LAND-USE/COVER PATTERN SCENARIOS IN ROMANIA MODELLED FOR 2075

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Key-words: land-use/cover pattern, scenarios, CLUE-s, Romania, national scale.

Abstract: Modelling land-use/cover (LUC) scenarios are essential issue to a better understanding of the potential future tendency in order to facilitate sustainable land management practices. Therefore, the present paper explores the simulated two LUC patterns for the year 2075, modelled through a spatially explicit model, i.e., the *Conversion of Land Use and its Effects at the Small Regional Extent* (CLUE-s). Hence, the location of the transitions and their quantity were analysed in comparison to the current pattern (year 2018) in order to explore the potential LUC pattern change in the 2018–2075 period. Overall, the resulting scenarios indicate an increase in built-up areas (+16%), arable lands (+3%), orchards (+13%), forests (+5%) and natural grasslands (+46%), but a decrease in vineyards (–31%), complex cultivation patterns (–21%), pastures (–9%), heterogeneous agricultural areas (–33%), scrub and/or herbaceous vegetation association (–69%), and open spaces with little or no vegetation (–43%). The analysis of the two scenarios shows that the LUC pattern does not vary significantly at national scale. However, the identified changes within the protected areas suggest that a more appropriate land management could have an important influence on the LUC system in the future. The overall scores of $K_{Simulation}$ (0.84) and its components, $K_{Transition}$ (0.97) and $K_{TransLoc}$ (0.86), indicate that the modelled data captured well the simulated trend in the LUC pattern, pointing to a high potential of the data to be used not only to better understand the possible impact on the LUC system, but also to explore the possible environmental and socio-economic implications.

1. INTRODUCTION

LUC change is recognized as a key driver of global change through its interactions with the climate, ecosystem processes, biogeochemical cycles, biodiversity, and human activities (IGBP and IHDP, 1999). This change is influenced by the spatial-temporal interactions between biophysical and human factors at different scales (Turner *et al.*, 1995; Veldkamp *et al.*, 2001; Verburg *et al.*, 2004; Verburg and Overmars, 2009). Given its implication for global environmental change, LUC change has become a priority research-topic of international programmes and projects: e.g., the Land Use and Cover Change (LUCC), launched in 1994 as a core project of the International Geosphere-Biosphere Programme (IGBP), contributing now to the current Global Land Programme (GLP) – a global research project of the Future Earth Initiative; NASA Land Cover and Land Use Change (LCLUC); Land Change Monitoring, Assessment, and Projection (LCMAP); the CORINE Land Cover Programme, coordinated by the European Environment Agency (EEA). These actions recognize the necessity to improve understanding, modelling, and projections of land-use/cover trend from a global

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to a regional scale. At the same time, the development of modern GIS analysis tools and remote sensing products have led to the exponential growth of studies related to LUC change, but with an increasing emphasis on interdisciplinary research (e.g., in relation to climate change, natural hazard and risk, ecosystem services).

Understanding past and recent LUC change and its driving forces is essential to predicting future transitions and, therefore, to facilitate the development of sustainable management practices designed to preserve essential landscape functions (Lin *et al.*, 2007). In this regard, different models have been developed in order to explain and predict the locations of change (Veldkamp and Fresco, 1996; Lambin *et al.*, 2000; Irwin and Geoghegan, 2001). One of the most widely used is the *Conversion of Land Use/Land Cover and its Effects at Small Regional Extent* (CLUE-s), an empirical model based on advanced statistical LUC change (Veldkamp and Fresco 1996). Specifically, CLUE-s is a process-based modelling framework that allows the user to develop a spatially explicit future LUC pattern dataset based on multiple scenarios. The model has been used across a wide range of scales of analysis, mainly in Europe, Asia and Central America; it was implemented to simulate forest-cover dynamics and conservation (e.g., Wassenaar *et al.*, 2007; Manuschevich and Beier, 2016), urban growth (e.g., Li *et al.*, 2014; Jiang *et al.*, 2015; Qian *et al.*, 2020), agricultural lands abandonment (e.g., Verburg and Overmars, 2009; Renwick *et al.*, 2013), or explore the impact of future LUC change on groundwater pollution (e.g., Lin *et al.*, 2007; Dams *et al.*, 2008; Lima *et al.*, 2015), ecosystem services (e.g., Wu *et al.*, 2015; Lei *et al.*, 2021), carbon storage (e.g., Jiang *et al.*, 2017) and land degradation (e.g., Promper *et al.*, 2014; Zare *et al.*, 2017; Chowdhuri *et al.*, 2021).

In Romania, after the fall of the communist regime, the LUC pattern underwent significant long-term changes, as a result of the socio-economic, political and institutional, as well as biophysical drivers (Strimbu *et al.*, 2005; Irimie and Essmann, 2009; Popovici *et al.*, 2013; Kucsicsa *et al.*, 2015; Popovici *et al.*, 2016; Petrişor AI. and Petrişor LE, 2018; Kucsicsa *et al.*, 2019a). The studies undertaken at national and regional level have revealed the strong connection between LUC change and environmental transformations (e.g., Bălteanu *et al.*, 2004, 2005; Bălteanu and Grigorescu, 2006; Popovici, 2008; Bălteanu and Popovici, 2010; Popovici, 2010).

This issue emphasizes the need for LUC prediction as a key step for the examination of the potential future consequences. Hence, few studies related to understanding and assessing the possible future LUC change, estimated through the CLUE-s model, were addressed at national scale. Specifically, based on the simulated LUC transitions (Kucsicsa *et al.*, 2019a), different related-topics were examined, i.e., the estimation of the main changes related to agricultural lands (Popovici *et al.*, 2018), the estimation of the forest-cover dynamics (Kucsicsa *et al.*, 2019b) and their potential impact on aboveground forest biomass (Dumitraşcu *et al.*, 2020), and the estimation of future urban sprawl and its regional differences (Grigorescu *et al.*, 2021). However, the resulting simulations were done at a relative medium spatial and temporal scale (cell resolution = 500 m; time-period <2050), and based on the past LUC tendency calculated for a relatively short period (1990-2000, or 1990-2006). Hence, the aim of the present-study is to analyse possible LUC transitions and their magnitude, increasing the performance and complexity of the simulation by improving the spatial resolution (100 m), expanding the simulated period (up to 2075), as well by considering a hypothetical scenario that shows how appropriate land management practices can affect the LUC system in the area. The calculated past rate of the LUC change used to formulate the baseline scenario of the model was also expanded for 22 years (1990-2012), which may lead to a better estimation of future LUC transitions.

Due to their predictive character, the proposed scenarios represent a background for a further detailed analysis at national and regional scale, not only to quantify and understand the LUC system, but also to examine the possible environmental and socio-economic implication, all this aiming at designing sustainable development plans and strategies at a large spatial scale.

2. STUDY AREA

Due to the complex biophysical features and specific socio-economic condition, Romania comprises a great diversity of LUC types, with significant regional differences. Overall, according to the CORINE Land Cover Database (EEA – European Environmental Agency, 2018), the actual LUC pattern (Fig. 1) is dominated by agricultural lands (arable lands = 8,665,700 ha, 36.4%; vineyards and orchards = 504,000 ha, 2.1%; complex cultivation patterns = 835,900 ha, 3.5%; heterogeneous agricultural areas = 916,700 ha, 3.9% and pastures = 2,623,400 ha, 11.0% of the total country surface), forests (7,129,000 ha; 29.9%) and built-up areas (1,277,500, 5.4% of the total country surface). A significant area is also covered by scrub and/or herbaceous vegetation associations (526,000 ha, 2.2%), and natural grasslands (578,400 ha, 2.4% of the total country surface). The low extension was noticed in the case of water bodies (379,100 ha, 1.6%), marshes (295,900 ha, 1.2%), open spaces with little or no vegetation (including beaches, dunes, sands, bare rocks and sparsely vegetated areas = 31,400 ha, 0.1%) and other categories (including mineral extraction, dump and construction sites = 41,200 ha, 0.2% of the total country surface).

In the recent past (post-1990), the significant socio-economic, political and institutional drivers have led to significant changes in the LUC system, having a major impact on agricultural and forest landscapes, as well as on artificial land expansion. The causes were mainly related to decollectivization and privatization processes, degradation/abandonment of the agricultural land improvement system, urbanisation, economic hardships or shadow businesses coupled with corruption, factors that led to a higher rate of agricultural land fragmentation and abandonment (Bălteanu and Popovici, 2010; Griffiths *et al.*, 2013; Popovici *et al.*, 2016; Dogaru *et al.*, 2019), urban growth (Kucsicsa and Grigorescu, 2018; Grigorescu *et al.*, 2019, 2021) and deforestation process (Dutca and Abrudan, 2010; Griffiths *et al.*, 2012; Popovici *et al.*, 2013; Dumitraşcu *et al.*, 2016; Kucsicsa and Dumitrică, 2019).

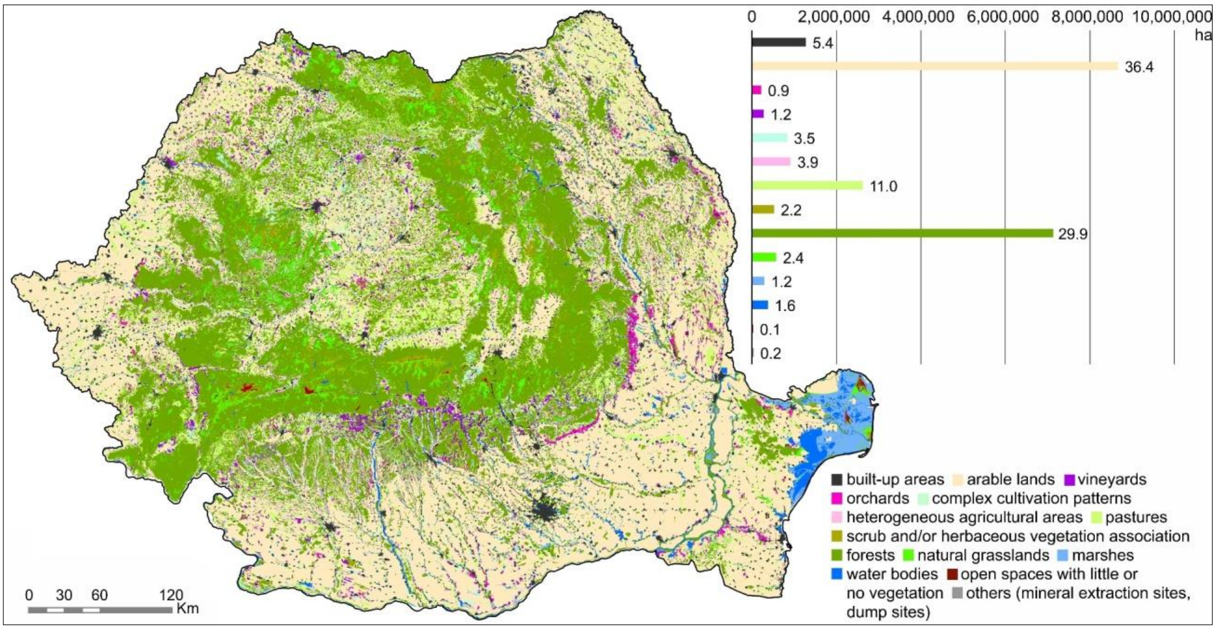


Fig. 1 – The actual distribution of the main land-use/cover classes in Romania (Extracted from the CORINE Land Cover Database, 2018).

3. DATA AND METHODS

3.1. The methodology used to estimate land-use/cover scenarios

The described and discussed LUC scenarios in the present paper represent new predicted outcomes as compared to the previous publications, in order to improve, in terms of spatial and temporal resolution, the number of simulated LUC classes and included determinant factors. The previous estimates already analysed the main future LUC flows (Kucsicsa *et al.*, 2019a), the potential changes concerning agricultural lands (Popovici *et al.*, 2018), the forest cover (Kucsicsa *et al.*, 2019b) and urban areas (Grigorescu *et al.*, 2019), or to estimate the future aboveground forest carbon stock dynamics (Dumitrașcu *et al.*, 2020) by 2050.

The implementation of the CLUE-s model

CLUE-s is a process-based modelling framework used to develop spatially explicit future LUC data that includes a non-spatial and spatial module (Verburg *et al.*, 2002), and combines statistical analysis and decision rules that determine the sequence of LUC types (Schaldach and Priess, 2008). The non-spatial module calculates the demands for LUC classes based on an analysis of the determinant factors, while the spatial one translates these demands into LUC change according to the probabilities and rules for LUC classes using a raster-based system (Verburg *et al.*, 2002).

The simulated LUC classes

The modelling integrates three CORINE Land Cover (CLC) datasets (EEA – European Environmental Agency, 2018): year 1990 and 2012, used to calculate the past LUC trend, and year 2018 to validate the outputs. Year 2012 was also used as the starting point of the modelling (year "zero") and to compute the simulation classes. The CLC classes were aggregated, in general, based on the level II of the CLC nomenclature: *built-up areas, arable lands, vineyards, orchards, complex cultivation patterns, pastures, heterogeneous agricultural areas, scrub and/or herbaceous vegetation association, forests, natural grasslands* and *open spaces with little or no vegetation*. Due to their characteristic and dynamics, several LUC classes (water bodies, wetlands, mineral extraction sites, road and rail networks and associated land, dumpsites, bare rocks) were not taken into account in the simulation.

The allocation procedure

The CLUE-s model requires four inputs (Verburg *et al.*, 2004): *LUC specific conversion settings, LUC demands, spatial policies and restrictions*, and *LUC location characteristics*. Subsequently, these requirements are synthetically discussed, but more details can be found in Verburg *et al.*, (2002) and Verburg and Overmars (2009), which provide a comprehensive description of the model implementation and procedure.

LUC specific conversion settings. The specific conversion settings, which indicate the temporal dynamics of the simulations (Verburg *et al.*, 2004), refer to two parameters required to characterize the individual LUC class: *conversion elasticity* (CE), indicating the reversibility of the LUC change (0 = easy to convert, 1 = irreversible change), and *transition sequences* (TS), expressing the potential conversion from one LUC class to another (0 = not allowed, 1 = allowed). The following values were considered for CE: 1.0 (for built-up areas); 0.3–0.4 (for arable lands); 0.4–0.5 (for vineyards); 0.5–0.7 (for orchards); 0.2–0.3 (for complex cultivation patterns); 0.2–0.3 (for pastures); 0.2–0.4 (for heterogeneous agricultural areas); 0.5–0.6 (for scrub and/or herbaceous vegetation association); 0.7–0.8 (for forests);

0.5–0.6 (for natural grasslands); 0.6–0.7 (for open spaces with little or no vegetation). According to TS, for each of them the LUC was indicated so as to be able to convert into any other, except for built-up areas for which the transition into other categories was not allowed. CE and TS were set based on the authors' understanding of the LUC system and its recent dynamics at regional level.

LUC demands and spatial policies and restrictions. In order to explore the possible differences between the LUC change inside and outside the protected areas, two baseline scenarios were formulated to indicate the demands for LUC in 2075, considering for each of them a level of restriction within the specific locations. ***The first scenario*** **(S_1)** was based on the assumption that future LUC dynamics will be in accordance with the recent registered changes, including within the protected areas. Hence, the calculated annual rate for the 1990-2012 period was linearly extrapolated for the simulated 2013-2075 period. ***The second scenario*** **(S_2)** also points to the future LUC trend in accordance with the recent LUC changes, but it assumes one hypothetical level of LUC transitions within the protected areas in agreement with the appropriate environmental policies. Hence, two protected area categories were considered (The Ministry of Environment, Water and Forests, 2020): (1) those classified as National Parks, for which only de expansion of natural and semi-natural areas (forests, scrub and/or herbaceous vegetation association, natural grasslands and open spaces with little or no vegetation) was allowed; and (2) those classified as Natural Parks (including geoparks, Danube Delta Biosphere Reserve and the Site of Community Importance –SCI / Special Protection Areas – SPA, other than those included among the national parks), for which the deforestation process (including the removal of transitional woodland-scrub) was restricted, while the transitions between other categories were allowed.

According to the recent detected LUC change (1990–2012), an overall increase of built-up areas (+12%), arable lands (+3%), forests (+4%) and natural grasslands (+47%), and the decrease of vineyards (–51%), orchards (–17%), complex cultivation patterns (–21%), heterogeneous agricultural areas (–36%), pastures (–3%), scrub and/or herbaceous vegetation association (–62%) and open spaces with little or no vegetation (–41%) are expected at national level, but with significant spatial differences at regional level.

LUC location characteristics. The location characteristics, which define the "preference" for the specific LUC class at a specific moment in time (Verburg *et al.*, 2005), were empirically estimated as the relation between the LUC pattern (in this case: 2012) and the included determinant factors, by using the following binomial logit model (Eq. 1) performed through the forward procedure in order to select the most statistically significant factors.

$$Log\left(\frac{P_i)}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \dots + \beta_n X_{n,i} \qquad \text{(Eq. 1)}$$

where P is the probability of a grid cell for the occurrence of the considered LUC class on location i; X_1, X_2 ... X_n are the determinant factors; β_0, β_1 ... β_n are the estimated coefficients.

This "preference" (or probability of transition) was established by estimating the relations between each LUC class (as a dependent variable) and 13 biophysical and socio-economic drivers of LUC change (as independent variables). The factors were selected according to data availability and the knowledge of the study-area: *the elevation*, *slope angle* and *slope exposure*[1]; *horizontal relief fragmentation*[2]; *the main soil classes*[3]; *the average annual precipitation* and *temperature* in 1961–2015[4]; *the average number of inhabitants* (1992–2012) and *employees* (1991–2012)[5]; *the protected*

[1] extracted from the Digital Elevation Model obtained by the SRTM–NASA Shuttle Radar Topographic Mission).

[2] calculated using the river network dataset (provided by the EU-Hydro River Network database, available at: https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-river-network-database).

[3] extracted from the data provided by the Research Institute for Soil Science and Agrochemistry–ICPA, 1963–1993.

[4] extracted from the data provided by the National Meteorological Administration.

[5] calculated using the statistical data, provided by the National Institute of Statistics: TEMPO-Online Statistical Databases 1990–2018; available at: http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table.

areas[6]; and *the distance to roads*[7], *settlements*[8] and *towns*[9]. A total of 11 continuous and 12 categorical variables were resulted, adapted into spatially explicit factors through various statistical and geo-processing procedures. For the categorical variables, a binary raster indicating the "presence" (value 1) and "absence" (value 0) was computed. Furthermore, prior to the regression analysis, the effects of multicollinearity between the independent factors were examined through *Pearson* correlations. Hence, in the case of significant statistical correlations ($R_{\min\ \pm 0.7}$), the better predictor variable (in univariate trials) was subsequently used.

Modelling process

After providing all the requirements for the simulation, the process was completed through Dyna-CLUE (v 2.0) (Verburg & Overmars, 2009), a modelling framework which estimates, based on the LUC demand, probability maps and specific conversion settings, the most probable location changes for the simulated LUC classes, conducted by an iterative procedure (Verburg *et al.*, 2002). According to the biophysical potential, land-use history and socioeconomic specifics at regional level, the prediction was achieved for each Romanian Development Region (NUTS II). The regional outcomes have been merged in single maps for further analysis. Due to the type and scale of the data used, and the complexity and limitation of the modelling procedure, a final spatial resolution of 1 ha was chosen for the simulation.

3.2. The predictive performance of the results

The statistic $K_{Simulation}$ (van Vliet *et al.*, 2011) was used to evaluate the predictive performance of the model. The resulting coefficients express the percentage of agreement between the predicted and real data (presently: 2018), including both quantity ($K_{Transition}$) and location information ($K_{TransLoc}$). The $K_{simulation}$ scores vary between −1 and 1, where 1 indicates perfect agreement, 0 the level of agreement expected by chance, and −1 no agreement. The $K_{Transition}$ values range from 0 to 1, 0 indicating that there are no transitions within both the simulated and the reference map, and 1 pointing to the perfect agreement for the transitions. The $K_{TransLoc}$ values range between −1 and 1, 1 indicating an allocation which is as high as possible given the distribution of class transitions, 0 indicating the agreement as expected by chance, and <0 pointing to allocation of class transitions which are worse than can be expected by random allocation (van Vliet *et al.*, 2011). The comparison of the simulated and real data was performed with the help of the Map Comparison Kit (Visser and de Nijs, 2006).

4. RESULTS

4.1. The predicted LUC pattern for 2075. The potential changes between 2018-2075

Fig. 2 illustrates the predicted LUC pattern for 2075 (a) and the changes detected for the 2018–2075 period (b) under S_1 and S_2. In detail, the total amount of the simulated LUC classes and the expected changes for the analysed period are displayed in Fig. 3.

[6] provided by the Ministry of Environment, Water and Forests, 2020, classified into three classes: national parks, natural parks (including geoparks and the Danube Delta Biosphere Reserve) and others (the Site of Community Importance – SCI and Special Protection Areas –SPA, other than those included in the national and natural parks).

[7] calculated using the roads infrastructure, provided by the ESRI Romania database; the influence was established through the multiple *Euclidean* ring buffers (=1000 m).

[8] calculated using the data extracted from the CLC 2012 dataset; the influence was established through the multiple *Euclidean* ring buffers (=1000 m),

[9] calculated using the urban centres' locations; the influence was established through multiple *Euclidean* ring buffers (=1000 m).

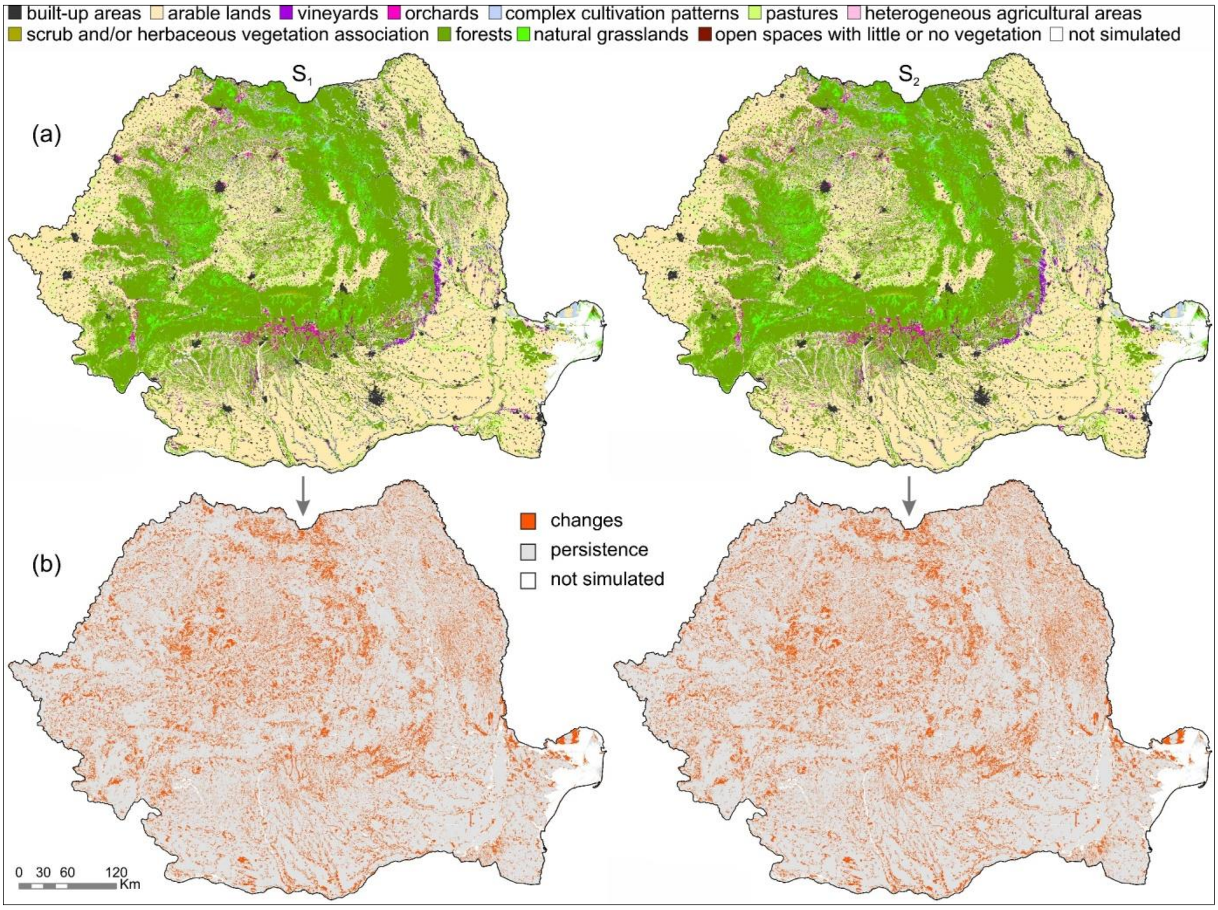


Fig. 2 – The LUC pattern in 2075 (a) and the affected areas by change in the 2018–2075 period (b) as predicted under S_1 and S_2.

The total predicted area of change adds up to 3,776,540 ha (16.4%) under S_1, and 3,840,340 (16.7% of the total simulated lands) under S_2, affecting about 16% of the total country area. Specifically, the model predicted an increase in built-up areas (+16%), arable lands (+3%), orchards (+13%), forests (+5%) and natural grasslands (+46%). On the opposite, the future trend is on the downturn for vineyards (–31%), complex cultivation patterns (–21%), pastures (–9%), heterogeneous agricultural areas (–33%), scrub and/or herbaceous vegetation associations (–70%), and open spaces with little or no vegetation areas (–43%).

The results show a relatively common trend for both S_1 and S_2, the degree of net changes between the scenarios varying insignificantly. Slight difference was obtained for the simulated vineyards (–1.4%), scrub and/or herbaceous vegetation association (+1.2%), complex cultivation patterns (+0.4%), heterogeneous agricultural areas (–0.2%) and natural grasslands (–0.2%) under S_2, in comparison with S_1. However, as expected, the location-specific restrictions indicated for S_2 are more evident within the protected areas, where the predicted forest area is +24.3% higher, and built-up areas are –19.0% lower. Values of –5.6% for agricultural lands and –21.0% for scrub and/or herbaceous vegetation association were also obtained. The values are more significant within the national and natural parks where the predicted forest area is +52.0% higher, and the built-up areas and the agricultural lands are –39.1% and –9.7% lower, respectively, under S_2, when compared to S_1.

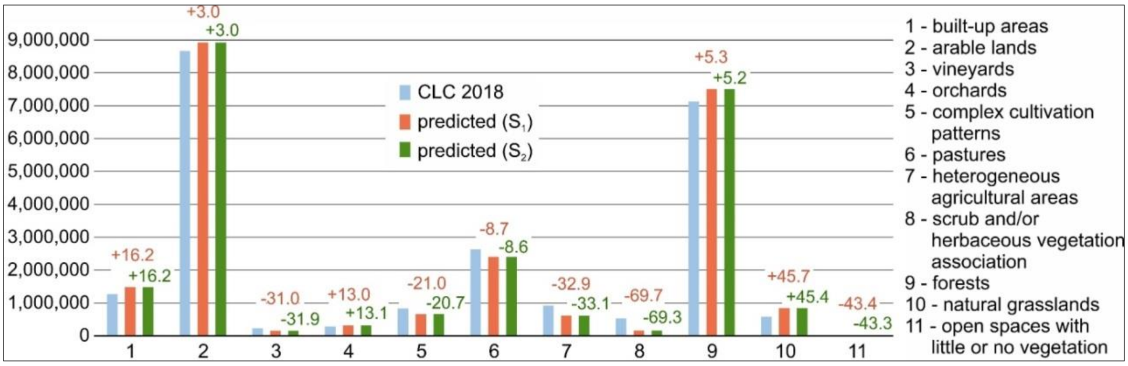


Fig. 3 – The amount (in ha) of the predicted LUC classes compared to the reference year, and the calculated potentially net gains and losses (in %) for the 2018–2075 period.

In terms of the possible transitions (Fig. 4), the built-up areas were predicted to increase mainly to the detriment of arable lands (about 30%), complex cultivation patterns (about 31% for each), heterogeneous agricultural areas (about 16%) and pastures (about 12% of the total). The arable lands were predicted to increase mainly to the detriment of pastures (about 43%), complex cultivation patterns (about 20%) and heterogeneous agricultural areas (about 15%), while orchards – to the detriment of pastures (about 28%) and arable lands (about 21% of the total). The increase in forest area was predicted mainly to the detriment of scrub and/or herbaceous vegetation association (about 39%) and pastures (about 24%), but also heterogeneous agricultural areas (about 14%) and natural grasslands (about 12% of the total). The natural grasslands were mainly predicted to increase on the areas covered by pastures (about 26%), scrub and/or herbaceous vegetation association (about 20%), heterogeneous agricultural areas (about 17%) and forests (about 16% of the total).

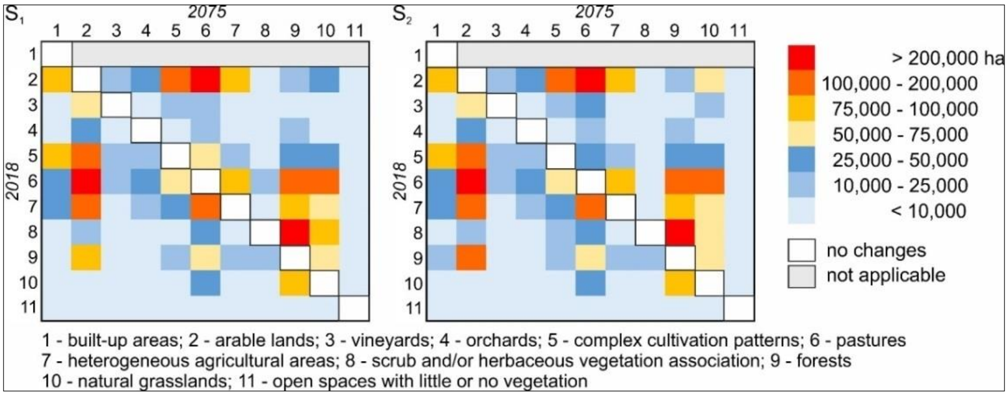
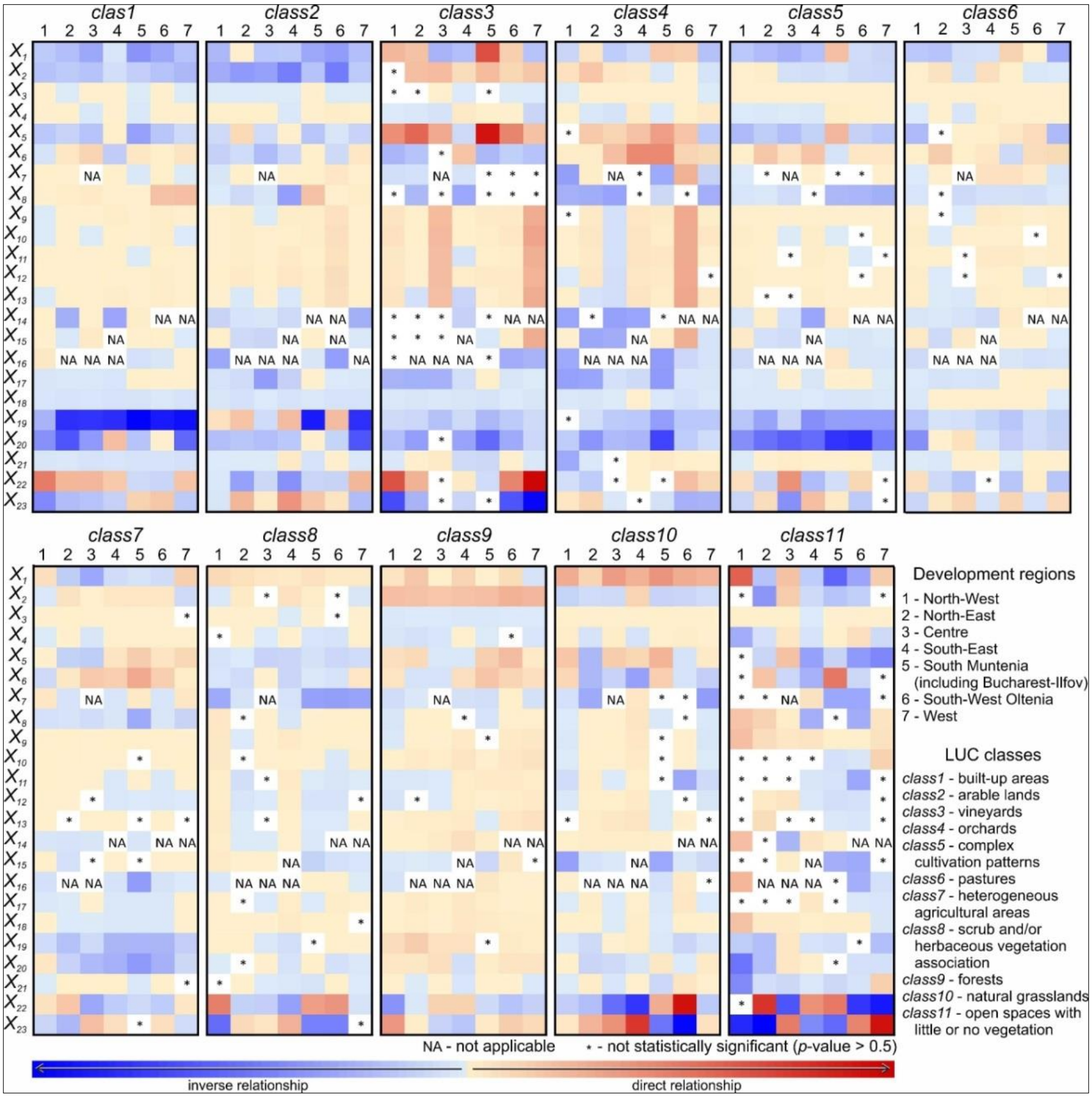


Fig. 4 – The total amount of the potential transitions between the LUC classes in 2018 and as predicted for 2075.

On the opposite, the decline of vineyards was predicted mainly in relation to the expansion of arable lands (about 48%), pastures (about 18%) and heterogeneous agricultural areas (about 17%), while the complex cultivation patterns were predicted in relation to the expansion of arable lands (about 42%), built-up areas (about 17%) and pastures (about 11% of the total). The decline of pastures was mainly predicted in relation to the expansion of arable lands (about 45%), forests (about 16%), natural grasslands (about 11%) and heterogeneous agricultural areas (about 17% of the total). As expected, the decrease of the scrub and/or herbaceous vegetation association was mainly predicted in relation to the expansion of forests (about 60%), but also natural grasslands (about 19%) and pastures (about 9% of the total).

4.2. Driving change factors

Fig. 5 displays the effects of the explanatory factors on the LUC pattern, classified based on the estimated *ß* coefficients in the regression models. In general, the most important explanatory powers are indicated for the specific socio-economic condition in the area, but also for the topographically related indicators and climatic conditions. With the exception of the few LUC classes, the categorical soil classes and the protective measures have, in general, a slight effect or, in some cases, are not statistically significant within a confidence interval of 95% (*p*-value >0.5).



X_1– Altitude; X_2 – Slope angle; X_3– Slope aspect; X_4 – Horizontal relief fragmentation; X_5– Average annual temperature; X_6– Average annual precipitation; X_7– Soil class (salsodisoils); X_8– Soil class (spodisols); X_9– Soil class (protisols); X_{10}– Soil class (luvisols); X_{11}– Soil class (hydrisols); X_{12}– Soil class (cernisols); X_{13}– Soil class (cambisols); X_{14}– Soil class (umbrisols); X_{15}– Soil class (vertisols); X_{16}– Major protected areas (national parks); X_{17}– Major protected areas (natural parks); X_{18}– Major protected areas (others); X_{19}– Distance to settlements; X_{20}– Distance to roads; X_{21}– Distance to towns; X_{22}–Average number of inhabitants; X_{23}–Average number of employees

Fig. 5 – The graph illustrating the effect of factors on LUC, computed based on the estimated *ß* coefficients in the resulting min/max interval of –50.0/+50.0.

Specifically, the regression coefficients indicated that the increase in built-up and agricultural areas are inversely related to the increase in *distance to the roads* infrastructure and *settlements* (including towns), and the decrease in the *average number of inhabitants and employees*. In other words, it all means that urban growth and agricultural lands are more likely to be found in areas with high accessibility, close to the existing (mainly urban) built-up areas. The effect of *altitude* is also evident, a strong negative outcome for the built-up areas, arable lands and complex cultivation patterns, but positive for the natural grasslands, forests, scrub and/or herbaceous vegetation association. Comparatively, the same influence direction was noted for the *slope angle*, the expansion of built-up areas and arable lands increasing whenever the slope declivity values decrease. However, a direct relationship was found between the vineyards, orchards and pastures, and the increase of the slope angle. The *slope aspect* has a slight contribution to the LUC pattern, the occurrence of built-up areas and agricultural lands being, in general, directly related to the increase in solar radiation. A slight effect was also found for the *horizontal relief fragmentation*, with a direct influence mainly on built-up areas, pastures, heterogeneous agricultural areas and natural grasslands, and a reversed effect on forests and open spaces with little or no vegetation.

The climatic condition also brings a significant contribution to the LUC pattern change, the built-up areas, arable lands, complex cultivation patterns and scrub and/or herbaceous vegetation association being more likely to extend in areas where the *average annual temperature* is lower. However, the probability of a LUC transition to vineyards increases where temperatures rise. The increase in the *average annual precipitation quantity* indicates a high suitability for agricultural lands development (except for vineyards) and forests expansion, but a low suitability for scrub and/or herbaceous vegetation association and open spaces with little or no vegetation.

In terms of categorical factors, the regression coefficients suggest that the soil classes, namely *protisols, luvisols, hydrisols, cernisols and cambisols*, are more favourable for the expansion of arable lands, but in general restrictive for the scrub and/or herbaceous vegetation association, and open spaces with little or no vegetation areas. The suitability for agricultural lands decreases in the areas where the *salsodisols, spodisols, umbrisols* and *vertisols* soil classes are well developed. In terms of *protective measures* (as measured according to the S_1), the statistical analysis shows a low probability for built-up areas and agricultural lands, but a high probability for the scrub and/or herbaceous vegetation association, and forests to be extended within the protected areas in the future. The effect of protective measures increases mainly within the national and natural parks, in comparison with the other protected areas taken into consideration (SCI and SPA located outside of the national and natural parks).

4.3. Model performance

The examination of the modelled data for 2018 in comparison with the real data (CLC 2018) shows a fraction of 88% as predicted correctly. In terms of the agreement regarding quantity and location, the resulting overall values were 0.84 for $K_{Simulation}$, 0.97 for $K_{Transition}$ and 0.86 for $K_{TransLoc}$, suggesting that the model performs better than expected by chance (van Vliet *et al.*, 2011). As detailed in Table 1, the better accuracy was obtained for the built-up areas, arable lands, forests, natural grasslands, orchards and pastures, for which the resulting scores were higher than 0.7, suggesting that the spatial allocation is fairly precise. However, the minimum resulting scores for open spaces with little or no vegetation, scrub and/or herbaceous vegetation association and complex cultivation patterns point to a level of uncertainty described by these metrics (van Vliet *et al.*, 2011), especially in terms of the degree to which the transitions agree in their allocations.

Table 1

Model performance indicated by the statistics of $K_{Simulation}$, and its components, $K_{Transition}$ and $K_{TransLoc}$.

	per LUC class											Total	
	1	2	3	4	5	6	7	8	9	10	11		
$K_{Simulation}$	0.93	0.88	0.66	0.73	0.63	0.72	0.65	0.60	0.94	0.78	0.33	$K_{Simulation}$	0.839
$K_{Transition}$	0.98	0.99	0.83	0.88	0.96	0.95	0.99	0.86	0.99	0.99	0.56	$K_{Transition}$	0.974
$K_{TransLoc}$	0.94	0.89	0.79	0.83	0.65	0.76	0.66	0.70	0.95	0.80	0.60	$K_{TransLoc}$	0.862

1 = built-up area; 2 = arable lands; 3 = vineyards; 4 = orchards; 5 = complex cultivation patterns; 6 = pastures; 7 = heterogeneous agricultural areas; 8 = scrub and/or herbaceous vegetation association; 9 = forests; 10 = natural grasslands; 11 = open spaces with little or no vegetation

5. DISCUSSION

New versus previous outcomes

Overall, the produced LUC scenarios are in line with the results reported by previous simulations (Kucsicsa *et al.*, 2019a). However, when it comes to breaking things down, the location of changes and their amount significantly vary in the present outcomes, suggesting a different performance of the simulation. Specifically, different demands for simulation were formulated, more appropriate change factors were included, and a finer spatial resolution together with a longer temporal scale were chosen compared to previous outcomes. On the one hand, increasing the resolution of the simulation from 25 ha to 1 ha supported a better analysis of the location of potential LUC transitions and their amount of change at regional, but also local level. Then, the calculated past rate of LUC change for a longer period, used to formulate the baseline scenario of the model, has better indicated the potential tendency of the LUC pattern for the future. Furthermore, the simulated period up to 2075 resulted in an extended perspective (+25 years) for the analysis, thus supporting the implementation of other related LUC scenarios (e.g., natural hazards in relation to the future LUC change) for a longer time-period. On the other hand, the authors consider that the two formulated scenarios help to explore the potential effect of the more appropriate future protective measures compared to the current situation, thus contributing to a better understanding of how sustainable land management could influence the LUC system in the area.

LUC scenarios and change factors

A significant amount of LUC change was predicted for the study area. The results show that future LUC patterns are likely to continue on the same recent trend (except for orchards), with a calculated change rate of 66,255 ha/year under S_1, and 67,374 ha/year under S_2. The significant net gains were mainly predicted for the natural grasslands, built-up areas, orchards and forests, while net losses were modelled for the scrub and/or herbaceous vegetation association, open spaces with little or no vegetation, heterogeneous agricultural areas and vineyards by 2075. The magnitude of the LUC change between the two scenarios does not vary significantly. However, by analysing LUC transitions inside and outside the protected areas in relation with the formulated scenarios, we have found that a more appropriate land management approach could have an important influence on the LUC process. That is, the location-specific restrictions entailed by S_2 point to a higher level of the expansion of afforested lands, but to a lower level for built-up areas and some of the agricultural land classes in comparison to S_1. Nevertheless, the results suggest that the appropriate environmental policies within the protected areas could lead to an increase in the LUC transition outside them, close to their boundaries, possibly as the result of the increasing demand for wood resources, but also for the agricultural and built-up lands expansion.

The statistical analysis suggests a varying effect of drivers for the LUC pattern, in terms of explanatory power and influence direction, showing that the mechanisms that influence LUC transitions and their magnitudes in the area are complex and interrelated. Among all included variables, anthropogenic factors were found to be the most important of the LUC change, the effect varying significantly according to the specific socio-economic characteristic (but also historical evolution) within the development regions. However, their influence is in relation with the local biophysical features, the effect changing according to the topographic, pedological and climatic characteristics. Thus, in general, the areas covered by the built-up, agricultural lands (with the exception of vineyards and orchards) and open spaces with little or no vegetation are expected to increase within the plains and tablelands, while forests, natural grasslands and scrub and/or herbaceous vegetation association are assumed to be on a rising trend in the hill and mountain units. Furthermore, the indicated relationship direction and the explanatory power for climatic factors suggest an important impact of future climate change on LUC transitions, mainly related to the forest-cover and agricultural lands dynamics. Thus, the observed climate variability and change in the study area (Busuioc *et al*., 2010) could suggest an increase in afforested areas, mainly at high elevations, but a decrease in arable lands and complex cultivation areas, principally at low altitudes. The (current) role of the protected areas is not, obviously, as expected. However, this seems to lead to a slight restriction in the expansion of urban and agricultural areas, supporting instead the expansion of natural/semi-natural areas (forests, scrub and/or herbaceous vegetation association, natural grasslands), especially within the national and natural parks.

The need for LUC scenarios

This prediction of the future LUC pattern offers the possibility to quantify and analyse in detail the LUC transitions in order to explore their possible effect on landscapes, not only at national, but also at regional and local level. For example, Fig. 6 presents the main important changes, aggregated according to the transitions described in section 4.1, with the possibility to quantify and analyse them for major relief units.

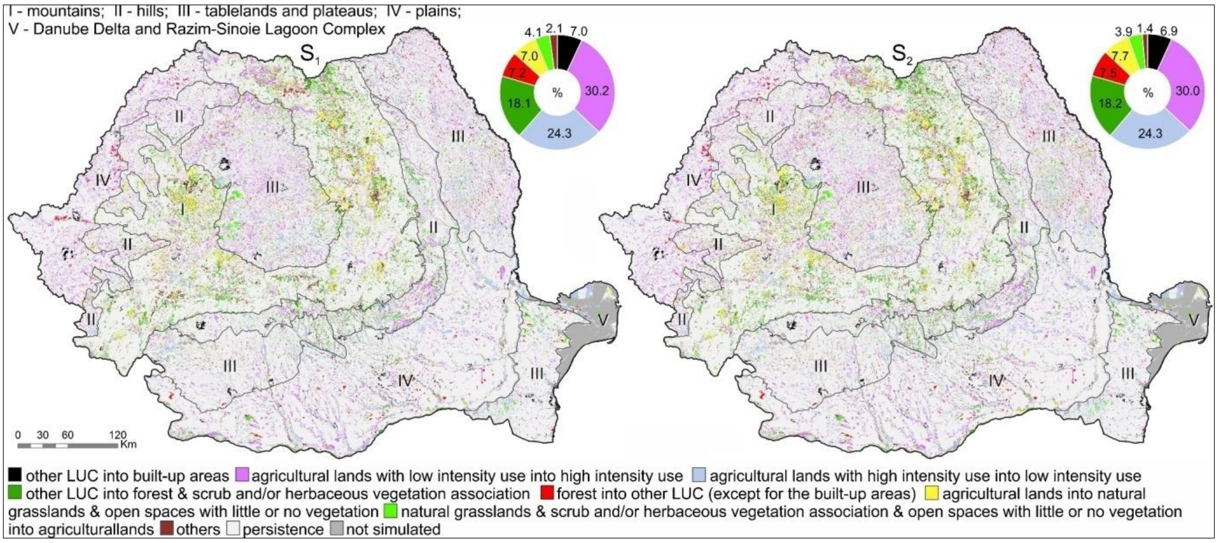


Fig. 6 – The main detected transitions between the LUC classes and fraction of the total changes within the major relief units of Romania.

Hence, the simulated transitions clearly suggest an increased future level of urban growth (7% of the total simulated changes), but taking up 1.8% of the current agricultural land areas, predominantly arable lands and complex cultivation patterns. Furthermore, the detected transition of agricultural lands from a low intensity to a high intensity of use (30% of the total simulated transitions) indicates a possible increase in the process related to the agricultural intensification, predominantly on the large area of plains and tableland/plateau regions. The opposite process (24% of the total simulated transitions) also indicates a possible increase in the risk for agricultural land abandonment in the area. In addition, the predicted increase in forest-cover area (18% of the total simulated transitions), mainly related to the decrease in agricultural lands and natural grasslands in the mountain regions, may suggest the increasing decline in traditional practices (including animal husbandry) for the future. At the same time, the predicted forest-cover gains at high altitudes may suggest the expansion of the recent upward shift in trees detected within the highest mountain units of the Romanian Carpathians (Kucsicsa and Bălteanu, 2020). Conversely, the spatial location and magnitude of the future deforestation process (7% of the total simulated changes) points to a continuous forest loss and fragmentation in the plain and tableland/plateau regions, but also in some of the Carpathian areas, resulting in an even more intense degradation and fragmentation of natural habitats. As the aim of the study is not focussed to such an analysis, further studies using the presented outcomes might examine in detail the LUC transitions, in the context of different topics. These could be combined in the main change flows as proposed by Haines-Young and Weber (2006) and Feranec *et al*. (2010, 2017), and previously examined for Romania at national (Popovici *et al*., 2013, 2018; Kucsicsa *et al*., 2019a) and regional level (Kucsicsa *et al*., 2015; Popovici *et al*., 2022).

The presented scenarios are not only a background to quantify and understand the possible impact on the LUC system, but also to design development plans and strategies at large spatial scale (Koomen *et al*., 2008). For example, the estimation of the future potential LUC pattern change is an important key for the analysis addressed to the spatial-temporal variability of landslide hazard and risk (Promper *et al*., 2014) and hazard mitigation plans (Frazier *et al*., 2013), given that the study area is one of the European countries severely affected by landslides (Bălteanu *et al*., 2010). Furthermore, the resulting spatial data could be useful to explore the possible consequences of LUC transition on landscape diversity and biodiversity (MacDonald *et al*., 2000; Fischer *et al*., 2008; Verburg *et al*., 2009), the implications for ecosystem services (Field *et al*., 2007; Zimmermann *et al*., 2010), or aboveground carbon allocation (Le Page *et al*., 2013; Dumitrașcu *et al*., 2020).

The uncertainties of the simulation

Overall, the proposed scenarios captured the trend in LUC change, the accuracy assessment suggesting a concurrence between the simulated and the real data. However, the results could be subject to several errors mainly associated with the methodology, but also to the LUC base-data used for the simulation, as well as the change factors taken into account. Next, some of the most important uncertainties are concisely described, but more details can be found in the previously mentioned studies (Kucsicsa *et al*., 2019a, b; Grigorescu *et al*., 2019; Dumitrașcu *et al*., 2020). On the one hand, the model parameters and structural uncertainties within the model (Verburg *et al*., 2013) might lead to uncertainty for the future LUC patter outcomes and, therefore, to uncertainty within the future LUC transition and quantity of change. On the other hand, the possible miss-classification of the CLC database used may lead to some mistakes related to the recent real LUC transition (Popovici *et al*., 2013; Kucsicsa and Dumitrică, 2019), thus resulting in an un reliable LUC pattern prediction. Furthermore, the LUC trend calculated for 22 years, used to formulate the baseline for the scenarios, may result in an underestimation of the future LUC transitions for such a long period of time (63 years). In addition, the proposed comparative scenarios were only in line with the understanding of how a more appropriate land management can influence the LUC characteristic. Thus, the formulated S_2 should be considered as hypothetical, since the implementation of such suitable protective future measures is more or less probable. Under these circumstances, the predicted maps must be regarded as indicating a LUC tendency rather than an accurately predicted location of change, the uncertainties increasing at the local level.

6. CONCLUSIONS

The present study explores the newly predicted LUC pattern for the entire area of Romania, simulated regionally through spatially explicit LUC change modelling, i.e., the CLUE-s approach. We have produced and analysed two future potential LUC pattern change, based on the recent LUC change tendency in the area, but considering different specific transition criteria for the future.

The resulting spatial data demonstrate a significant LUC dynamic for the future, resulting in a significant positive tendency of built-up areas, orchards, forests and natural grasslands, but a decline in the case of vineyards, heterogeneous agricultural areas, scrub and/or herbaceous vegetation association, and open spaces with little or no vegetation by 2075. Furthermore, we tested whether the appropriate land management could have an effect on the LUC system, by exploring the situation of two different areas (protected and non-protected). Overall, our findings indicate that the magnitude of the LUC change between the two scenarios does not vary significantly at national scale, but does show significant differences at the regional level, as shown from the specific LUC transitions inside versus outside the protected areas.

The data also demonstrates that the mechanisms that influence LUC pattern are complex and interrelated, the change and its amount varying significantly depending on the regional biophysical and socio-economic specific characteristic. Overall, the statistical analysis suggests that the anthropogenic type is the most important of the LUC change factors, but their effect is linked to the specific biophysical features.

The detected LUC transitions and their quantity clearly suggest a possible involvement of LUC change in any future landscape transformation, with possible important environmental and socio-economic implications. Therefore, the presented outcomes were produced not only as a baseline for a further detailed analysis related to the LUC system, but also to explore other connected issues in the fields of geomorphology, biogeography or ecology. Furthermore, the findings resulting from the analysis of the relationship between the LUC pattern change and its determinant factors may increase the knowledge regarding the mechanisms that influence the LUC pattern change in different environments. Also, the predictive character of the study could represent a background to design appropriate plans for sustainable land management at different spatial scales.

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