selected countries or territorial divisions from a given region. Thus, the models can be used to study the directions of changes at the national or regional level for

urbanised areas based on a wide range of the spatial LUC data. For those purposes, the models can be applied for any target countries and even for the whole of Europe. The models provide information that can be used to evaluate the spatial planning documents introduced in the past, define future planning directions, or to eliminate the negative effects of changes. The models can be used to forecast various variants of urban growth and, thus, assess their impact on natural environments and sustainable development (e.g., air pollution, damage of ecosystems).

It should be mentioned that, apart from the models proposed by the authors, there are existing more complex LUCC models [53–56], the use of which require knowledge of the factors causing these changes, such as socioeconomic or demographic ones. The proposed models can be used as preliminary information for more complex models/research. An implementation of the models in the set of the already existing models could eliminate the limitations of the proposed models (that they provide only general information of LUC without identifying factors that have the most significant impact on these changes). Moreover, the methods of the models do not consider the dispersion, clustering, and proximity patterns of LU, which could be revealed through the analysis of spatial metrics at local level. The UA classification nomenclature seems to be a certain limitation of the proposed models, because the vegetation areas can contain areas of temporary vegetated (e.g., arable land) or areas with little or no vegetation (e.g., class 33000: open spaces with little or no vegetation).

Concerning the next development and usage, the models, methods, and results of this study should contribute to research in the field of LUC and its association with changes in the population as well as in urban planning, urban sprawl, or urban growth. The proposed models can also be applied for rural areas, thus providing information for research in the field of agriculture, e.g., changes and conversion of agricultural land. A certain type of limitation may be that models were built on the basis of changes only over a period of 6 years, which is not a long period. Thus, the first step in development of the proposed model will be applied and tested the UA data for period 2012–2018. A completion of UA 2018 in the years 2021/2022 is expected. Thus, the development of the UA project will allow further development of the proposed models. Using data from a longer time period will increase the reliability of the model. Last, but not least, an idea for the development in the future is an implementation of remote sensing data into the models, especially the data from the Copernicus programme (e.g., Sentinel satellite data). Sentinel data and vegetation indices derived (e.g., the normalized difference vegetation index (NDVI)) should enable to validate the results of changes of vegetated areas.

## 5. Conclusions

The main aim of this study was to build LUC direction original models for urban areas from 2006 to 2012 in Czechia, Poland, and Slovakia using LUC data from the UA. The insight into the LUC direction for the investigated FUAs and periods were provided. Urban areas in Czechia, Poland, and Slovakia gained urbanised areas constituting from 0.43% to 0.85% of the analysed areas. The growth was mainly at the expense of agricultural areas. The authors demonstrated that the most significant LUC dynamics can be found in Poland (at around 10%), the second intensive in Czechia (at around 8%), and the least dynamic changes took place in Slovakia (at around 5%). The increase in urbanised areas in Poland was greater than in Czechia and Slovakia by 81% and 93%, respectively.

According to the proposed LUC models, areas considered class 1 LU in FUAs grow on average in six years, by 5.5900‰ in Czechia, 7.5936‰ in Poland, and 4.0769‰ in Slovakia. LU models with the best fit for each country are those for which values for classes 1 and 2 are the closest to the actual percentage changes. For Czechia, the closest values were reached for model  $W_U$ , for Poland,  $W_{U/B}$ , and for Slovakia,  $W_{MN}$  and  $W_{U/B}$ . The weighted mean models that take into consideration areas of urbanised and vegetated land ( $W_{U/B}$  and  $W_U$ ) can be useful for urbanised areas, the mean model  $W_{MN}$  and the median model  $W_{MD}$

can be used, not only for urbanised areas, but also for other functional units. The selection of the specific model depends on the dynamics of changes in the area of interest.

The models and results of this study should contribute to research in the field of LUC and its association with changes in the population, as well as in urban planning, urban sprawl, or urban growth. The models can be used to forecast various variants of urban growth and, thus, assess their impact on the natural environment and sustainable development (e.g., air pollution, damage of ecosystems).

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