Technical workshop

Prospective trends in the mapping of future expected land use and land cover patterns”

24 April 2025

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Agenda

10 00 (EET) Maris Klavins (University of Latvia, Latvia). Introduction. Europe-Land project: creation of new perspective on land use changes in Europe

10 15 Lucie Kupkova (Charles University, Czech Republic) Land use/land cover modelling tool database and success stories of modelling applications

10 45 Janis Krumins (University of Latvia, Latvia). Scenario-Based Modeling Land-Use and Land-Cover Changes to Promote Sustainability in Biosphere Reserves: A Case Study from North Vidzeme, Latvia

11.15 Gheorghe Kucsicsa and Mihaela Sima (Institute of Geography, Romania) Modelling case study on land use/land cover changes in Romania

Discussion moderated by Maris Nartiss

Introduction.

Europe-Land project: creation of new perspective on land use changes in Europe

24 April 2025

Maris Klavins

University of Latvia

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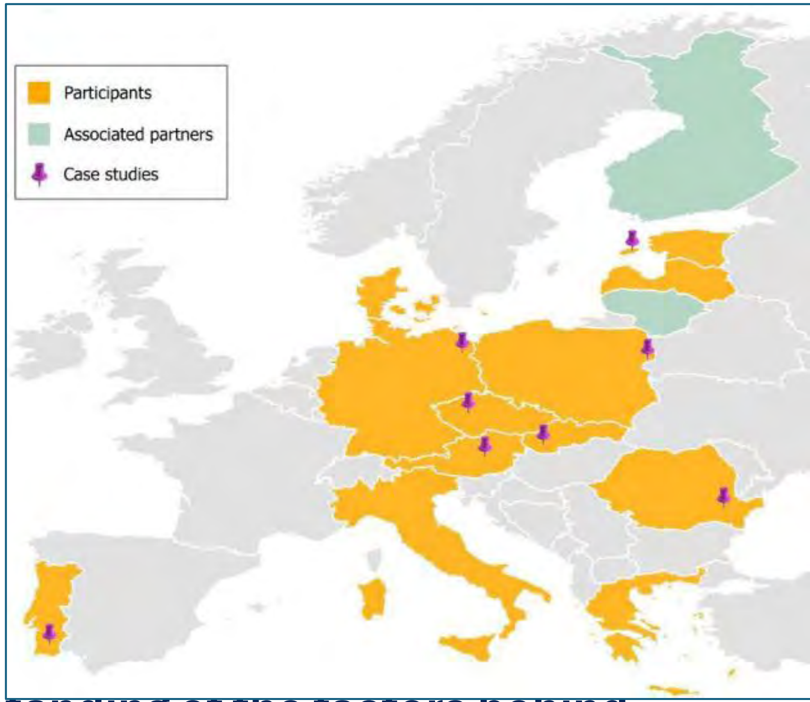
Europe-LAND in a nutshell



- **Consortium**: 13 partners (12 countries, 8 cases), 2 Associates (FIN, LIT)
- **Duration:** 1 June 2023 til 31 May 2027

<u>Main Objective:</u>

to identify, develop, test and implement integrated tools to **improve the understanding of the factors behind land-use decisions** as well as the **stakeholders‘ awareness and engagement** in terms of climate change and biodiversity challenges across Europe.

This includes **increasing the knowledge base** on how such decision can be oriented towards the efficient and socially responsible pursuit of multiple policy objectives on various scales in order to **gain a national, regional and pan-European vision** that supports land-use strategies, climate change mitigation and adaptation, as well as biodiversity conservation.

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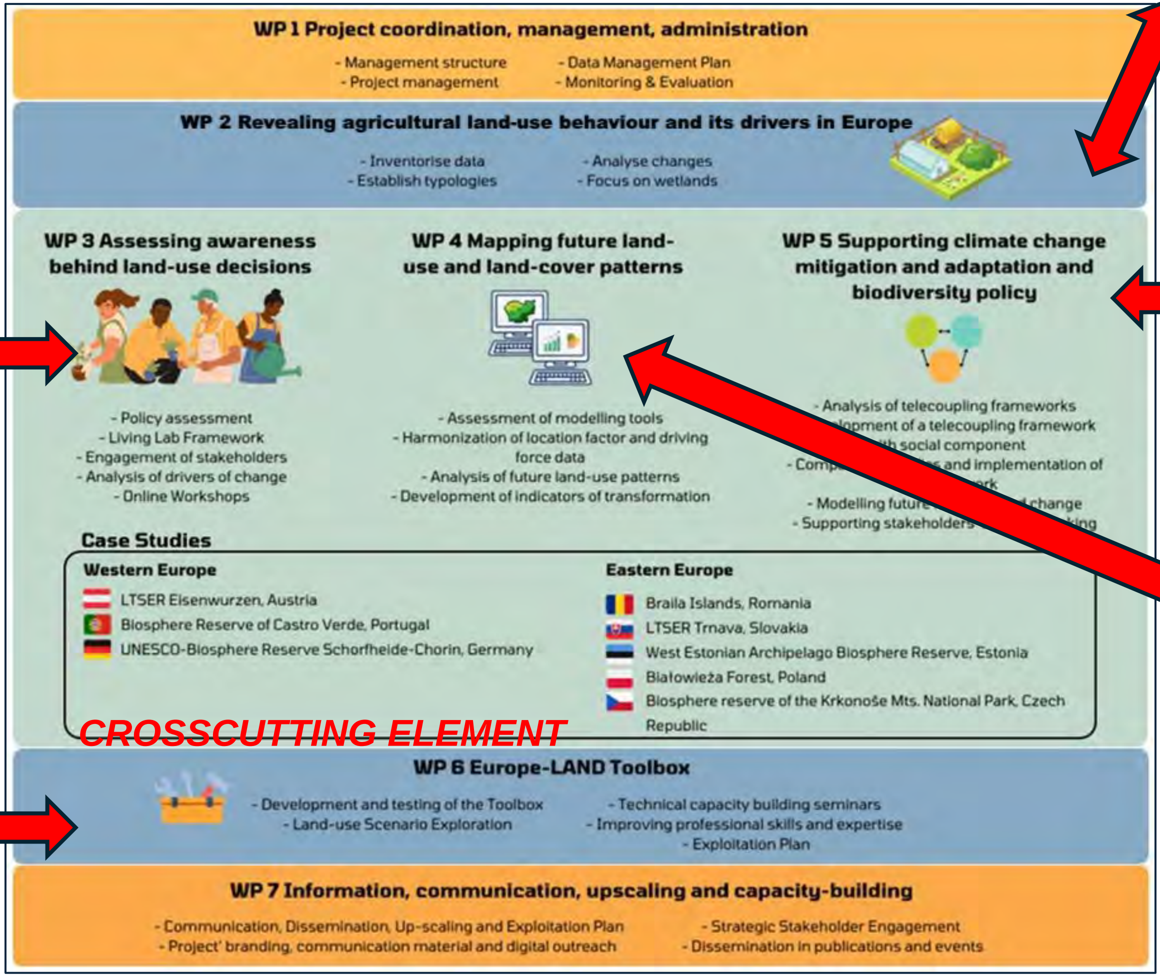
Integrated Methodology

SO1: To foster a wide understanding of the key motivations and drivers behind land-use related decisions in Europe (Means of delivery: WP2).

SO2: To identify the awareness of key actors about climate change and biodiversity challenges in respect to land-use + willingness to address them (Means of delivery: WP3).

SO4: To support climate change mitigation and adaptation efforts and biodiversity policy design and implementation by constructing and testing a dedicated conceptual telecoupling framework to analyse LU strategies (Means of delivery: WP5).



INTEGRATING ELEMENT

SO5: To gather and consolidate land-use experiences by means of a dynamic toolbox of instruments to be used by the key actors at various levels in order to visualise spatial and temporal changes in land-use, based on different planned actions

SO3: To characterise future expected land-use patterns that are consistent with long-term objectives and with a focus on climate and biodiversity in comparison with current and past situations (Means of delivery: WP4).

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WP 1

Task 1.1: Establishing the Management Structu (M1-3, lead: 01/HAW)

Setting up Project Management Board, Project Assembly, Advisory Board

Task 1.2: Project Management (M1-48, lead: 01/HAW)

Establishing and staffing project office, partner guidance (project management handbook deliverables) daily operational management, activity and financial monitoring and reporting, quality control, timely organisation of project assemblies and management board meetings, communication with EU, ambassador for the project.

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WP2: Revealing agricultural land-use behaviour and its drivers in Europe

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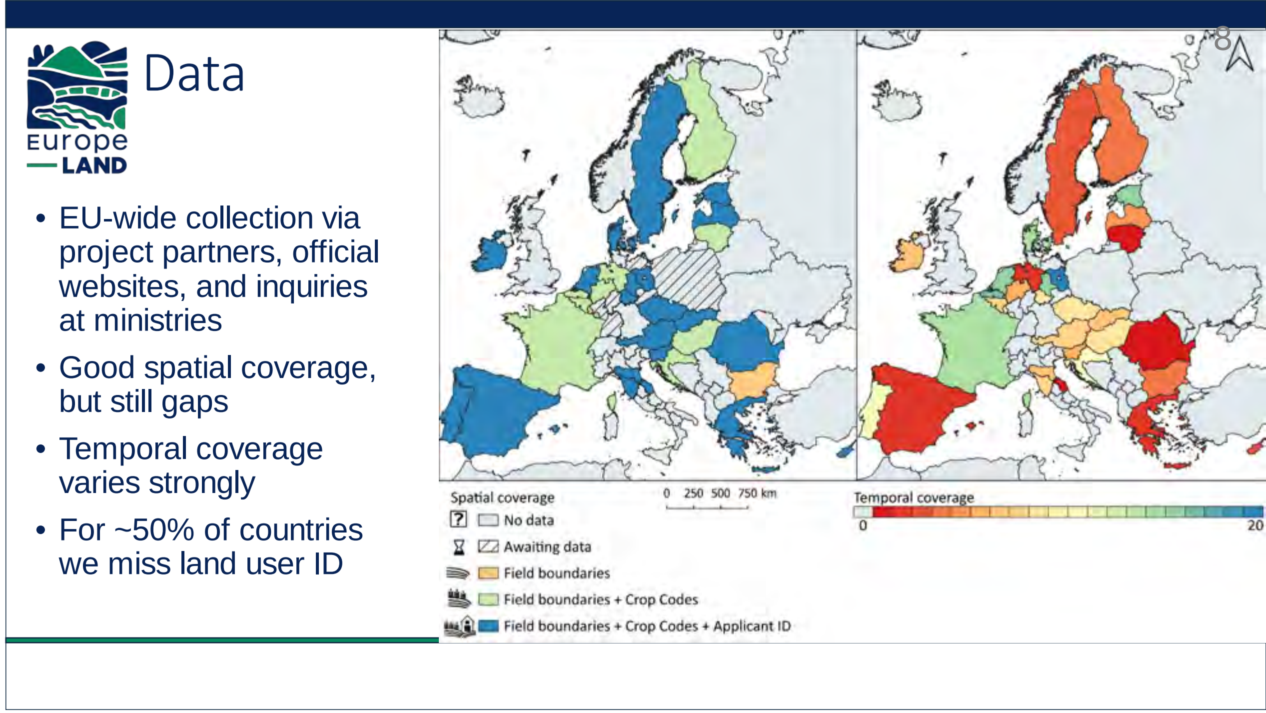
WP 2 – Tasks



Task 2.1: Inventorise and harmonise IACS data across the EU (M1-12; lead: UCPH)

IACS Database with novel high-quality EU land-use and land management data compiled, in ZENODO repository

Task 2.2: Establish EU-wide farm typology (M4-42; lead: UCPH)

EU-wide farm typology. The coding of a clustering algorithm has begun, and a local case study of the German Federal State of Brandenburg, provided first results of the methodological approach towards identifying spatially differentiated farm typologies based on the IACS geodatabase

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WP 2 – Tasks

Task 2.3 Analyse agricultural behaviour and its drivers (M12-40; lead: IAMO)

assessment of policy effects on land-use changes across the EU was evidenced in the conceptualisation of the empirical strategy of the regression analysis, further advancement is linked with the finalization of the IACS database

Task 2.4: The carbon cases: wetlands (M1-44; lead: BUT)

literature search for EU-wide GHG Emission Factors has been completed, resulting in 176 analysed papers, and an EU-wide histosol and peatlands mapping is under way

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WP3: The awareness behind land-use decisions related to climate change and biodiversity

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WP 3 – Tasks

Task 3.1: Assessment of policy incentives and instruments related to land-use decisions (M1-32; lead: BUT)

Structured review of national policy instruments pursued within consortium, current research work pursued by all partners comprises review of national policy instruments, classifying and detailing the instruments in line with classification guidelines

Task 3.2: A Living Lab Framework for understanding the awareness of climate change and biodiversity challenges (M1-24; lead: IGAR)

A LL Framework and Co-Creation Roadmap have been developed, characterize the 8 case studies of the project using a standard template, map the stakeholders using common guidelines and templates, performed a systematic literature review to draft the Living Lab framework of the project, organise the "Mirror" Workshops in the partners' countries


Europe — LAND

D3.2. Methodological framework "Living Labs"

Dissemination Level	☒ Public ☐ Sensitive
Version	V[X] (This deliverable resembles a tentative version until official approval by the EU)

Project Acronym	Europe-LAND
Work Package	WP3
Lead Author (Partner)	Mihaela Sima (Institute of Geography - IGAR, Romania) and Nicos Theodossiou (AUTh, Greece)
Contributing Author(s) (Partner)	Ines Grigorescu, Ana Ursanu, Laura Lupu, Alexandra Vrinceanu, Gheorghe Kursicsa (IGAR), Charis Stavridis, Lysandros Katsifarakis (AUTh), Daniel Müller (IAMO) + ALL PARTNERS
Deliverable	D3.2 Methodological framework "Living Labs"
Deliverable Lead	IGAR+AUTh
Type	Report
Contractual delivery date	30.11.2024
Actual submission date	29.11.2024

No	Country	Date of the Mirror Workshop	Format	No. external of participants	Observations
1	Romania	13th June 2024	In-Person	21 participants	Europe-LAND event
2	Germany	1st October 2024	Online	7 participants	Europe-LAND event
3	Portugal	14th October 2024	In-person	13 participants	Europe-LAND event (session) in the framework of a national conference
4	Latvia	16th October 2024	Hybrid	29 participants	Europe-LAND event
5	Poland	17th October 2024	Online	21 participants	Europe-LAND event
6	Greece	23rd October 2024	Online	19 participants	Europe-LAND event
7	Slovakia	10th October 2024, 17th October 2024 and 7th November 2024	In-person and hybrid	110+35+75= 220 participants	expert workshop, seminar with practical demo and national dialogue
8	Austria	14th October 2024; 18thNovember 2024	Online	11 participants	Europe-Land events
9	Italy	30th October 2024	Online	22 participants	Europe-LAND event
10	Czechia	18th October 2024	Online	6 participants	Europe-LAND event
11	Denmark	9th October 2024	In-person	200 participants	Expert exchanges in the frame of national land-use conference "Fremtidens arealanvendelse (Future land use)" in Aarhus, DK
12	Estonia	27th November 2024	In-person	32 participants	Europe-LAND event

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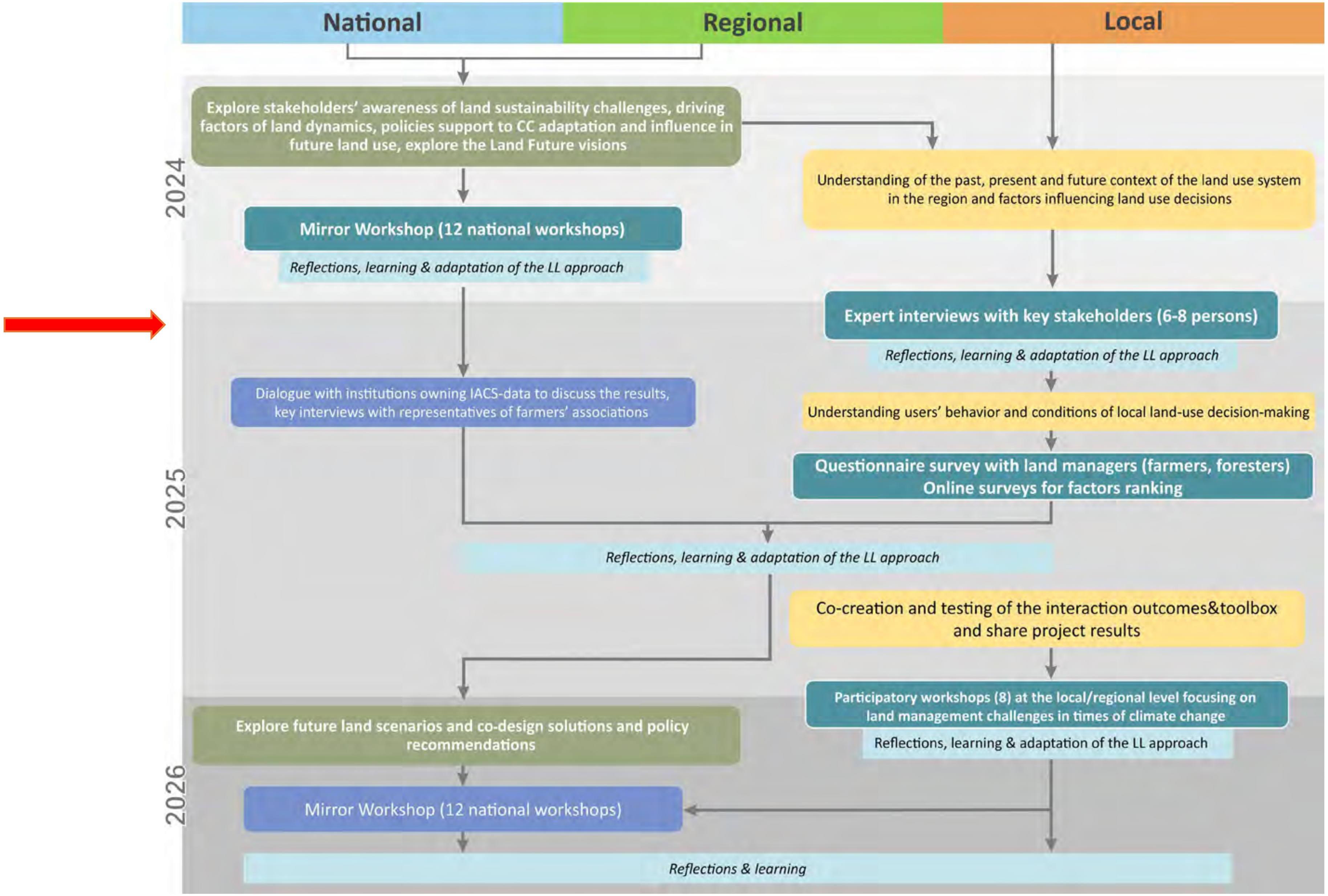

Europe-LAND Co-Creation Roadmap

WP5: Supporting climate change mitigation and adaptation efforts and biodiversity policy design

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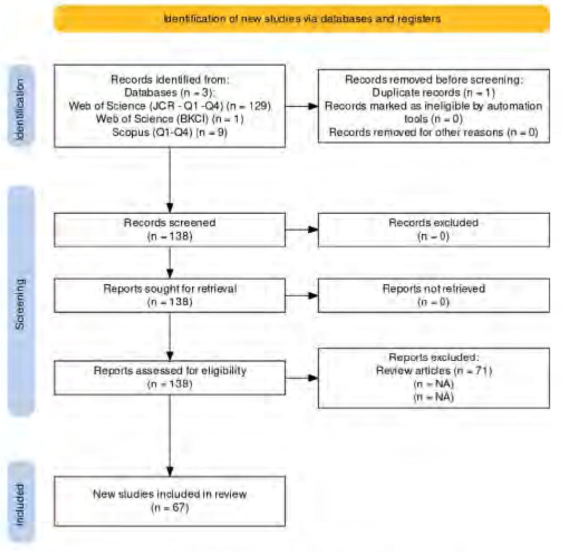
WP 5 – Tasks

Task 5.1: Analysis of telecoupling frameworks on land-use and climate changes and biodiversity protection, highlighting SSH aspects (M1-12; lead: SUA)

Descriptive literature review focusing on disclosing existing methodological approaches (quantitative and qualitative), in line with the PRISMA (Preferred Reporting Items for systematic Reviews and Meta-Analysis) standard

Figure 2: PRISMA of the literature included for review



Source: Figure generated from own data in PRISMA

Task 5.2: Developing a telecoupling framework including evaluation of various socio-spatial structures (M12-30; lead:SUA)

Draft Europe-LAND TC framework developed, research action has been progressing, with the analysis of factors and causes, i.e. so-called proxima underlying drivers or driving forces.

WP5: D5.2 Dataset- Draft EuropeLAND telecoupling framework

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WP 5 – Tasks

Task 5.3: Comparative study on land-use cases and transitions (M12-46; lead: EMU)

Bilateral online meetings of SUA with Task leader EMU – conceptual notes prepared / methodological steps discussed + literature review; SUA - redundancy analysis of the IACS data - clustering countries for comparative study (D5.4)

Task 5.4 Modeling future land-use change (LULCC) under different socio-economic and biophysical scenarios (M18-47; lead: BOKU)

BOKU – initial list of indicators for ABM prepared

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WP6: The Europe-LAND Toolbox: Exploring the dynamics of future land use

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WP 6 – Tasks

Task 6.1: Development and testing of Toolbox (M1-46; lead: AUTh)

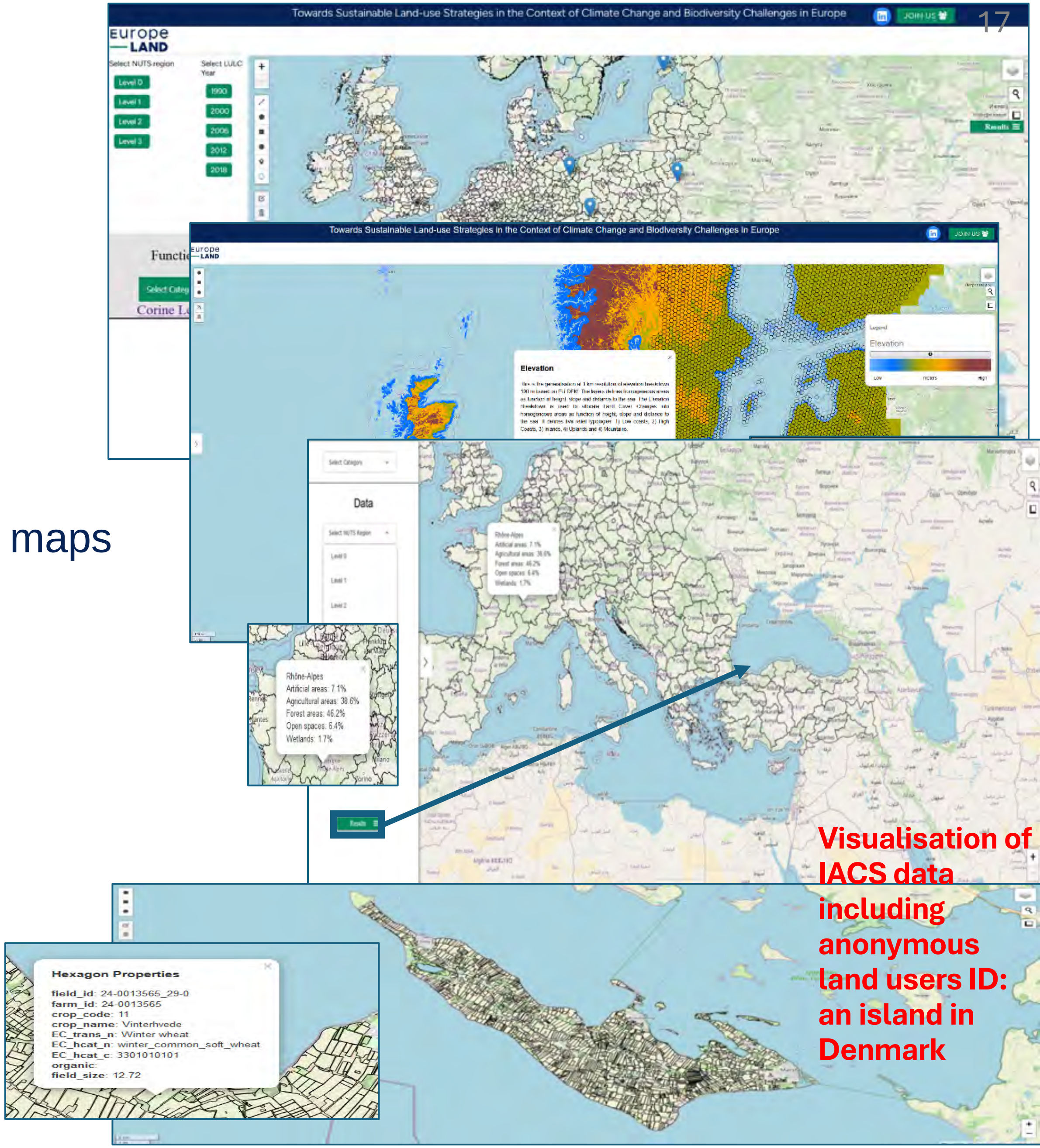
Review of various open-source web GIS platforms led to

→Leaflet (https://leafletjs.com/reference.html) = open-source JavaScript library for (mobile-friendly) interactive maps

→Basic structure of the platform has been established

Layers that are already operational:

- Background: Web Map services
- Copernicus layers
- NUTS regions with LU/LC analysis/stats
- CORINE Land Cover
- NATURA areas
- Platform data-ready for data and results case studies
- Results from IACS harmonised data can be visualised



Visualisation of IACS data including anonymous land users ID: an island in Denmark

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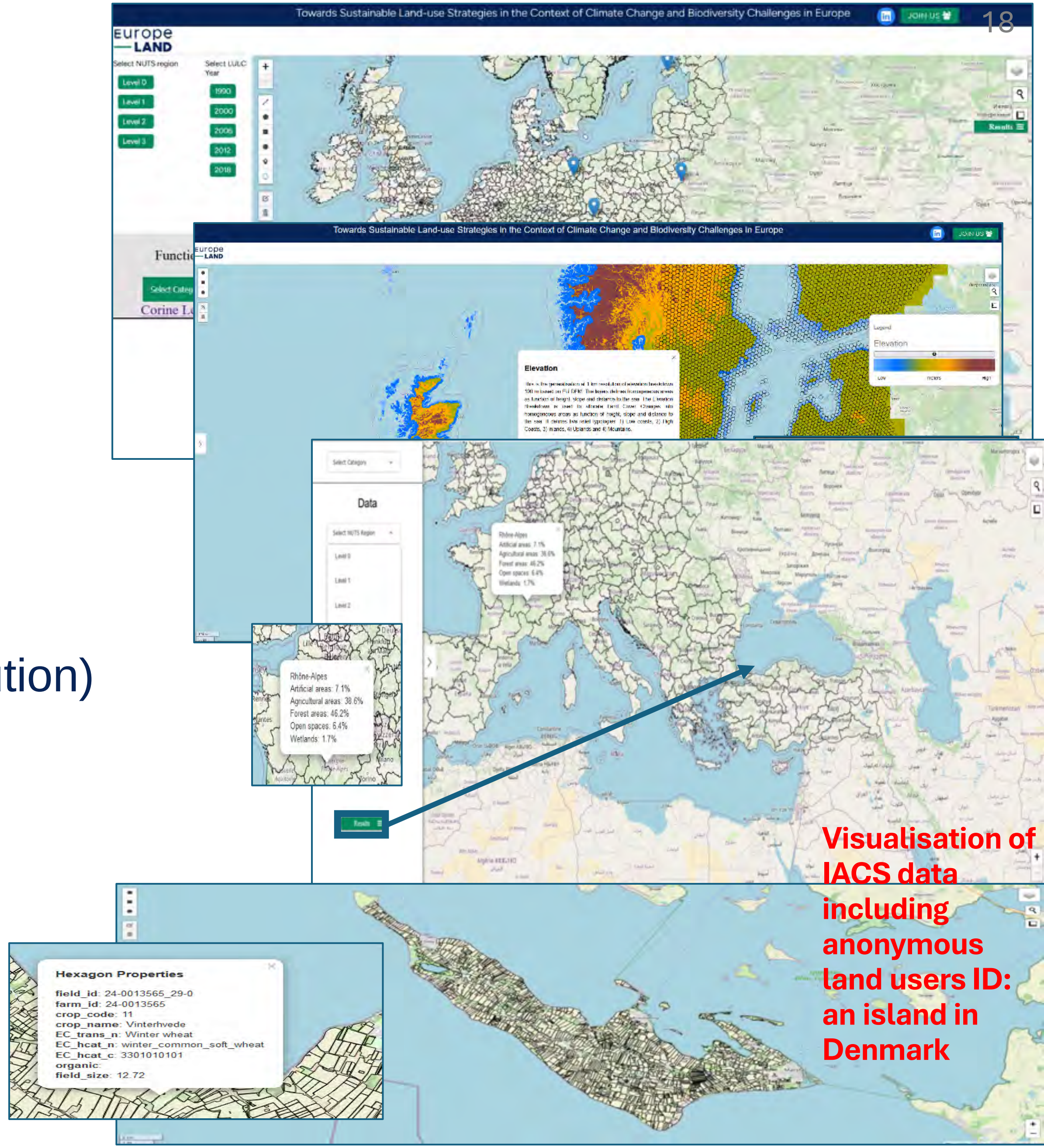
WP 6 – Tasks

Task 6.1: Development and testing of Toolbox (M1-46; lead: AUTh)

Features/Tools already operational:

- User can upload kml file to select area
- Compare tool (side by side before and after images)
- Slider tool (image transition presenting temporal evolution)
- Tile server functionality for optimised performance, reduced bandwidth usage, dynamic styling, improved interactivity



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WP 6 – Tasks

Task 6.3: Technical capacity building (M6-45; lead: HAW)

draft programme overview developed; CB seminars backto be held back-to-back with upcoming external events (2x WP3 organised (IAMO Forum 2024, IGU International Geographer’s Union Conference, Dublin)

Task 6.4: Improving professonal skills and expertise in land-use management (M12-46; lead: UNIBO)

MOOC conceptualization, review and finetuning of concept, curriculum building with inputs from all WPs; guidance for content production (video, texts, interactive quizzes, additional information), adapting given content with MOOC requirements is ongoing, scheduling of further exchanges with UNIBO technical team; first discussion on strategic alignment of the MOOC with summer school proposal by EMU

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WP7: Information, Communication, Upscaling and Capacity-Building

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WP 7 – Tasks

Task 7.4: Dissemination of Europe-LAND results in scientific publications, seminars, and international conferences and outreach, including students (M6-47; lead:HAW)

Wide dissemination of project progress and first results could be observed on local / national / international level; press releases; master class lecture held; podcast series in development, first episode forthcoming

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Land use/land cover modelling tools: database, cards and success stories

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Dpt. of Applied Geoinformatics and Cartography

Europe-LAND

Europe LAND

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WP 4 Mapping of Future Expected Land Use and Land Cover Patterns Consistent with Long-Term Objectives

Objective: To undertake the mapping of future expected land use, with a focus on **climate change** and **biodiversity** challenges, and by analysing the current situation and future trends

Task 4.1 Assessment of land use and land cover (LU/LC) change spatial modelling tools and databases, considering impacts of climate change, mitigation potential and biodiversity (Duration: M1 – M24)

Database on existing LU/LC patterns and Database on LU/LC modelling tools – current state and further development

Motivation

LU/LC datasets and dynamic spatial simulation models of LU/LC can serve as informative platforms and data sources for policy setting and decision-making processes on the use and management of land resources.

Stakeholders must have information about available modelling tools and LU/LC datasets.

The database and assessment of existing LU/LC layers/datasets can help stakeholders/decision-makers to work efficiently with available LU/LC data sources.

Goals

To provide a list/database of:

1) Existing LU/LC layers/geodatabases in the EU

2) LU/LC spatial modelling tools

Anticipated results

Current LU/LC layers/geodatabases (e.g., Copernicus monitoring services, LULUCF, LUCAS, NATURA 2000, outputs from various LU/LC projects etc.) can be used by stakeholders for a comparative temporal evaluation of LU/LC change at regional, national and international levels and potentially (mainly by scientists) for the evaluation of climate change and its impact for mitigation and biodiversity preservation.

The database of LU/LC spatial modelling tools will enable the stakeholders/scientists/decision-makers to select the appropriate tool according to the modelling requirements, based on parameters that will be listed/described.

LU/LC spatial modelling tools

3 products/outputs for modelling tools:

- Database of modelling tools – based on papers dealing with modelling tools
  - Sorted by:

    a) type of used modelling approach/tool (CA models, CLUE-S models, LCM models, IAM models… etc.)

    b) special interest land use/cover categories – forests, wetlands, croplands

    c) geographical interest – Europe and particular European countries (mainly countries of project partners and countries with tradition in modelling practice)

  - Stored information (based on papers that use the tool) – name of modelling tool, topic, year of publication, authors, Access/link, Used modelling method, scale, LCLU categories, inputs to modelling, outputs, published case studies, area of interest, continent, references

- Cards of modelling tools
- Success stories for modelling tools

… Database, Cards and Success stories will be interconnected and published (on the project webpage or on a web connected to the project web page), ZENODO fx 1- Name of modelling tool/ software

A	B	C	D	E	F	G	H	I	J	K	L	M	N	
1- Name of modelling tool/ software	1-year	topic	Author/Provider	Access (link)	free of charge or not (Y/N)	Type of model (Table 1)	Used modelling method/s	scale (local/regional/global - L/R/G)	focus - types of LCLU categories	inputs	outputs	published case studies (area, purpose, scale, categories, methods)	continent	references
A-Markov and Random Forest	2023	Modelling of land	Asif, M., Kazmi, J. H.	https://www.tar	Y	Statistical models	CA-Markov and	R	Land use and land cover ch	Satellites images of the Lands	to predict the land use map for	deserts in Punjab, Pakist	AS	Asif, M., Kazmi, J. H., Tariq, A., Zhao, N., Gu
BPNN_CA_Markov tools	2020	Spatiotemporal LU	Huang, Z., Du, H., Li	https://www.mc	Y	Statistical models	BPNN_CA_Mark	L	Land use and land cover ch	Land-use data 2004, 2008	demands of each land-use type	Anji County in China	AS	Huang, Z., Du, H., Li, X., Zhang, M., Mao, F.
CA-Markov	2014	Predicting Urban L	Nouri, J., Gharagozl	https://link.sprii	N	Statistical models	CA-Markov	L	distribution of urban land u	land use maps of years 1989-	spatial distribution of urban lan	Bandar Anzali in Iran	AS	Nouri, J., Gharagozlou, A., Arjmandi, R., Fa
CA-Markov	2020	Multi-scenario sim	Zhou, L., Dang, X., S	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Land use Land use 2000, 201	to predict the land use map for	Shanghai in China	AS	Zhou, L., Dang, X., Sun, Q., & Wang, S. (202
CA-Markov	2021	Predicting land c	Gemitzi, A	https://www.tar	y	Statistical models	CA-Markov	R	Land use and land cover ch	provided annually from 20	Future land cover projections u	Greece	E	Gemitzi, A. (2021). Predicting land cover ch
CA-Markov - terrset18.31	2021	Land Use and La	Mathewos, M ; Le	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Landsat TM for 1991, ETM+ f	prediction LUCC for 2050	Matenchose Watershed,	AF	Mathewos, M., Lencha, S. M., & Tsega
CA-Markov and InVEST model	2019	Assessing the effe	Zhao, M., He, Z., Du	https://www.sci	Y	Statistical models	CA-Markov and	L	Land use and land cover ch	The 16-day 1000 m MODIS N	LUCC between 2001 and 2029	Heihe River IN cHINA	AS	Zhao, M., He, Z., Du, J., Chen, L., Lin, P., & F
CA-Markov and SWAT	2021	Future Runoff Vari	Ji, G., Lai, Z., Xia, H.,	https://www.mc	Y	Statistical models	CA-Markov and	L	Future Runoff Variation and	The land use data ,the month	future period (2040–2060) all s	yellow river basin in Chi	AS	Ji, G., Lai, Z., Xia, H., Liu, H., & Wang,
CA-Markov model module in t	2022	Comparison of mu	Lin, Z., & Peng, S.	https://www.sci	Y	Statistical models	CA-Markov and	L	Land use and land cover ch	five high-resolution remote s	Land use and land cover change	Lake basin in China,	AS	Lin, Z., & Peng, S. (2022). Comparison of m
CA-Markov- terrset18.31	2023	Land use and cove	Olipa Simon, James	https://link.sprii	N	Statistical models	CA-Markov	L	Land use and land cover ch	satellite imagery from Landsa	prediction LUCC in 2030	Dar es Salaam metropoli	AF	Simon, O., Lyimo, J., & Yamungu, N. (2
CA-Markov- terrset18.31	2018	Assessing tempora	Zheng, F., & Hu, Y.	https://link.sprii	Y	dynamic model	CLUE-S and Mar	R	simulating spatial temporal	spatial temporal evolution of	temporal-spatial land use simul	Beijing in China	AS	Zheng, F., & Hu, Y. (2018). Assessing tempo
Cellular automata (CA) and c	2019	A geographical dir	Firozjaei, M. K., Sed	https://www.sci	Y	Statistical models	Cellular automa	L	Mapping development pc	Google Earth, 2013	The results are further compare	Tainan City, Taiwan	AS	Firozjaei, M. K., Sedighi, A., Argany, M., Jel
CLUE-s and RUSLE tools	2017	Investigating effect	Zare, M., Nazari Sar	https://link.sprii	N	dynamic and Statistical m	CLUE-s and RUS	R	Predicting soil erosion chan	Three land use maps were cr	to simulate land use for the yea	north of Iran	AS	Zare, M., Nazari Samani, A. A., Mohamma
DEMATEL tools and Markov m	2021	Urban ecological s	Ghosh, S., Chatterje	https://www.sci	Y	Statistical models	CA-Markov and	L	Urban ecological security a	satellite data, Google Earth i	Changes and prediction of UES	Kolkata Metropolitan Ar	AS	Ghosh, S., Chatterjee, N. D., & Dinda, S. (2
GEE and Markov module of ID	2023	Evaluation and pre	Yang, Z., Dai, X., Lu,	https://www.sci	Y	Statistical models	CA-Markov	R	Land use and land cover ch	sing supervised classification	Comparison between the real L	Yellow river basin in Chi	AS	Yang, Z., Dai, X., Lu, H., Liu, C., Nie, R., Zha
InVEST 3.10.2 software an	2022	Spatiotemporal Ev	Zhong, C., Bei, Y., G	https://www.mc	Y	Statistical models	Cellular Autom	L	The Spatiotemporal Distrib	the degree of the habitat deg	2025 were predicted and analy	Wanhe Watershed in Ch	AS	Zhong, C., Bei, Y., Gu, H., & Zhang, P.
LCM is a module of IDRISI	2019	Assessment and p	Yadav, V., & Ghosh,	https://www.tar	Y	Statistical models	LCM	L	urbanisation, LULC change	Landsat data (1981 - 2011)	Land Use Land Cover (LULC) (20	Chennai district in india	AS	Yadav, V., & Ghosh, S. K. (2021). Assessme
logistic-CA-Markov and WI	2019	Dynamic simulatio	Guan, D., Zhao, Z.,	https://link.sprii	N	Statistical models	logistic-CA-M	L	simulate land use structure	land use data in 2000, 2005,	to simulate spatial pattern of la	Chongqing, China	AS	Guan, D., Zhao, Z., & Tan, J. (2019). D
LUCC	2017	Trends in land use	Kamwi, J. M., Kaets	https://link.sprii	N	Statistical models	landuse change	R	Land use and land cover ch	Landsat TM and ETM+ image	fill this gap by analyzing the rel	Zambezi Region, Namib	AF	Kamwi, J. M., Kaetsch, C., Graz, F. P., Chirw
Markov module and Logistic	2018	Urban growth dyn	Siddiqui, A., Siddiqu	https://www.sci	Y	Statistical models	Markov module	L	Land use and land cover ch	landsat images for year 1993	to simulate land use change for	Uttar Pradesh in India	AS	Siddiqui, A., Siddiqui, A., Maithani, S.,
Markov module of IDRISI	2020	Simulating spatial-	Saadani, S., Laaja	https://link.sprii	N	Statistical models	CA-Markov	L	Land use and land cover ch	Land use/cover change (LUC	urban growth modelling (2010-	El Jadida city, Morocc	AF	Saadani, S., Laajaj, R., Maanan, M., Rhinan
Markov module of IDRISI	2023	A CA-Markov-Base	Gasirabo, A., Xi, C.,	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	evaluate the changes in LU	predict future fluctuations un	Nyabarongo River Bas	AF	Gasirabo, A., Xi, C., Hamad, B. R., & Edovia
Markov module of IDRISI	2023	Scenario-Based LU	Gebresellase, S. H.,	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	landsat data 1972 to 2017	to predict the land use map for	Upper Awash Basin (UAE	AF	Gebresellase, S. H., Wu, Z., Xu, H., & Muha
Markov module of IDRISI	2022	Analysis and mode	Kisamba, F. C., & Li,	https://link.sprii	N	Statistical models	CA-Markov	L	Land use and land cover ch	analyze LULC changes from 2	simulate future changes for the	Dodoma urban district ir	AF	Kisamba, F. C., & Li, F. (2023). Analysis
Markov module of IDRISI	2023	Predicting land use	Fogang, L. F., Tio	https://www.sci	Y	Statistical models	CA-Markov	L	Predicting land use/land co	Landsat images used in	Projected land use/land cover r	West-Cameroon	AF	Fogang, L. F., Tiomo, I. F., Kamga, B. Y., Kpo
Markov module of IDRISI	2020	Analysing past lan	Hishe, S., Bewket, V	https://www.tar	Y	Statistical models	CA-Markov	L	Land use and land cover ch	aerial photographs from 193	to simulate from 2015 to 2030.	Middle Suluh Valley in Et	AF	Hishe, S., Bewket, W., Nyssen, J., & Ly
Markov module of IDRISI	2023	Future land use la	Atef, I., Ahmed, W.,	https://link.sprii	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Landsat images obtained 200	Predicted LULC map for years 2	El-Fayoum Egypt	AF	Atef, I., Ahmed, W., & Abdel-Maguid, R. H.
Markov module of IDRISI	2022	Assessment of lan	Hind, M., M'hamm	https://link.sprii	N	Statistical models	CA-Markov	L	Land use and land cover ch	analyze a series of satellite im	assess changes in each land use	Algiers, Algeria	AF	Hind, M., M'hammed, S., Djamal, A., & Zou
Markov module of IDRISI	2021	Analysis of the Fut	Matlhodi, B., Kenab	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Classified Landsat images fro	to simulate the likely LULCs in 2	Gaborone dam catchme	AF	Matlhodi, B., Kenabatho, P. K., Parida, B. P.
Markov module of IDRISI	2021	Future Scenarios o	Beroho, M., Briak, H	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Satellite images for the years	to simulate LULC for years 2028	Mediterranean Watersh	AF	Beroho, M., Briak, H., Cherif, E. K., Boulahf
Markov module of IDRISI	2023	Stochastic modelir	Megersa, W., Derib	https://www.tar	Y	Statistical models	CA-Markov	L	examine the process of urb	The Landsat images of 19	to simulate Built-up area for 20	Mettu area in southwes	AF	Megersa, W., Deribew, K. T., Abreha, G., Li
Markov module of IDRISI	2022	Modelling and Ass	Weslati, O., Bouaziz	https://link.sprii	N	Statistical models	CA-Markov	L	Land use and land cover ch	Landsat images (ETM + and O	predict future LULC changes	Mellegue Catchment, N	AF	Weslati, O., Bouaziz, S., & Sarbeji, M. M. (2
Markov module of IDRISI	2022	Quantitatively Ass	Daba, M. H., & You,	https://www.mc	Y	Statistical models	CA-Markov	L	Land use and land cover ch	landsat data 1984- 2019	Future land use simulated in 20	Awash River in Ethiopia	AF	Daba, M. H., & You, S. (2022). Quantitative
Markov module of IDRISI	2022	Analysis of land us	Mwabumba, M., Ya	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	LULC maps for the years 199	projected for 2025 and 2035 ur	Ngorongoro Conservatio	AF	Mwabumba, M., Yadav, B. K., Rwiza, M. J.,
Markov module of IDRISI	2023	Predicting future c	Lopes, N. D. R., Li, T	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	landsat images 2000–2020 ar	The projected coastal LULC that	Guinea-Bissau's	AF	Lopes, N. D. R., Li, T., Zhang, P., Matomela,
Markov module of IDRISI	2018	Deriving suitability	Fu, X., Wang, X., &	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	Land cover data in two period	Simulation of land use for 2011	Ohio in the United State	AMN	Fu, X., Wang, X., & Yang, Y. J. (2018).
Markov module of IDRISI	2021	Future scenarios b	da Cunha, E. R., San	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	GeoEye, RapidEye and Lands	cenarios of LULC based on the	Serra da Bodoquena reg	AMS	da Cunha, E. R., Santos, C. A. G., da Silva, R
Markov module of IDRISI	2014	Assessing spat	Puertas, O. L., Henr	https://www.sci	Y	Statistical models	CA-Markov	L	Land use and land cover ch	LUC data from 1975 to 2010,	Future land use simulated in 20	Santiago Chile	AMS	Puertas, O. L., Henríquez, C., & Meza, F. J. (
Markov module of IDRISI	2022	Occurrence Predic	Liu, D., & Zhang, X.	https://www.mc	Y	Statistical models	CA-Markov	L	Prediction of Pine Wilt Dise	factors, such as weather, terr	PWD in 2030 is predicted basec	Anhui is located in Eas	AS	Liu, D., & Zhang, X. (2022). Occurrenc
Markov module of IDRISI	2018	MCR-Modified CA-	Li, X., Wang, M., Liu	https://www.mc	Y	Statistical models	CA-Markov	L	simulation of urban expa	land use change 1996 to 200	The expansion of the Wuhan m	Wuhan metropolitan a	AS	Li, X., Wang, M., Liu, X., Chen, Z., Wei, X., &
Markov module of IDRISI	2022	CA-Markov model	Mokarram, M., & Pl	https://www.sci	Y	Statistical models	CA-Markov	R	predict crop yield using re	land use data in 2000, 2010,	predict yield of two crops in 20	southern Iran	AS	Mokarram, M., & Pham, T. M. (2022). C

Cards of modelling tools

Card of the Tool for the modelling of land use/land cover change (prediction)

Modelling tool title: CLUE-S

Authors/Institution: Wageningen University for GUI and Aristotle University for R package

Version/year: 2009/2023

Available extensions for the tool:

There are two environments for the CLUE-S model: one in R programming (Kiziridis et al, 2023) and the other in terms of a GUI (Verburg et al, 2009). We have generated a table (1) and included an access link.

Table (1): this table provides some links that give useful information about the CLUE-S environment model.

Some accessible links	Graphic User Interface	R programming
Link -download:	LINK	LINK
Link – information:	LINK	not
Link – installation:	LINK	not
Link – tutorial:	LINK	not
Link- help:	LINK	not

- Author/Institution
- Version/year/Extension
- Purpose/Target group
- Tool description
- Used method, Approach, Scheme
- Used/required data (data format)
- Scenarios, results/outputs
- Hardware requirements
- Knowledge requirements
- List of articles using the tool – connection to the Database of modelling tools - applications

Success stories for modelling tools

Success story on the Tool for the modelling of land use/land cover change (prediction)

Modelling tool title: CLUE-S

1) **Introduction based on selected publication/s – Titile, authors, DOI/link, short summary/presentation of the paper (abstract)**

Title: Assessing the Potential Future Forest-Cover Change in Romania, Predicted Using a Scenario-Based Modelling

Authrs: Gheorghe Kucsicsa, Elena-Ana Popovici, Dan Bălteanu, Monica Dumitrașcu, Ines Grigorescu & Bianca Mitrică

Institute: Institute of Geography, Romanian Academy, 12 Dimitrie Racoviță Street, sect. 2, 023993, Bucharest, Romania

Journal: Environmental Modeling & Assessment **Publisher**: Springer **Impact factor**: 2.4

Year: 2019

Abstract:

Forest-cover dynamics is of wide concern due to its role in climate change, biodiversity losses, water balance and land degradation, as well as social and economic development. Hence, exploring land-use/cover dynamic is important in order to improve our understanding of the

Based on selected open source publication

- Title/Author/Institution/Journal
- Year, DOI/Link
- Abstract/Goals of the study
- Study area, data, methods
- Modelling scheme/diagram
- Results, Mentioned problems
- Applications and recommendation for future use
- Outputs from project case studies will also be used

LULC Models

Model	Use of LULC	Suitable for
CLUE-S (Conversion of Land Use and its Effects at Small regional extent)	✅ Spatially explicit allocation model using empirical rules and land suitability.	Scenario-based land use projections at regional/local scale.
CA-Markov (Cellular Automata–Markov Chain)	✅ Uses transition probabilities and neighborhood rules for simulating LULC dynamics.	Urban expansion, deforestation, and long-term land change prediction.
GEOMOD (Geographic Modeling System)	✅ Uses logistic regression and suitability maps for future land cover change.	Simple land use prediction with limited data requirements.
LCM CLIMATE (Land Change Modeler with Climate driver integration)	✅ Integrates LULC transitions with climate variables and emissions scenarios.	Coupled land–climate studies, mitigation and adaptation scenarios.
LSTM (Long Short-Term Memory neural network)	✅ Deep learning model using past land cover, drivers, and sequences.	Data-driven LULC prediction with high spatio-temporal resolution.
MOLUSCE (Modules for Land Use Change Evaluation)	✅ QGIS plugin combining statistical and machine learning methods.	Academic and practical LULC change evaluation in GIS.
SECLAND (Socio-Economic and Climate Linkages in Land Use)	✅ Agent-based, socio-economic land use model with climate linkages.	Exploring land use under socio-political and climate constraints.
SLEUTH (Slope, Land use, Exclusion, Urban extent, Transportation, and Hillshade)	✅ Cellular automata urban growth model based on physical drivers.	Urban sprawl, infrastructure development, planning simulations.
FLUS (Future Land Use Simulation)	✅ Combines system dynamics	

Climate Models

Model	Use of LULC	Suitable for	How LULC Changes Influence Model Outputs
GUESS (General Ecosystem Simulator)	✅ Simulates vegetation dynamics based on LULC and climate interactions.	Terrestrial biosphere modeling and land–climate feedbacks.	Affects vegetation succession, evapotranspiration, and carbon fluxes.
JULES (Joint UK Land Environment Simulator)	✅ Land surface model including vegetation, soil, and carbon processes.	Global/UK land surface simulations; part of Earth system models.	Modifies albedo, soil moisture, heat fluxes, and CO_2 exchange.
MEGAN (Model of Emissions of Gases and Aerosols from Nature)	✅ Uses land cover to simulate biogenic VOC emissions.	Air quality, biosphere–atmosphere interactions, chemistry–climate studies.	Changes VOC emissions depending on vegetation types and coverage.
ORCHIDEE (Organizing Carbon and Hydrology in Dynamic Ecosystems)	✅ Dynamic global vegetation model; LULC strongly affects water and carbon cycles.	Carbon–water cycle modeling in Earth system simulations.	Impacts carbon storage, transpiration, GPP, and water balance.
WRF (Weather Research and Forecasting model)	✅ Uses LULC as surface parameterization in regional climate simulations.	High-resolution regional weather and climate modeling.	Alters surface roughness, radiation balance, and precipitation.
GCAM (Global Change Analysis Model)	✅ Integrated assessment model with land use included in socio-economic scenarios.	Climate policy modeling and global scenario assessments.	Affects land availability, GHG emissions, and mitigation strategies.
CLM (Community Land Model)	✅ Land surface model using LULC for simulating energy, water, and carbon fluxes.	Coupled land–atmosphere processes in climate models.	Influences surface temperature, ET, runoff, and CO_2 fluxes.
Biome-BGC (Biome BioGeochemical Cycles)	✅ Ecosystem productivity model driven by vegetation type and land cover.	Climate change impacts on forest productivity and water use.	Modifies NPP, water balance, and nutrient cycling.
PRECIS (Providing REgional Climates for Impacts Studies)	✅ Uses fixed LULC maps for regional climate boundary conditions.	Regional climate impact studies, scenario simulations.	Changes surface energy and water balance, regional precipitation patterns.

Hydrological Models

Model	Use of LULC	Suitable for	How LULC Changes Influence Model Outputs
SWAT (Soil and Water Assessment Tool)	✅ Each Hydrologic Response Unit (HRU) is defined by land use, soil, and slope. LULC changes directly impact surface runoff, evapotranspiration, erosion, and crop yield.	Agricultural catchments, land management impacts, urbanization, deforestation scenarios.	LULC affects ET, infiltration, erosion rates, nutrient loading, and streamflow timing.
EPIC (Environmental Policy Integrated Climate)	✅ Simulates crop growth, soil erosion, and nutrient cycling under different land use types and agricultural practices.	Agricultural systems, policy evaluation, field-scale land management.	Changes in land use modify crop rotations, soil loss, nutrient transport, and water balance.
MIKE SHE (Systém hydrological European)	✅ Fully distributed and physically based; spatial LULC inputs affect surface and subsurface hydrology.	Complex, mixed land use systems (urban, agricultural, natural); water resource planning.	Changes impact surface runoff, groundwater recharge, ET, and overall water balance.
VIC (Variable Infiltration Capacity)	✅ Supports land cover scenarios at coarse resolution. Less detailed than SWAT, but useful for large-scale analysis.	Regional and continental-scale studies with focus on climate–land interactions.	Affects ET partitioning, infiltration capacity, and spatial runoff generation.
InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)	✅ Focuses on ecosystem services modeling; LULC maps are central to hydrological and water quality assessments.	Policy scenarios, ecosystem service valuation, conservation planning.	LULC changes influence sediment yield, nutrient export, baseflow, and service supply.
LANDIS-II (linked with other models like SWAT, RHESSys)	✅ Simulates forest succession, disturbance (fire, harvest), and land cover transitions; outputs often serve as LULC input for hydrological models.	Forest ecosystems, long-term land cover evolution, disturbance regime impacts.	Affects interception, soil moisture retention, ET, and erosion when coupled with hydro models.

Forest Models

Model	Focus	Use of LULC	Suitable for	How LULC Changes Influence Model Outputs
iLand (individual-based forest Landscape and disturbance model)	Forest landscape dynamics and disturbance	✅ Simulates cover change and individual-tree response	Resilience, biodiversity, ecosystem services	LULC alters regeneration, carbon storage, fire risk
LANDIS-II (LANDscape DIsturbance and Succession model)	Succession and disturbance modeling	✅ Uses LULC with disturbance history	Policy evaluation, forest planning	LULC shapes disturbance spread, species composition
3-PG (Physiological Principles Predicting Growth)	Forest growth and productivity	✅ Requires site LULC and environment inputs	Yield modeling, carbon accounting	LULC shifts growth potential, productivity and carbon fluxes
FORMIND (Forest Model for INdividual-based Dynamics)	Tree competition and tropical forests	✅ Integrates LULC in harvesting and natural scenarios	Tropical forest management, climate change	Affects biomass recovery, species mix, regeneration
SORTIE-ND (Spatially Explicit Individual-based Forest Dynamics Model)	Tree-level spatial dynamics	✅ Uses LULC to place spatial forest structure	Fine-scale forest ecology	LULC affects species coexistence, growth and structure
ForClim (Forest Succession Model)	Temperate/mountain forest succession	✅ Responds to land-use legacy and management	Climate resilience, ecological planning	LULC changes affect stage transitions and forest types
EFISCEN (European Forest Information SCENario model)	EU forest policy and projection tool	✅ Uses inventory + LULC scenarios	National wood supply, long-term forest planning	LULC alters harvest volumes, forest age and structure
PICUS (Forest Patch/GAP Model)	Forest patch/gap dynamics	✅ Needs spatial LULC and disturbance data	Patch-level biodiversity and productivity	LULC drives patch dynamics, species turnover, forest structure

Biodiversity Models

Model	Focus	Use of LULC	Suitable for	How LULC Changes Influence Model Outputs
MaxEnt (Maximum Entropy Model)	Species distribution modeling (SDM)	✅ Uses LULC as predictor of species habitat	Species distribution, conservation planning	Changes shift predicted habitat ranges and suitability zones
BIOMOD2 (Biodiversity Modelling in R)	Ensemble modeling of species distributions	✅ Uses LULC with climate for predictive accuracy	Biodiversity forecasting, conservation	LULC determines habitat availability, influencing ensemble predictions
InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)	Ecosystem services and habitat quality	✅ LULC is a key input for habitat modeling	Land use planning, ecosystem service trade-offs	LULC drives habitat fragmentation, quality loss or gain
GLOBIO (Global Biodiversity Model for Policy Support)	Biodiversity intactness index (BII) modeling	✅ Incorporates LULC, infrastructure, and pressures	Global biodiversity policy support (e.g. IPBES)	Reduced habitat area and quality lowers MSA/BII indicators
AIM-biodiversity (Asia-Pacific Integrated Model – Biodiversity)	Regional/global biodiversity under scenarios	✅ Uses harmonized LULC in climate scenarios	Scenario analysis, risk mapping	LULC changes influence species loss, extinction probabilities
SAR models (Species–Area Relationship models)	Estimation of biodiversity loss	✅ Links habitat loss from LULC to species richness	Quick assessments of deforestation and fragmentation	Direct loss of habitat translates into estimated species loss
Madingley (Madingley Model)	Mechanistic trophic and ecological modeling	✅ Simulates impacts of LULC on ecosystem structure	Functional biodiversity projections	LULC influences food web integrity, biomass flow, extinctions
RangeShifter (RangeShifter Dispersal Simulation Tool)	Dispersal and gene flow simulation	✅ LULC determines landscape permeability	Corridor design, conservation of connectivity	Fragmented LULC reduces dispersal success, increases isolation

Example of card for modelling tool

ACard of the Tool for the modelling of land use/land cover change (prediction)

Modelling tool title: CLUE-S

Authors/Institution: Wageningen University for GUI and Aristotle University for R package

Version/year: 2009/2023

Available extensions for the tool:

There are two environments for the CLUE-S model: one in R programming (Kiziridis et al, 2023) and the other in terms of a GUI (Verburg et al, 2009). We have generated a table (1) and included an access link.

Table (1): this table provides some links that give useful information about the CLUE-S environment model.

Some accessible links	Graphic User Interface	R programming
Link -download:	LINK	LINK
Link – information:	LINK	not
Link – installation:	LINK	not
Link – tutorial:	LINK	not
Link- help:	LINK	not

Purpose:

The CLUE model is designed to forecast changes in land use, including deforestation, urbanization, and agricultural practices. It provides detailed insights into the factors influencing these changes, both natural and human-driven, across various scales. By mapping out potential land use scenarios, the model helps inform decision-making processes, offering guidance on effective policy interventions and suitable land management strategies.

Target group: Governments, NGO's.

Tool description

The CLUE model is a simulation model to spatially allocate land use changes. The CLUE methodology (Verburg et al. 2002) is based on the analysis of land use dynamics as a multi-level interaction of complex systems. Land use systems operate at the interface of multiple social and ecological systems. The CLUE model is a simulation model to spatially allocate land use changes. The spatial allocation of land cover types is simulated by combining information on the following drivers of land use change:

- relative suitability of a location for different uses
- regional competitiveness of the different land use types
- land use history
- specific land use policies or constraints

The location preference for the different land use types is based on the spatial variation of the location factors that were hypothesized to be important determinants of the land cover pattern. Results of the analysis of drivers are incorporated into a dynamic model, which describes potential changes in the different land cover types in the area over the simulated time horizon.

Example of card for modelling tool

Short characteristics ├ history, description, principle, background, use…..

The original idea of the first CLUE model version was made by Tom Veldkamp and Louise Fresco and published in 1996. Later versions were created by Peter Verburg in collaboration with colleagues at Wageningen University and worldwide. The CLUE-Scanner version is an implementation of the Dyna-CLUE version in DMS software of ObjectVision.

Applications:

Applications of the CLUE model has been made around the world in many different environments. Typical applications include the simulation of deforestation, land degradation, urbanization, land abandonment and integrated assessment of land cover change. The accessibility CLUE is defined in DEMO , Commercial levels, and R programming explained in table (1).

Table (1): this table provides Access levels in CLUE software.

properties	Demo	Commercial and R
The Maximal grid dimensions:	108, 128	unrestricted
The maximal number of land use types:	5	unrestricted
The maximal number of regions:	1	unrestricted
The maximal number of factors:	13	unrestricted

Note: Exceeding these restrictions will cause the model to exit as soon as the 'Run' button is clicked.

Result description :

CLUE output is given in the form of a time series of land use maps. Changes in land use can be seen from the maps (visually: amount of change, location of change). The amount of change per land use type per spatial area (e.g. country) between time steps can be given as a percentage about the original (e.g. current; 2005) land use map.

Used method/approach (including short description):

Land use/cover (LUC) is one of the key input data for simulation and forecasting using the CLUE-S model. The amount of Land use/cover changes (LUCC) and annual demand for each of them should be calculated. Satellite images are the best sources to prepare LUC for two periods of time (past and present) so that the amount of changes and their manner can be used as a basis for creating a land demand model for each of the LUC. So identification and classification of LUC with new methods with high accuracy(machine learning and deep learning) can increase the prediction accuracy of LUCC with the CLUE-S model.

Used/required data (different types – land cover, social, economic etc.):

the effective factors (independent variables) on the types of land use have been selected by reviewing the sources, as well as the availability of data. These factors include: geology, soil science, land suitability, slope, slope direction, height, distance from roads, distance from waterways, distance from faults, solar radiation, annual precipitation, average temperature, average humidity, population changes, industrial and urban developments, climate changes, and air quality. Adding these data to

Scenarios (possibility of scenarios definition, how it works… etc.):

The CLUE model is one of the specialized land use simulation models, which is based on the empirical analysis of land suitability, temporal and spatial changes in land use, and factors affecting land use. This model not only simulates land use for the future, but by using it, you can make changes in the process of land use changes in the future and design different scenarios. In general, the goal of designing scenarios is to optimize land use and limit changes in some areas. These scenarios encompass various aspects including: (1) an environmental scenario (ES); (2) scenario based on population and social indicators (SP); (3) scenario emphasizing economic (SE); (4) scenario centered on natural expansion (SN).

Scheme/diagram of modeling steps:

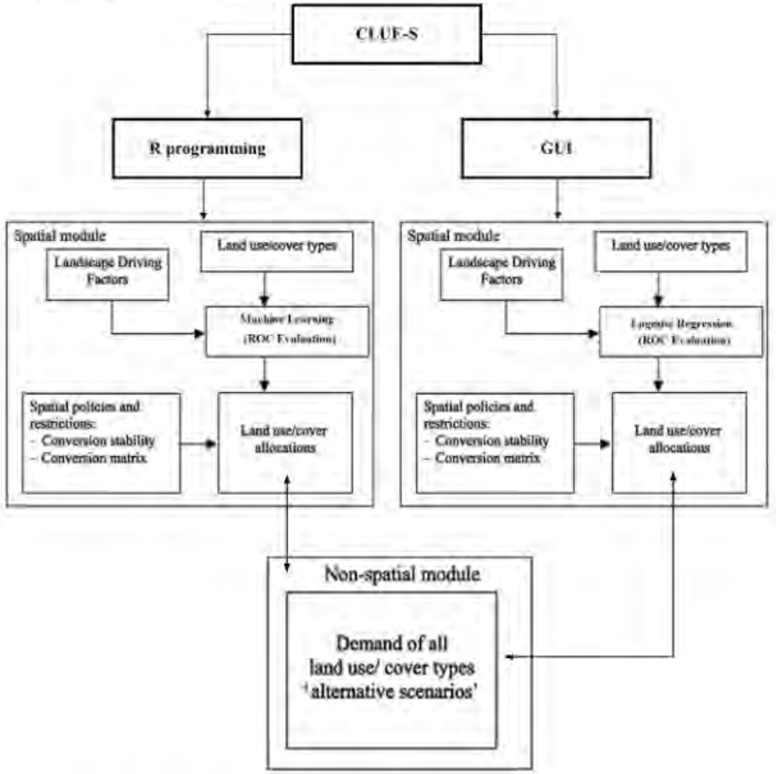


Figure (1): Flow chart of the information used to run the ClUE-S(Chouvardas et al, 2009)

Example of card for modelling tool

Hardware requirements:

As a complex simulation model, the CLUE-S model requires significant computing resources. This model demands powerful processors and ample memory resources for running and storing relevant data. Given that CLUE-S simulates complex processes and conducts geospatial analyses, it is recommended to use powerful servers or computer systems with multi-core processors and high memory capacities. Generally, running CLUE-S on hardware with high computing capabilities and adequate memory resources provides the most optimal performance. It should also be noted that the model's performance relative to the computer system is directly related to the size of the study area, the number of rows and columns, and the pixel size of the input data to the model."

Knowledge requirements:

To effectively work with the CLUE-S model, a person should have a combination of skills and knowledge in several areas:

1. Geospatial Analysis:

2. Land Use Planning and Management:

3. Computer Science and Programming:

4. Simulation Modeling:

5. Data Management

Requirements for further software/applications/scripting/programming:

To work with the CLUE-S (Conversion of Land Use and its Effects at Small regional extent) model, you typically need several types of software tools for various tasks, including:

1. GIS Software: Geographic Information System (GIS) software is essential for preprocessing spatial data, conducting geospatial analyses, and visualizing model inputs and outputs. Common GIS software includes:

- ArcGIS by Esri
- QGIS (Quantum GIS), an open-source alternative
- GRASS GIS

List of articles using the tool – link for the database here:

[Link to articles database]

Example of success story

Success story on the Tool for the modelling of land use/land cover change (prediction)

Modelling tool title: CLUE-S

1) **Introduction based on selected publication/s – Titile, authors, DOI/link, short summary/presentation of the paper (abstract)**

Title: Assessing the Potential Future Forest-Cover Change in Romania, Predicted Using a Scenario-Based Modelling

Authrs: Gheorghe Kucsicsa, Elena-Ana Popovici, Dan Bălteanu, Monica Dumitraşcu, Ines Grigorescu & Bianca Mitrică

Institute: Institute of Geography, Romanian Academy, 12 Dimitrie Racoviţă Street, sect. 2, 023993, Bucharest, Romania

Journal: Environmental Modeling & Assessment **Publisher**: Springer **Impact factor**: 2.4

Year: 2019

Forest-cover dynamics is of wide concern due to its role in climate change, biodiversity losses, water balance and land degradation, as well as social and economic development. Hence, exploring land-use/cover dynamic is important in order to improve our understanding of the causes of forest-cover change and to detect the future trend. Furthermore, projecting a future land-use/cover pattern can help identifying potential areas where forest-cover change will occur in the future and the potential consequences of these processes in order to improve land-use planning and policies. Similar to other East European countries, Romania is experiencing rapid land-use/cover changes after the breakdown of socialism; a clear trend was registered by deforestation, which reflects the consequences of a continuous forests dynamics and little environmental care. Consequently, this study, carried out in order to analyse the potential future cover-change, resulted in the land-use/cover scenario (2007–2050) simulated using CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) modelling framework, applied to development regions in Romania. Overall, the model results in different spatial patterns of land-use/cover change, projecting a slight increase in the forest-cover area of about 82,000 ha. Furthermore, the model simulated widespread deforestation, mainly in relation to agricultural land expansion. The area under the curve (AUC) for the relative operating characteristic (ROC) and the Kappa simulation (KSimulation) were used to assess the predictive power of the determinant factors included and to evaluate the spatial performance of the model. The obtained ROC/AUC values (0.83–0.88) indicate the great power of the determinant factors to explain the forest-cover pattern in the area. Furthermore, the KSimulation scores (0.69–0.79) highlight the potential of the CLUE-S model to simulate future forest-cover change in relation to the other land-use/cover categories. The results can provide useful inputs for effective forest resource management and environmental policies. Moreover, the spatial data obtained can contribute to exploring future potential environmental implications (e.g. assessing landslide and flood hazard scenarios, forest biomass dynamics and their impact on carbon allocation, or the impact of forest-cover change on ecosystem services).

DOI/link: https://link.springer.com/article/10.1007/s10666-019-09686-6

2) **Goals of the study**

the main goal of this study is to analyse the potential forest-cover change, as a result of a land-use/cover scenario in the 2007–2050 period, projected according to the historical changes registered in the 1990–2006 period. Specifically, their objectives are: (1) to estimate explicative power of biophysical and socio-economic determinant factors of the current forest-cover pattern in Romania through a regression analysis, in order to better understand the causes of future forest-cover change, (2) to identify the areas with high potential change rates, (3) to identify the possible conversion between the forest-cover category and non-forest categories and (4) to identify some of the main possible future environmental implication in the area.

3) **Study area**

The forests of Romania

4) **Used data and categories used for the modelling**

Dependent variable			
Dataset	**Source**	**Link**	**Pixel size**
Landcover data	CORINE Land Cover (CLC)	LINK	100 m

Independent variables		
Variables	Data source	Data preparation procedure
Elevation	Digital Elevation Model (DEM–30 m)	Merging datasets into elevation raster (m)
Slope declivity	Digital Elevation Model (DEM–30 m)	Calculating slope raster layer (°)
Precipitation (1961–2015)	National Meteorological Administration	Merging datasets into annual average precipitation raster (mm)
Temperature (1961–2015)	National Meteorological Administration	Merging datasets into annual average temperature raster (°C)
Horizontal relief fragmentation	EU-Hydro River Network	Horizontal relief fragmentation (km/km^2)
Total organic matter content in topsoil	Romania – Soil quality and electricity transmission grid. Geographical atlas	Categorical to continuous raster, ranging from extremely low to excessive (8 categories)
Population density	Population census (2006)*	Calculating population density (inh/km^2)
Population growth	Population census (1992, 2006)*	Calculating population growth in the 1992–2006 period (‰)
Employees	Population census (2006)*	Number of employees
Unemployment rate	Population census (2006)*	Calculating unemployment rate (%)
Large Livestock Units (LLU)	Population census (2006)*	LLU/ha
Employment in tertiary sector	Population census (2006)*	Number of employees in tertiary sector

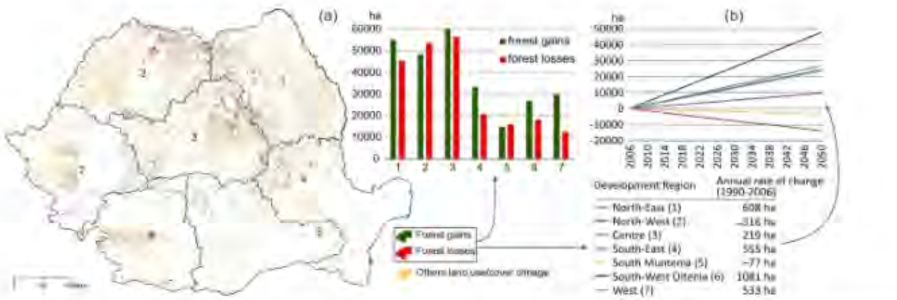
Example of success story

5) Used methods… introduction of the particular steps of the used approach

The CLUE-S model was applied to simulate land-use/cover dynamics in the 2007–2050 period and therefore to evaluate the future potential forest-cover change. To evaluate the predictive power of the determinant factors, the ROC (receiver operating characteristic) was used. This is a measure for the goodness of fit of a logistic regression model similar to the R2 statistics in ordinary least-square regression. The comparison method was implemented in the Map Comparison Kit , version 3.2.3 (available at http://mck.riks.nl/), a software tool which includes a range of algorithms for the comparison of raster maps.

6) Scenarios

Land-use/cover requirements. A baseline scenario was formulated to represent the demand for land-use/cover change in the 2007–2050 period. This is based on an extrapolation of the linear trend of change registered in the 1990–2006 period, calculated for each land-use/cover category.



Land-use/cover dynamics over 1990–2006, highlights forest-cover changes (a) and the extrapolation of the annual rate of forest-cover change into a linear trend for the simulated period

7) Modelling scheme/diagram

Figure (1): The allocation procedure of the model, the accuracy assessment and the analysis of potential future forest-cover change are synthetically illustrated in Fig. 2.

7) Modelling scheme/diagram

Figure (1): The allocation procedure of the model, the accuracy assessment and the analysis of potential future forest-cover change are synthetically illustrated in Fig. 2.

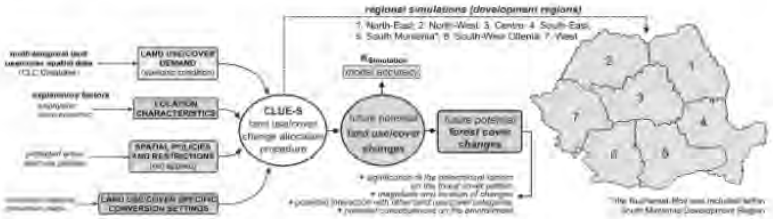


Figure (2): Flowchart of the modelling procedure used to assess future potential forest-cover change.

8) Results of the modelling and their significance

Setting the forward stepwise procedure in the logistic regression, the best predictor sets associated with the forests cover pattern have resulted for each development region. the increase in the annual mean temperature, slope declivity and total organic matter content in topsoil, in particular, might trigger an increased forest-cover occurrence. Furthermore, the regression coefficients obtained for elevation indicate that the suitability for forest-cover increase in the mountain areas and decrease in the lowlands where the determinant factors, which better explain the occurrence of the non-forest categories. the simulated results suggest an increase in the forest-cover area of Romania by about 1.2% (81,200 ha) until 2050.

9) Mentioned problems

we assume several limitations related to calibration and validation procedures. First, a limitation number of determinant factors included in the simulation (due to unavailability, or difficulty in collecting) can be seen in the resulted pseudo R2 values. These indicate that all together the considered factors explain only 35.1 to 48.4% of the forest-cover pattern, suggesting that other determinant factors (e.g. land tenure, forest fragmentation, or local economic situation) may have been relevant in further explaining forest-cover change in Romania.

10) Application and recommendation for future use

further studies can use the resulted data to examine the interaction of forest-cover change and carbon allocation, or agricultural practices and to evaluate the potential impact on landscape diversity and biodiversity and the implications in ecosystem services. The outputs of the current research can also represent a basic background in implementing more accurately scenarios after integrating other significant determinant factors of forest-cover change and upgrading the used data according to the biophysical and socioeconomic changes in the area.

Thank you for attention!

Scenario-Based Modeling of Land-Use and Land-Cover Changes to Promote Sustainability: Two Case Studies From Latvia

24 April 2025

Jānis Krūmiņš

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EC-CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union

What is Scenario Modeling?

It is creating plausible future outcomes based on ‘what if’ situations.

- <u>Explores possibilities, not predictions.</u>

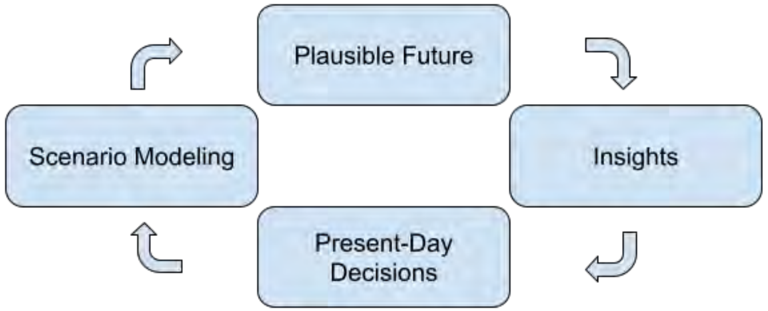
  Scenario modeling does not aim to forecast one "correct" future but instead it presents a range of possible futures.
- <u>Shows choices, not forecasts.</u>

  These scenarios show options we have today and how our choices could influence future outcomes.
- <u>Informs present-day decisions.</u>

  Even though scenarios look ahead, they are grounded in the idea that what we do right now matters.
- <u>Today's decisions drive tomorrow's reality.</u>

  Reasonable choices we make right now greatly increase the likelihood of achieving more just and desirable futures.
- <u>Encourages adaptive thinking.</u>

  By considering diverse futures, scenario modeling helps stakeholders prepare for uncertainty and build resilience into future planning and policy.



How do We Model Future Scenarios?

We learn from the past and adjust the drivers of change for the scenario of choice.

1. Source Data:

- Earlier period LULC map.

  Used as the base map, for instance, a map of 2000.
- Later period LULC map.

  Used as the reference map to learn from, for instance, a map of 2025.
- Driving variables.

  Used to explain LULC changes that happened between the base map and the reference map.

2. Source Data Processing:

- Multi-Layer Perceptron Algorithm.

  Used to calculate the probability of transition from one LULC category to another between earlier and later period based on driving variables.
- Cellular Automata Analysis.

  Used to introduce spatial rules and neighborhood influence, like what changes tend to happen near other changes.
- Markov Chain Analysis.

  Used to analyze the transition matrix between earlier and later period to project how much of each LULC category is expected to change in the future.
- Integrated MLP-CA-Markov Modeling.

  Used to combine the data to simulate future period LULC map.

3. Scenario Simulation:

- Modifying driving variables.

  Assuming changes in drivers under different scenarios, for instance, road expansion under conservation.
- Changing transition constraints/rules.

  Limiting changes in certain areas, for instance, in strictly protected areas.
- Changing transition probabilities.

  Limiting certain changes, for instance, the rate of deforestation.

What are the Best Options for Scenario Selection?

Those are scenarios that combine natural and human-induced changes.

- SSP-RCP scenarios.

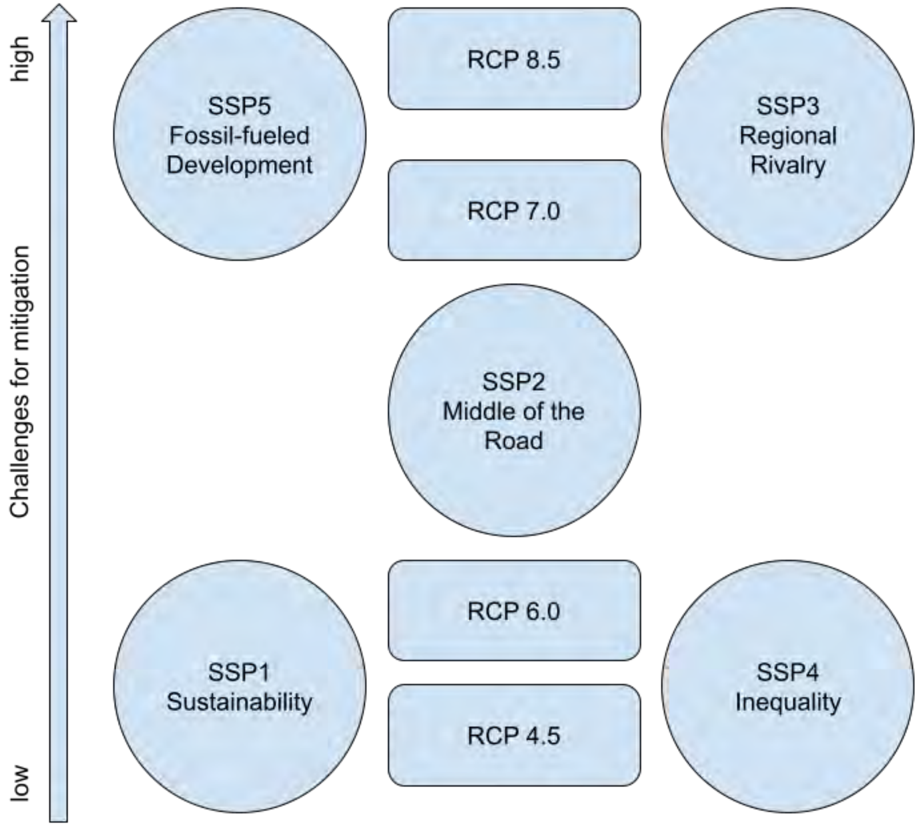
  To capture both climate and socio-economic dynamics, we must combine various options.
- SSP1-RCP4.5.

  A sustainability-oriented scenario with moderate emissions reduction.
- SSP3-RCP7.0.

  Regional rivalry, limited cooperation with weak climate policies and high land use pressure.
- SSP4-RCP6.0.

  A world with high socio-economic inequality. Wealthy regions adopt cleaner technologies, while poorer regions experience high land-use pressure, degradation and slow climate action.
- SSP5-RCP8.5.

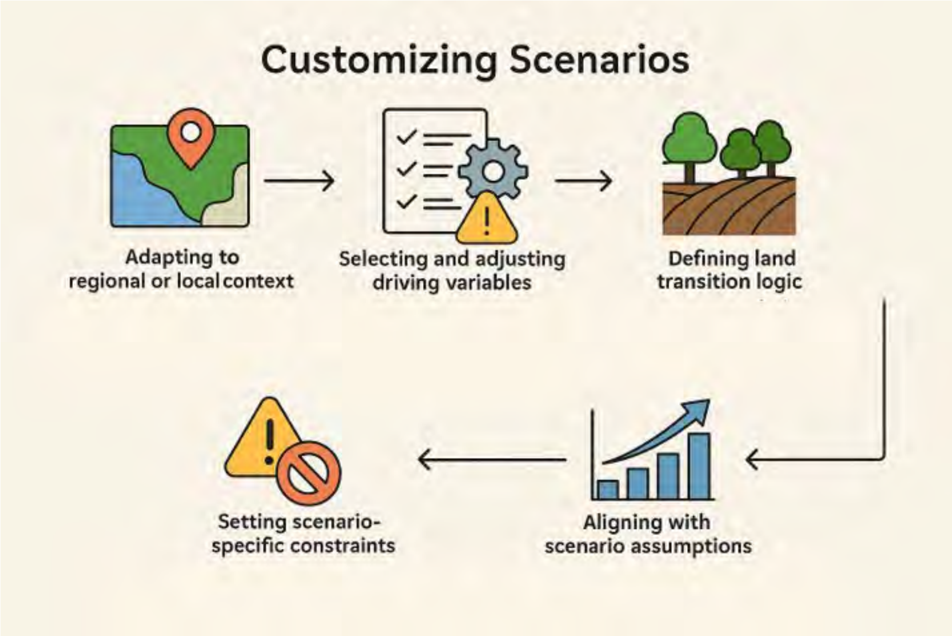
  Fossil-fueled development with high emissions and intense land-use pressure.



How do We Customize Scenarios?

We adapt global scenarios to the specific context of our case study area.

- **Adapting to regional or local context.**
  Tailoring the model to show local geography, socio-economic patterns, and ecological realities.
- **Selecting and adjusting driving variables.**
  Enabling or disabling relevant drivers, modifying their weights, and updating time-sensitive inputs like population growth, land prices, or road expansion.
- **Setting scenario-specific constraints.**
  Introducing land use restrictions such as zoning laws, protected areas, or legal boundaries.
- **Defining land transition logic.**
  Establishing rules for how land types can change, and customizing probabilities based on scenario narratives.
- **Aligning with scenario assumptions.**
  Scaling transitions and pressures in line with the socio-economic and climate storylines being modeled.



What are the Key Drivers of LULC Change?

It is accessibility, suitability, human factor and environmental factor.

- <u>Biophysical/Natural.</u>

  Elevation, slope, aspect, soil type, rainfall, temperature etc.

- <u>Accessibility.</u>

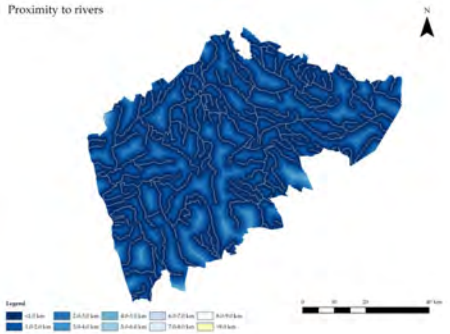
  Distance to roads, settlements, rivers. Travel time to cities. Proximity to infrastructure etc.

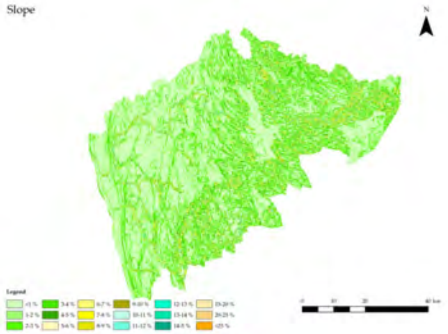
- <u>Land Suitability.</u>

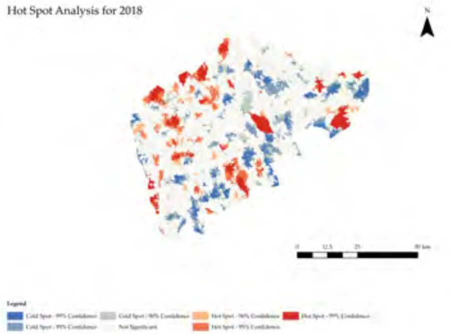
  Land capability index, soil fertility, drainage capacity etc.

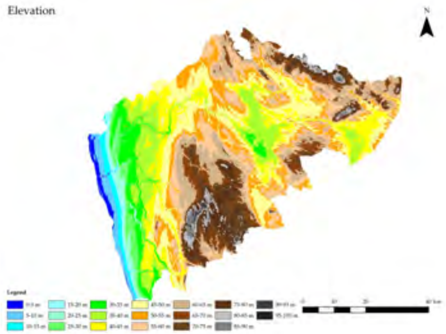
- <u>Socioeconomic/Anthropogenic.</u>

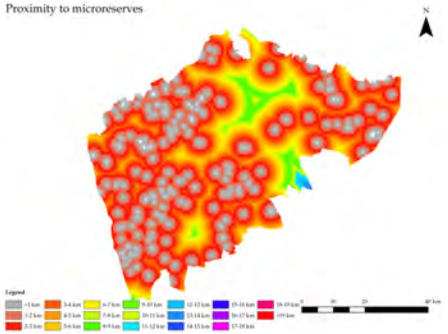
  Population density, GDP or income proxies, land value, agricultural intensity, protected area status, policy zones etc.

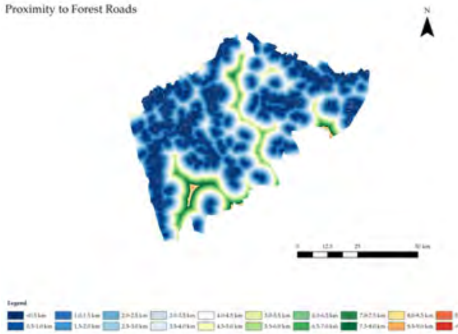


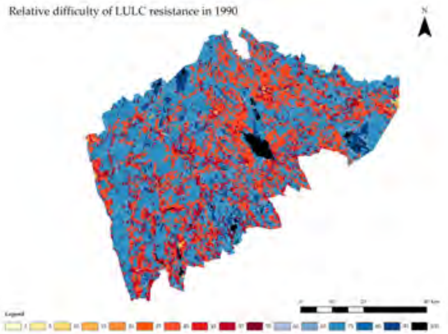


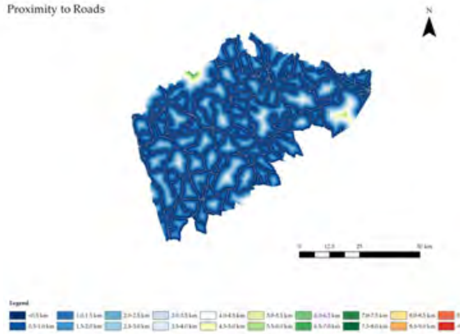








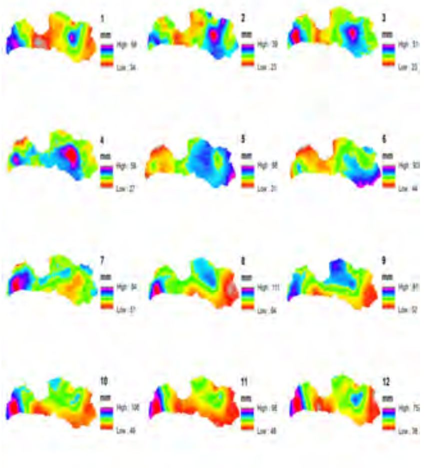


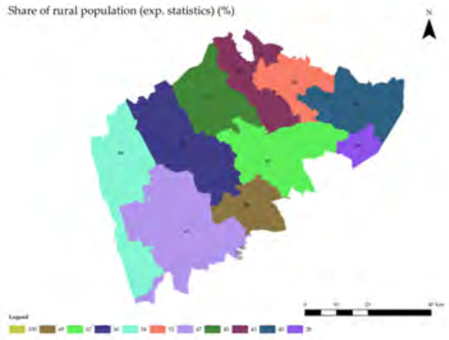


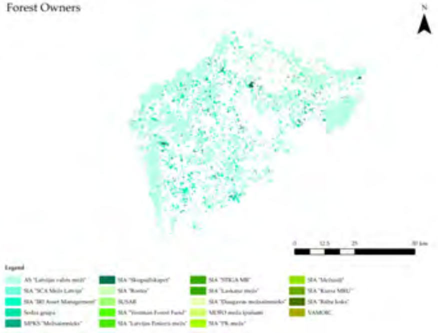
How do We Account for Novel LULC Drivers?

We learn from other case studies where similar areas were affected by different drivers.

- <u>Recognizing the limitation of historical data.</u>
  ML models depend on past data and cannot directly learn from events that have not occurred before.
- <u>Using indirect or scenario-informed approaches.</u>
  Applying existing knowledge to simulate new conditions using proxies, scenario narratives, or assumed patterns.
- <u>Incorporating expert judgment and modified inputs.</u>
  Adjusting variables, weights, or constraints based on expert insights and anticipated trends.
- <u>Leveraging hybrid modeling techniques.</u>
  Combining empirical models with rule-based or agent-based components to enhance flexibility.
- <u>Testing robustness through sensitivity and transfer learning.</u>
  Evaluating how the model behaves under unfamiliar inputs and adapting models trained on other regions or periods.







What Tools can We Use to Model Scenarios?

Machine learning tools that learn spatial and temporal patterns of change.

- <u>TerrSet by Clark Labs.</u>

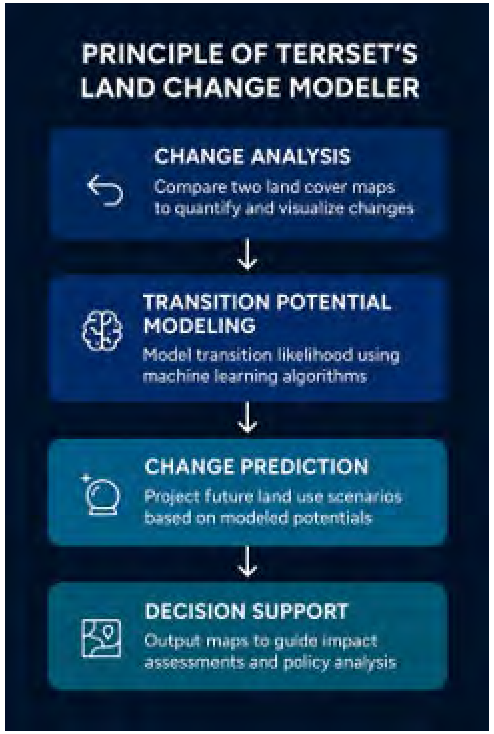
  A comprehensive GIS and remote sensing software suite designed for analyzing and visualizing geospatial patterns.
- <u>Includes the Land Change Modeler (LCM).</u>

  Specialized for land-use/land-cover change analysis, transition potential modeling, and scenario-based forecasting.
- <u>Supports sustainable land planning.</u>

  Helps stakeholders make informed, data-driven decisions in environmental management and resource policy.
- <u>Enables scenario-based simulations.</u>

  Integrates spatial models and ML to simulate plausible land change trajectories under different assumptions.
- <u>Ideal for dynamic predictions.</u>

  Combines historical data, driver variables, and scenario logic into robust predictions of future land change.



Why Is Scenario Modeling Important for Biosphere/Nature Reserves?

Because their core mission is to preserve biodiversity and ecological integrity.

- <u>Protects unique biodiversity.</u>

  These areas harbor regionally and globally important ecosystems, often including rare or endangered species.
- <u>Prevents irreversible loss.</u>

  Unsustainable land use can permanently damage fragile habitats and trigger cascading biodiversity collapse.
- <u>Guides sustainable management.</u>

  Scenario modeling supports long-term strategies that align ecological conservation with development needs.
- <u>Supports climate resilience.</u>

  Biodiverse ecosystems are vital for buffering climate change impacts—both locally and globally.
- <u>Enables sustainable livelihoods.</u>

  Properly managed reserves can generate income through eco-tourism, organic agriculture, and green jobs.

A Case Study: Teiči Strict Nature Reserve (Latvia)

The largest nature reserve in Latvia

- <u>Overview and Location.</u>

  Established in 1982, the Teiči Reserve spans 19,771 ha, making it the largest nature reserve in Latvia.

- <u>Ecological significance.</u>

  Home to Teiči Bog, one of the largest intact moss bogs in the Baltics, and a rare mire ecosystem.

- <u>Biodiversity hotspot.</u>

  Critical for wetland flora, mire-specific bird species, migratory waterbirds, and diverse invertebrates.

- <u>Conservation role.</u>

  Supports the survival of species and habitats under threat from climate change and human land pressure.

- <u>Zoning for protection and research.</u>

  Managed through functional zones: strict regime, regulatory regime, buffer zone, and a nature park zone — balancing conservation with controlled access.

A Case Study: North Vidzeme Biosphere Reserve (Latvia)

The only biosphere reserve in Latvia

- <u>Overview and Scope.</u>

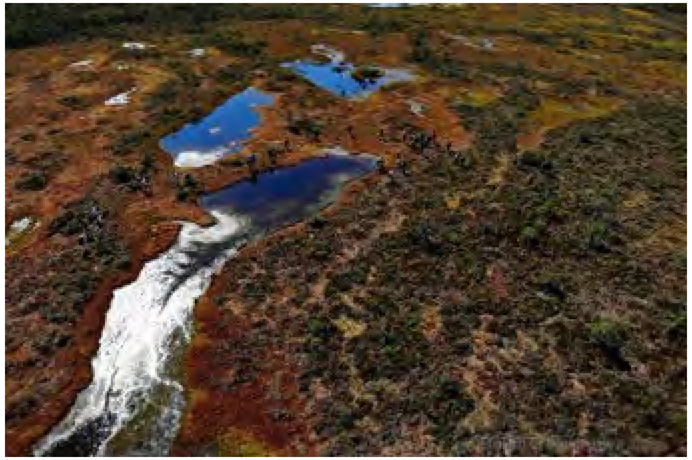
  Established in 1997, North Vidzeme is Latvia's only biosphere reserve, covering a vast 475,514 ha.
- <u>Integrated conservation model.</u>

  Created to balance biodiversity protection, economic development, and cultural heritage preservation.
- <u>International ecological relevance.</u>

  Represents globally important Baltic coastal and temperate forest ecosystems.
- <u>Zoning strategy.</u>

  Divided into landscape protection zones and neutral zones to support both conservation and human activity.
- <u>Platform for scenario application.</u>

  Ideal for testing land-use scenarios that reflect EU conservation policies, rural development, and climate adaptation.

Teiči Strict Nature Reserve Future (2064) Outcomes

Plausible futures depending on current choices

- <u>Scenario 1 – SSP3–RCP6.0 (A: Business-as-Usual).</u>

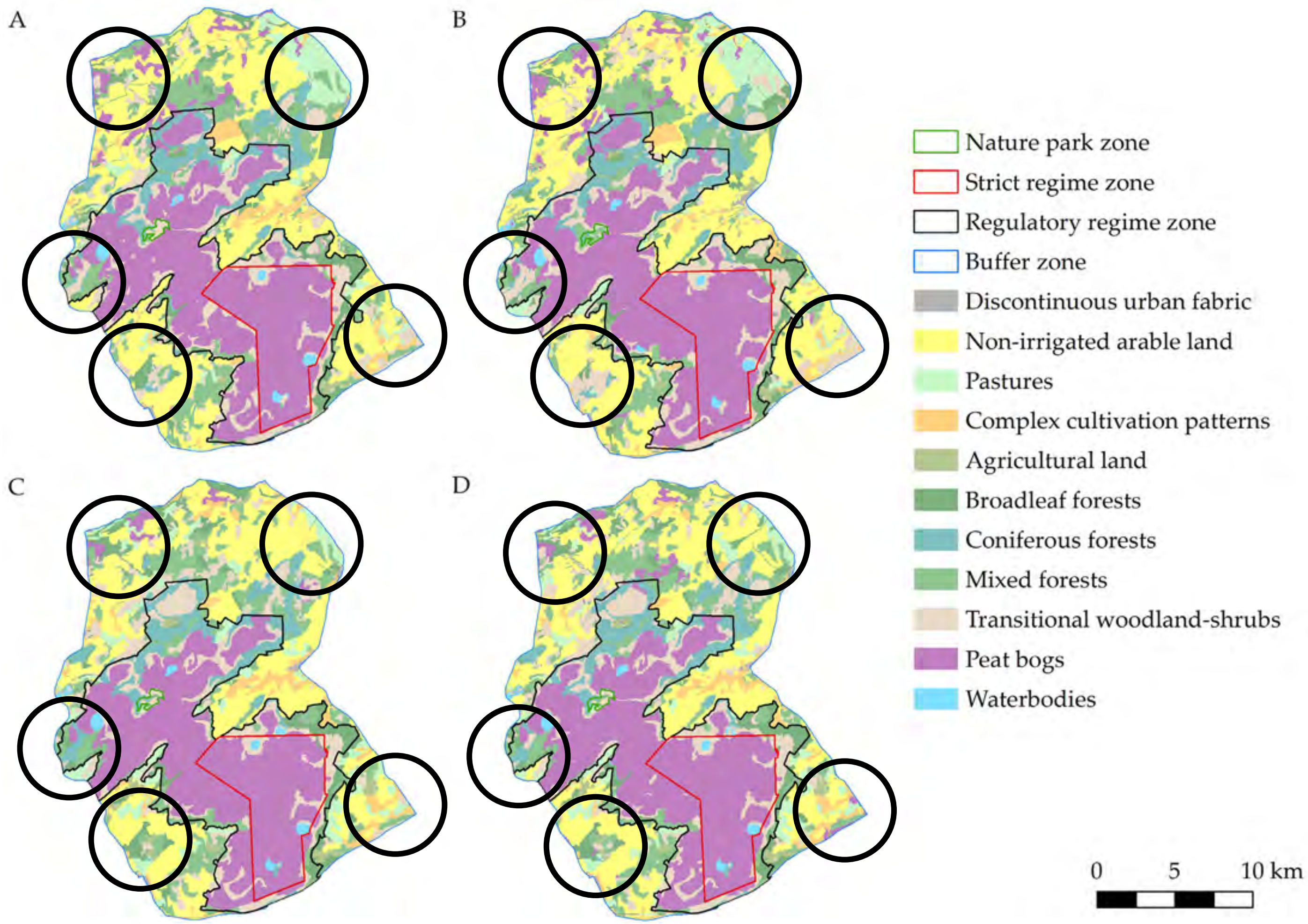
  Low policy intervention, moderate climate change, and land transitions driven by development priorities.
- <u>Scenario 2 – SSP1–RCP6.0 (B: Conservation-Oriented).</u>

  Emphasizes strict regulation, limits agriculture in buffer zones, and actively restores natural ecosystems.
- <u>Scenario 3 – SSP5–RCP6.0 (C: Agro-Expansion Focused).</u>

  Prioritizes agricultural growth with significant natural-to-agricultural conversion and urban growth near roads.
- <u>Scenario 4 – SSP3–RCP4.5 (D: Mixed Pathway).</u>

  Strikes a balance between conservation and development, allowing controlled agriculture with minimal fragmentation.
- <u>Illustrates localized adaptation of global pathways.</u>

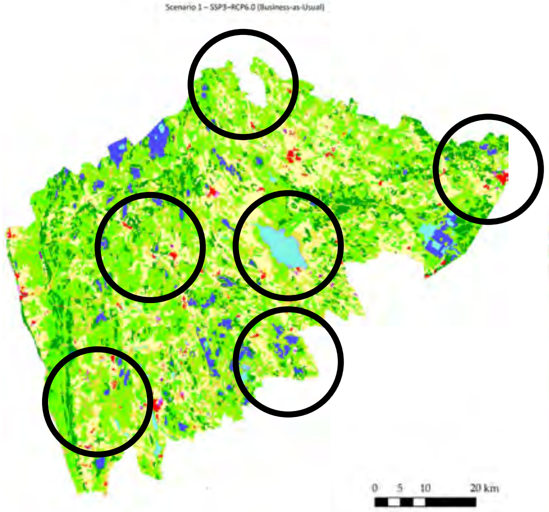
  These tailored narratives translate SSP–RCP logic into spatial impacts within a high-value conservation site.

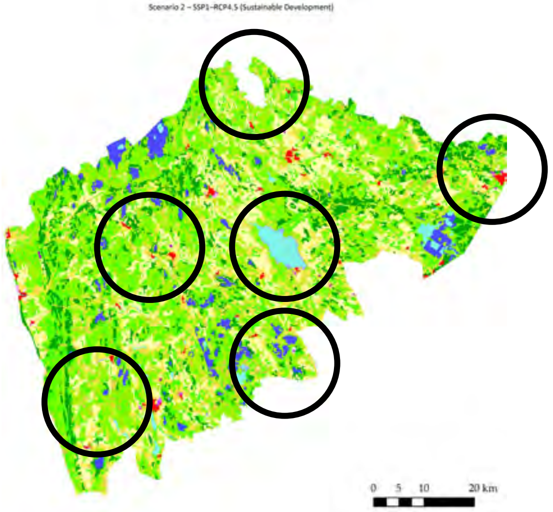


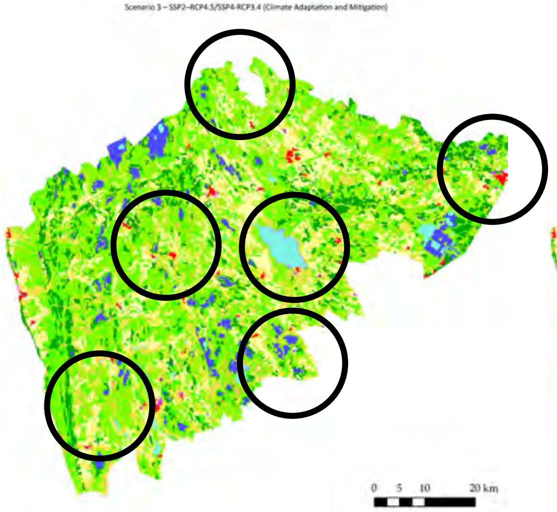
North Vidzeme Biosphere Reserve Future (2046) Outcomes

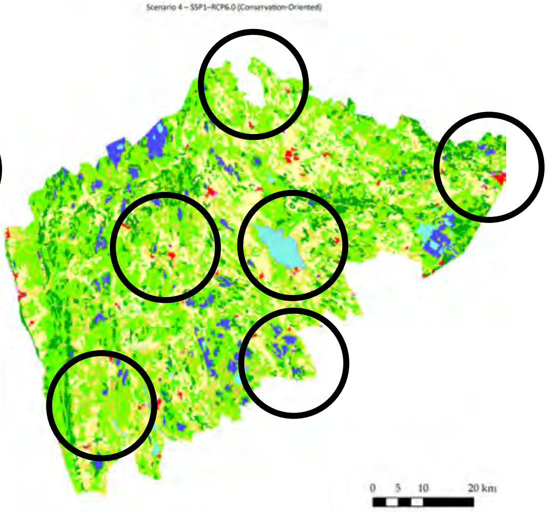
Plausible futures depending on current choices

- **Scenario 1 – SSP3–RCP6.0 (Business-as-Usual).**
  Continues historical land-use trends with limited restoration.
- **Scenario 2 – SSP1–RCP4.5 (Sustainable Development).**
  Balances land use and biodiversity, with active restoration efforts aligned with EU 2030 targets.
- **Scenario 3 – SSP2–RCP4.5/SSP4-RCP3.4 (Climate Adaptation and Mitigation).**
  Focuses on reforestation, wetland recovery, and adaptive land-use transitions to build ecosystem resilience.
- **Scenario 4 – SSP1–RCP6.0 (Conservation-Oriented).**
  Emphasizes strict protection with minimal land use. Prevents deforestation but limits active ecological restoration.









Land-use and land-cover categories

Continuous urban fabric
Discontinuous urban fabric
Industrial or commercial units
Road and rail networks and associated land
Green urban areas
Port areas
Sport and leisure facilities
Mineral extraction sites
Broad-leaved forest
Coniferous forest
Mixed forest
Transitional woodland-shrub
Non-irrigated arable land
Land principally occupied by agriculture
Complex cultivation patterns
Fruit trees and berry plantations
Pastures
Natural grasslands
Peat bogs
Inland marshes
Water bodies
Water courses
Beaches, dunes, sands
Sea and ocean

What are the Key Insights?

Before we interpret results and make decisions, we validate the model and ensure its accuracy.

- Model training.

  Model is trained using LULC data of an earlier period along with the associated driving factors.
- Model validation.

  Model is run to simulate LULC for a later know period. Simulated LULC map is compared to the actual observed LULC map.
- Accuracy assesment.

  Accuracy assessment uses the Kappa statistic to measure overall agreement between simulated and observed LULC maps, and Cramér’s V to assess the strength of association between land cover categories, especially for scenario comparisons.
- Size matters.

  Larger the case study area, the less pronounced the relative changes will be.
- Scenario modeling identifies critical choices.

  Helps visualize consequences of land-use decisions, emphasizing long-term outcomes.
- Highlights trade-offs clearly.

  Balances conservation, economic development, and land-use flexibility.
- Aligns decision-making with EU sustainability goals.

  Supports targeted actions toward biodiversity, climate resilience, and rural development.
- Enhances stakeholder engagement.

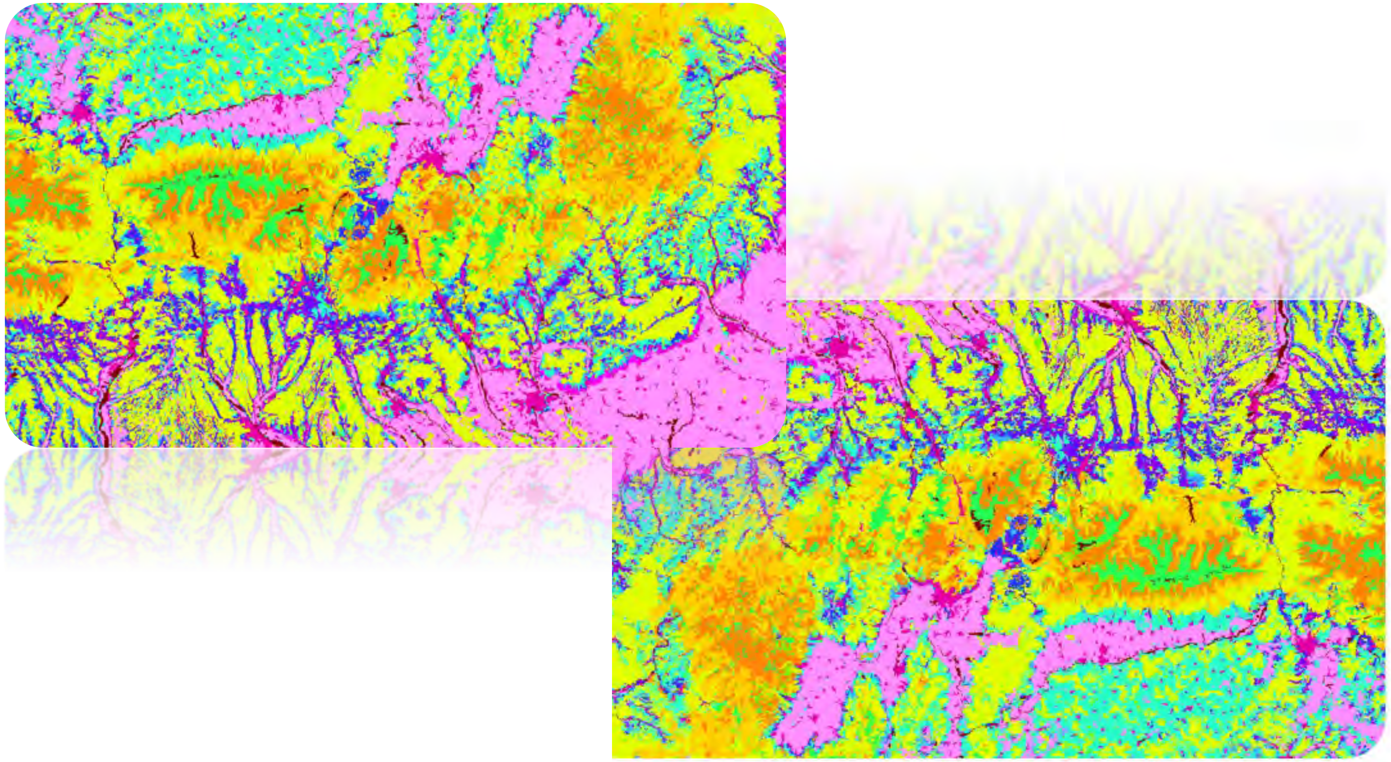
  Provides clear visuals and evidence-based scenarios to inform community participation in planning processes.
- Enables proactive adaptation.

  Guides strategic interventions to address biodiversity loss and climate-change impacts effectively.

Thank you for attention!!!

Modelling land use/land cover pattern changes

Case study: Romania



Gheorghe KUCSICSA, Mihaela SIMA,

Elena-Ana URȘANU, Marius-Victor BÎRSAN

Institute of Geography, Romanian Academy

1. CONTEXT

The LUC modeling: as an essential part of understanding the potential future developments. It helps in decision-making processes and allows for the assessment of the impacts of different policies or interventions on LUC patterns.

empirical-statistical & spatially explicit models

with the purpose of explaining and predicting LUC pattern, supporting the analyses of potential LUC changes under multiple scenarios

inductive / deductive

pattern / agent-based

dynamic or static

spatial / non-spatial

uncombined / hybrid

regionally / globally

SVMs (Support Vector Machines)

ANN (Artificial Neural Networks)

CELLULAR AUTOMATA

MARKOV CHAINS

Logistic Regression

CLUEs

LEAM (The Land-use Evolution And Impact Assessment Model)

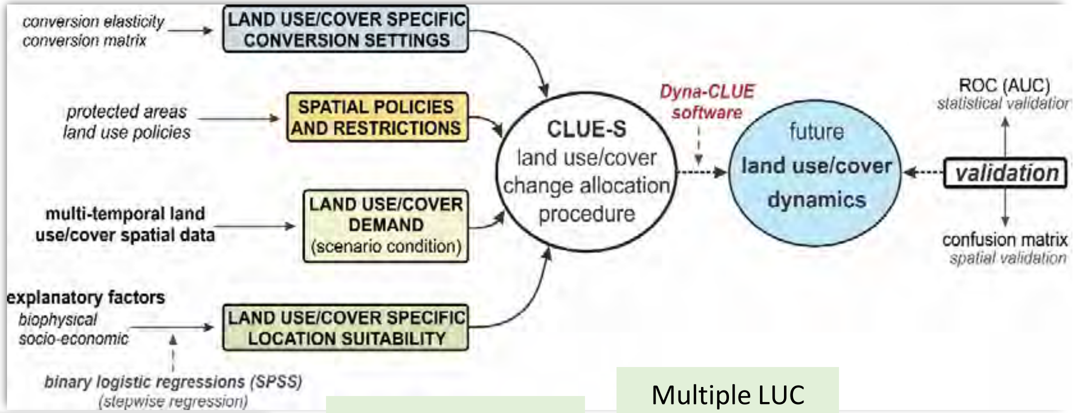
SLEUTH (Slope, Land use, Exclusion, Urban, Transportation, Hillshade)

LTM (Land Transformation Model)

to design appropriate plans for sustainable land management at different spatial scales:
e.g. possible consequences of LUC transition on landscape diversity and biodiversity; landslide hazard and risk & hazard mitigation plans; the implications for ecosystem services or carbon allocation

2. CLUEs model (the Conversion of Land Use and its Effects at Small regional extent)

CLUEs = a model specifically developed for the spatially explicit simulation of LU/LC pattern change, based on an empirical analysis of location suitability combined with the dynamic simulation of the competition and interactions between the spatio-temporal dynamics of LU/LC systems (Veldkamp and Fresco, 1996, Verburg et al., 1999; 2004; 2010)



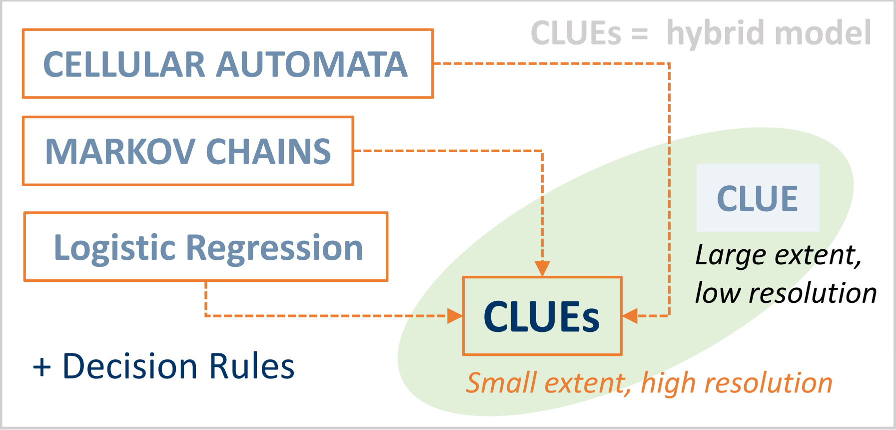
The model requires four inputs:

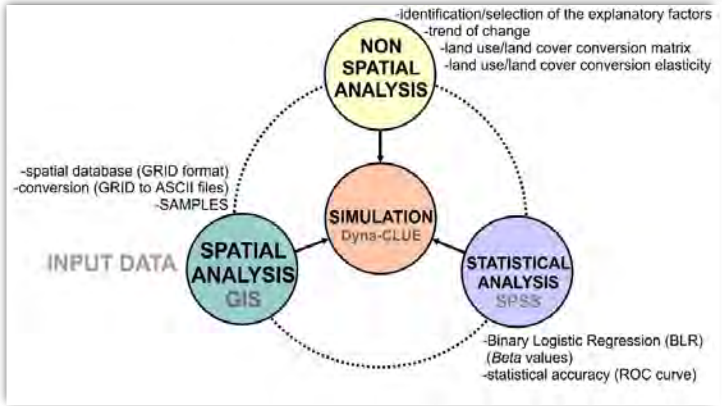
1) **LU/LC type-specific conversion settings**, which indicate _the conversion elasticity_ (0 = easy….1 = irreversible change) and _the conversion matrix_ (LUC type can/cannot be converted into any other LUC);

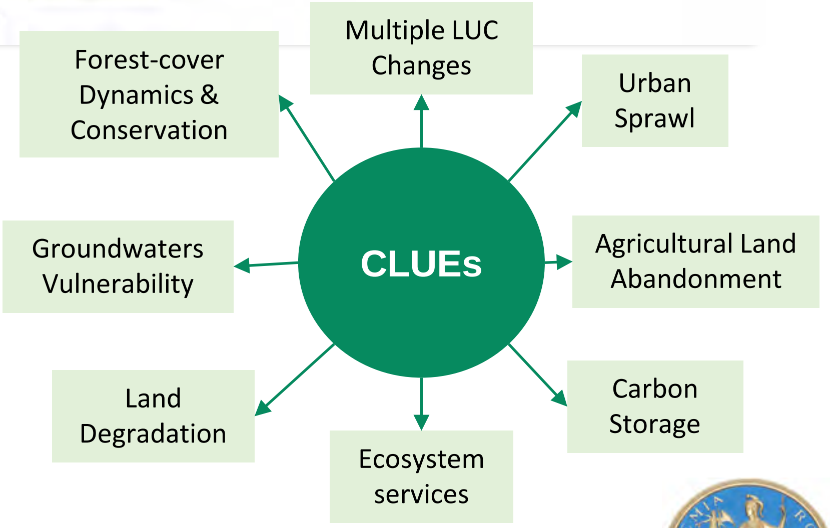
2) **Spatial policies and restrictions**, which can restrict/limit LUC change in certain areas (e.g., land-use policies, environmental policies);

3) **LU/LC demand** (scenarios based on simple trend extrapolations or complex models);

4) **Location characteristics** (LUC suitability), determined as the relations between the LU/LC pattern and explanatory factors.



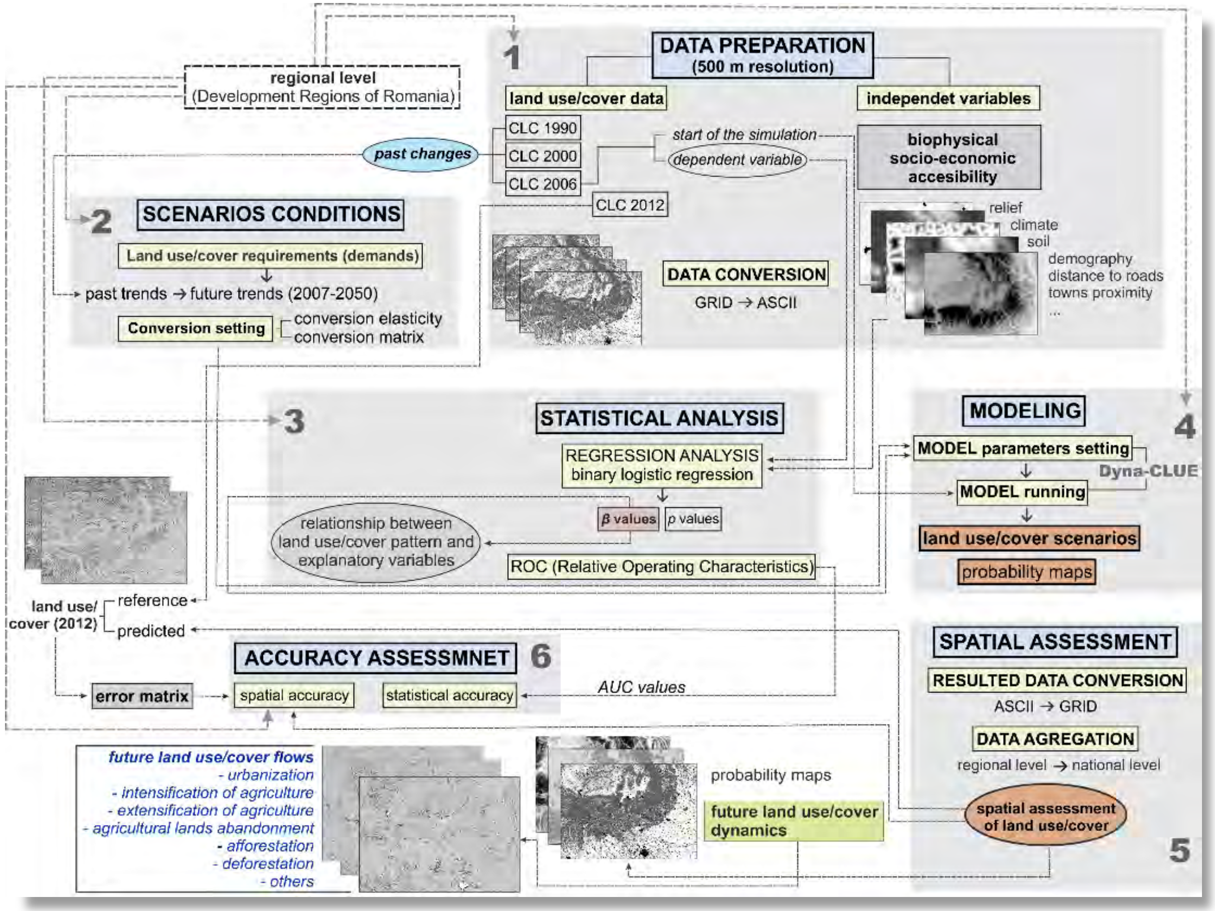


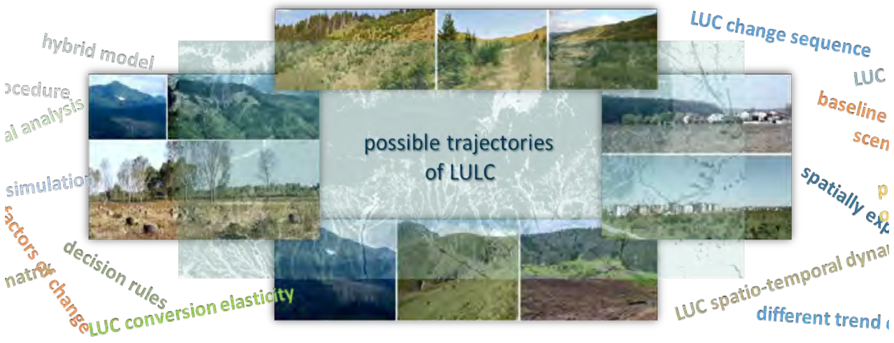


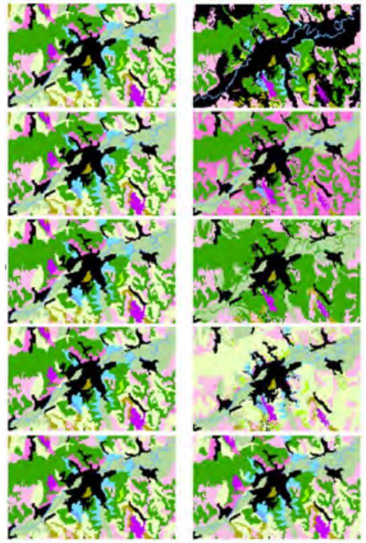
3. CLUEs model: implementation for Romania

The potential future LU/LC pattern changes:

CLC datasets + Biophysical & Socioeconomic factors







Modelling future scenarios = (qualitative & quantitative) in order to explore:

Where will the LU/LC pattern change take place? (location)
What LU/LC pattern change will occur? (transition/conversion)
When will the LU/LC pattern change take place? (time)
How much will it change? (magnitude)

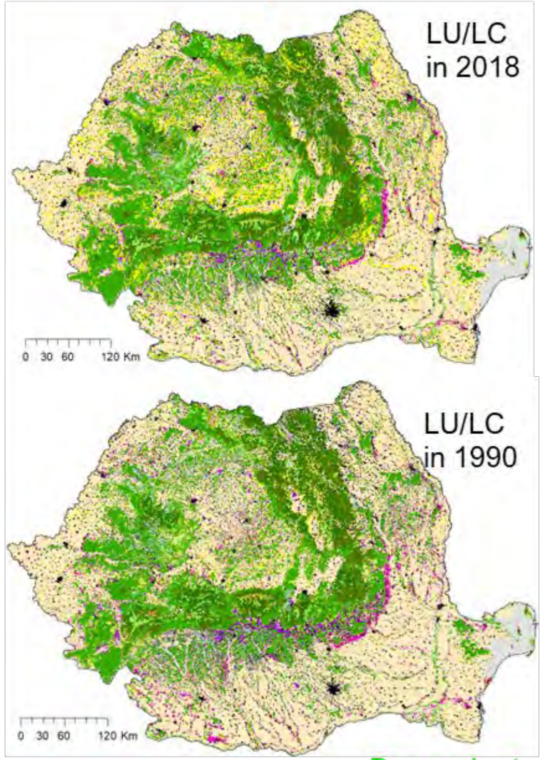
simulation = at national level (pixel size = 250m)
total simulated area = 23,058,000 ha (96.8% of country surface area) = 3,810,944 cells
the analysis of change = national + regional scale

3. CLUEs model: implementation for Romania

The simulated LU/LC classes

Copernicus – Land Monitoring Service
CORINE Land Cover (CLC)
https://land.copernicus.eu/en/products/corine-land-cover

CLC description (Level 3 of nomenclature)	LU/LC classes	Code	Main category
Discontinuous urban fabric	Built-up areas	0	ARTIFICIAL AREAS
Industrial or commercial units			
Continuous urban fabric			
Green urban areas			
Sport and leisure facilities			
Airports			
Construction sites			
Port areas			
Non-irrigated arable land	Arable lands	1	AGRICULTURAL AREAS
Rice fields			
Permanently irrigated land			
Vineyards	Vineyards	2	
Fruit trees and berry plantations	Orchards	3	
Complex cultivation patterns	Agricultural complex cultivation patterns	4	
Annual crops associated with permanent crops			
Land principally occupied by agriculture, with significant areas of natural veg.	Heterogenous Agricultural areas	5	
Agro-forestry areas			
Pastures	Pastures	6	
Natural grasslands	Natural grasslands	7	
Transitional woodland-shrub	Transitional woodland-shrub	8	SEMI-NATURAL/NATURAL AREAS
Moors and heathland			
Sclerophyllous vegetation			
Broad-leaved forest	Broad-leaved forest	9	
Mixed forest	Mixed forest	10	
Coniferous forest	Coniferous forest	11	
Beaches, dunes, sands	Open spaces with little or no vegetation	12	
Sparsely vegetated areas			
Water courses	Not simulated	13	LUC RESTRICTED/WITH COMPLEX DYNAMICS
Water bodies			
Sea and ocean			
Coastal lagoons			
Inland marshes			
Peat bogs			
Salt marshes			
Burnt areas			
Bare rocks			
Mineral extraction sites			
Road and rail networks and associated land			
Dump sites			



Historical LU/LC change (LU/LC 1990 & 2018)

Future possible trend

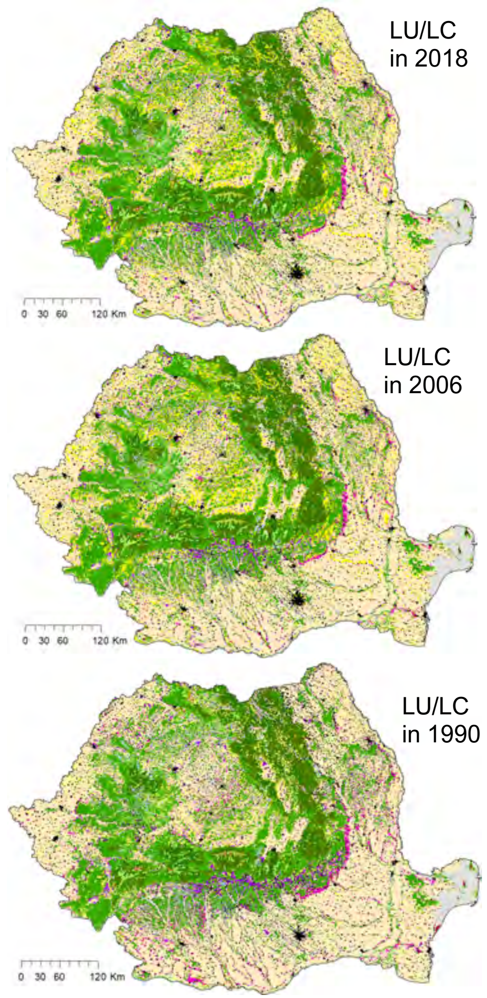
Dependent Variables (LU/LC 2018)

Start of the Simulation (LU/LC 2018)

3. CLUEs model: implementation for Romania

Developing two baseline scenarios + one alternative (until now)

LU/LC classes	Code	Main category
Built-up areas	0	ARTIFICIAL AREAS
Arable lands	1	AGRICULTURAL AREAS
Vineyards	2	
Orchards	3	
Agricultural complex cultivation patterns	4	
Heterogenous Agricultural areas	5	
Pastures	6	
Natural grasslands	7	SEMI-NATURAL/NATURAL AREAS
Transitional woodland-shrub	8	
Broad-leaved forest	9	
Mixed forest	10	
Coniferous forest	11	
Open spaces with little or no vegetation	12	
Not simulated	13	LUC RESTRICTED/WITH COMPLEX DYNAMICS



Past LU/LC pattern change (1990-2018; 2006-2018)

Linear trend of LU/LC pattern change (2019-2050)

BASELINE SCENARIOS

(business as usual)

BAU$_1$ = scenario that simulated future LU/LC pattern change under the current condition of driving factors, and current LU/LC changes. The future demand is adapted to current trend of LU/LC pattern change, registered in the post-communist period (>1990);

BAU$_2$ = scenario that simulated future LU/LC pattern change under the current condition of driving factors, and current LU/LC changes. The future demand is adapted to current trend of LU/LC pattern change, registered in the EU post-accession (>2006);

ALTERNATIVE SCENARIOS

(in relation to biodiversity conservation and climate change)

ASbc = scenario that simulated future LU/LC pattern change taking into account LU/LC conservation strategies inside the protected areas

AScc = scenarios that simulated future LU/LC pattern change under the under the climate change

1) **ACC$_o$** = optimistic scenario

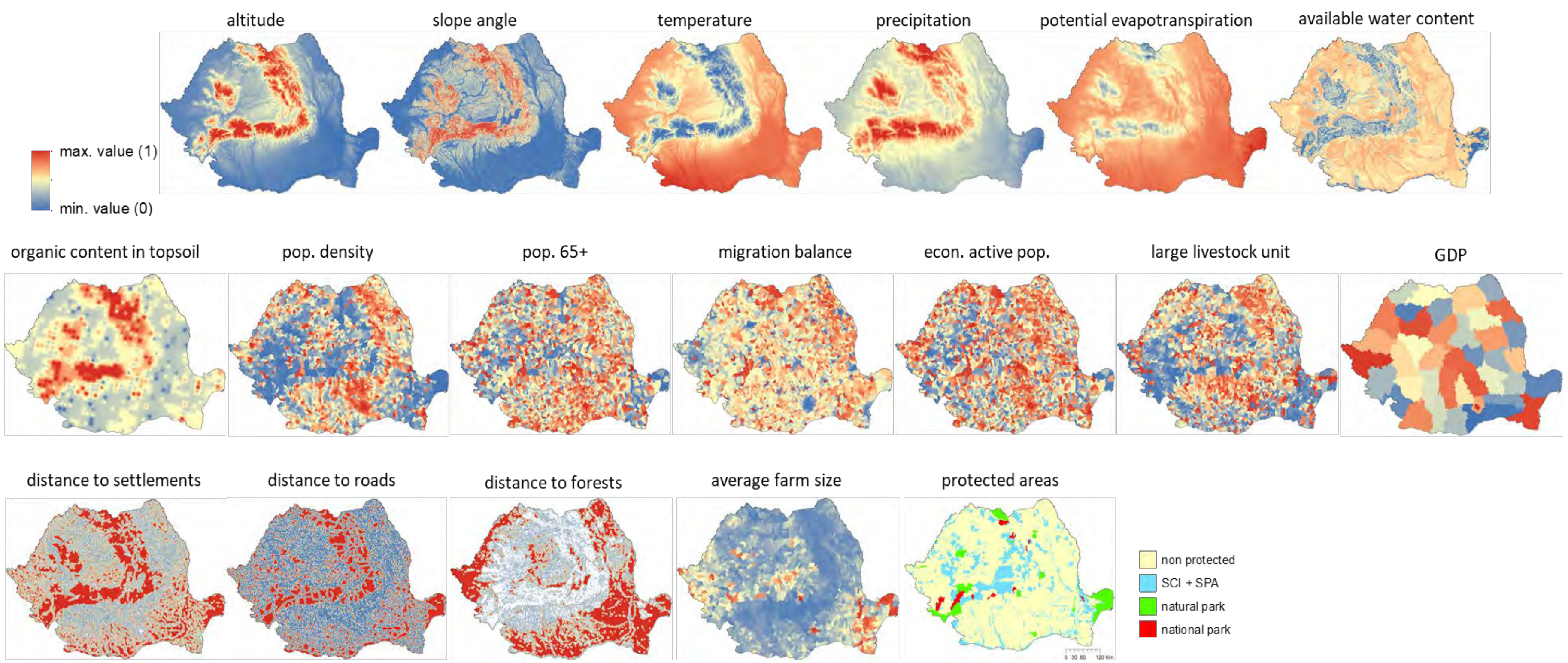
2) **ACC$_p$** = pessimistic scenario

3) **ACC$_i$** = intermediate (in between)

3. CLUEs model: implementation for Romania

The potential factors of LU/LC pattern changes

Integrating: **17 continuous** & **1 categorical explanatory factors**



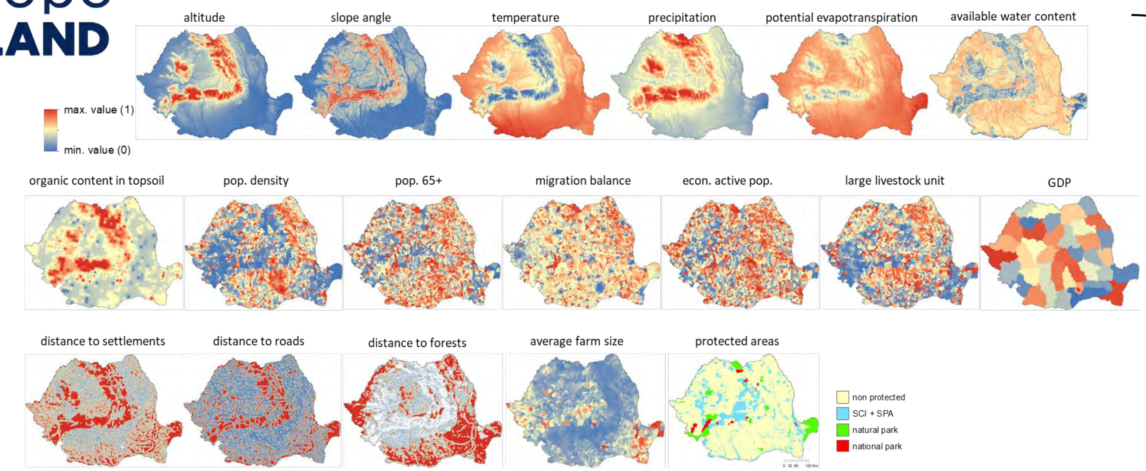
1	**Altitude** / cell (derived from SRTM)
2	**Slope** / cell (derived from SRTM)
3	**Temperature** $_{\text{multi-annual average 4-9}}$ / cell (derived from CHELSA, 1980-2018)
4	**Precipitation** $_{\text{multi-annual average 4-9}}$ / cell (derived from CHELSA, 1980-2018)
5	**Potential Evapotranspiration** $_{\text{multi-annual average 4-9}}$ / cell (derived from CHELSA, 1980-2018)
6	**Available Water Content** $_{\text{<1m}}$ / cell (derived from JRC database)
7	**Organic content in top soil** / cell (derived from Romania – Soil quality and electricity transmission grid. Geographical atlas)
8	**Population density** $_{\text{average}}$ /LAU (derived from NIS, 1992-2018)
9	**Population 65+** $_{\text{average}}$ /LAU (derived from NIS, 1992-2018)
10	**Permanent migration** $_{\text{average balance}}$ /LAU (derived from NIS, 1992-2018)
11	**Economic active pop** $_{\text{average}}$ /LAU (derived from NIS, 2002-2019)
12	**Large livestock units** $_{\text{average}}$ /LAU (derived from NIS, 2002-2010)
13	**PIB** $_{\text{ratio}}$ /county (derived from NIS, 2000-2021)
14	**Distance to Settlements in 1990** / cell (derived from CLC, 1990; buffer = 500m) *
15	**Distance to roads** / cell (derived from OpenStreet; buffer = 500m) *
16	**Distance to afforested area in 1990** / cell (derived from CLC, 1990; buffer = 500m)
17	**Average farm size** / LAU (derived from NIS, 2010)
18	**Major protected areas** $_{\text{national parks}}$ / cell (provided by Ministry of Environment, Water and Forests, 2020)
19	**Major protected areas** $_{\text{natural parks}}$ / cell (provided by Ministry of Environment, Water and Forests, 2020)
20	**Major protected areas** $_{\text{SCI+SPA}}$ / cell (provided by Ministry of Environment, Water and Forests, 2020)
14	**Distance to Settlements in 2018** (derived from CLC, 2018; buffer = 500m) *
16	**Distance to afforested area in 2018** (derived from CLC, 2018; buffer = 500m) **

** used for the regression models (to compute suitability maps)*
*** used for the simulation*

3. CLUEs model: implementation for Romania

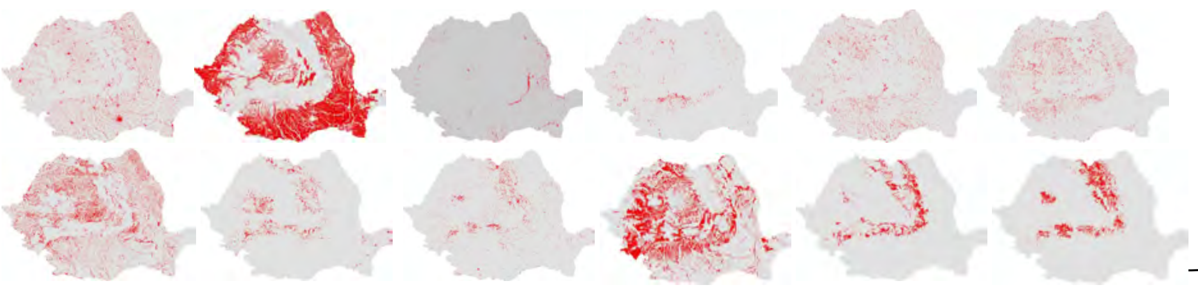
The contribution of driving factors on LU/LC pattern changes

driving factors



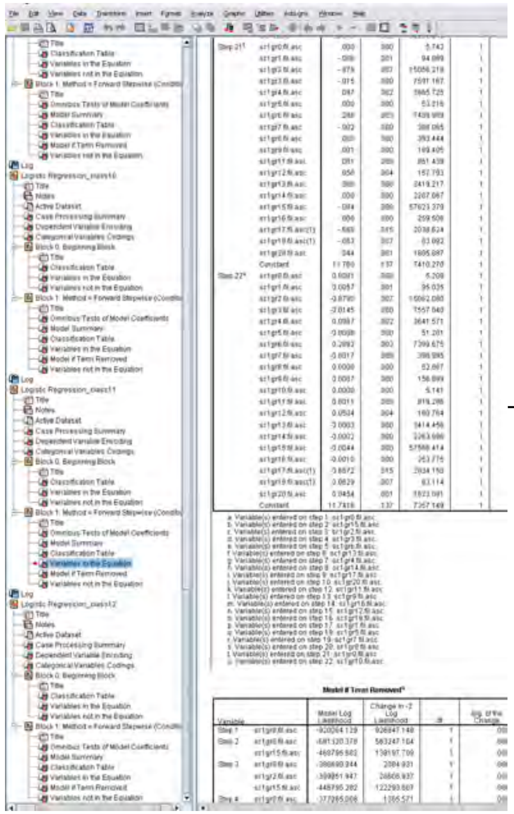
X

LU/LC actual status



Binary regression:

Method = Forward Stepwise



Contribution:

+ direct / – inverse

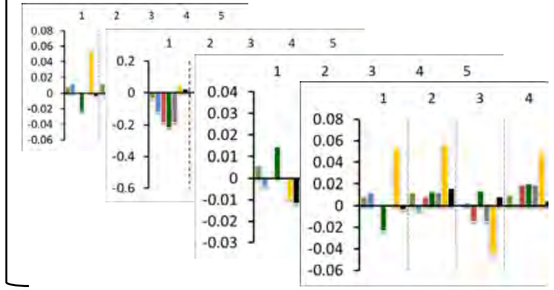
The most important:

- **Altitude**
- **Slope declivity**
- **Temperature**
- **Precipitation**
- **Organic content in top soil**
- **Protected areas**
- **Gross domestic product**
- **Average farm size**

p-value <0.05

The less important:

- Population density
- Population 65+
- Permanent migration
- Economic active pop
- Distance to roads



The ROC statistic metric:

AUC (Area Under the Curve)

= observed LU/LC x predicted probability

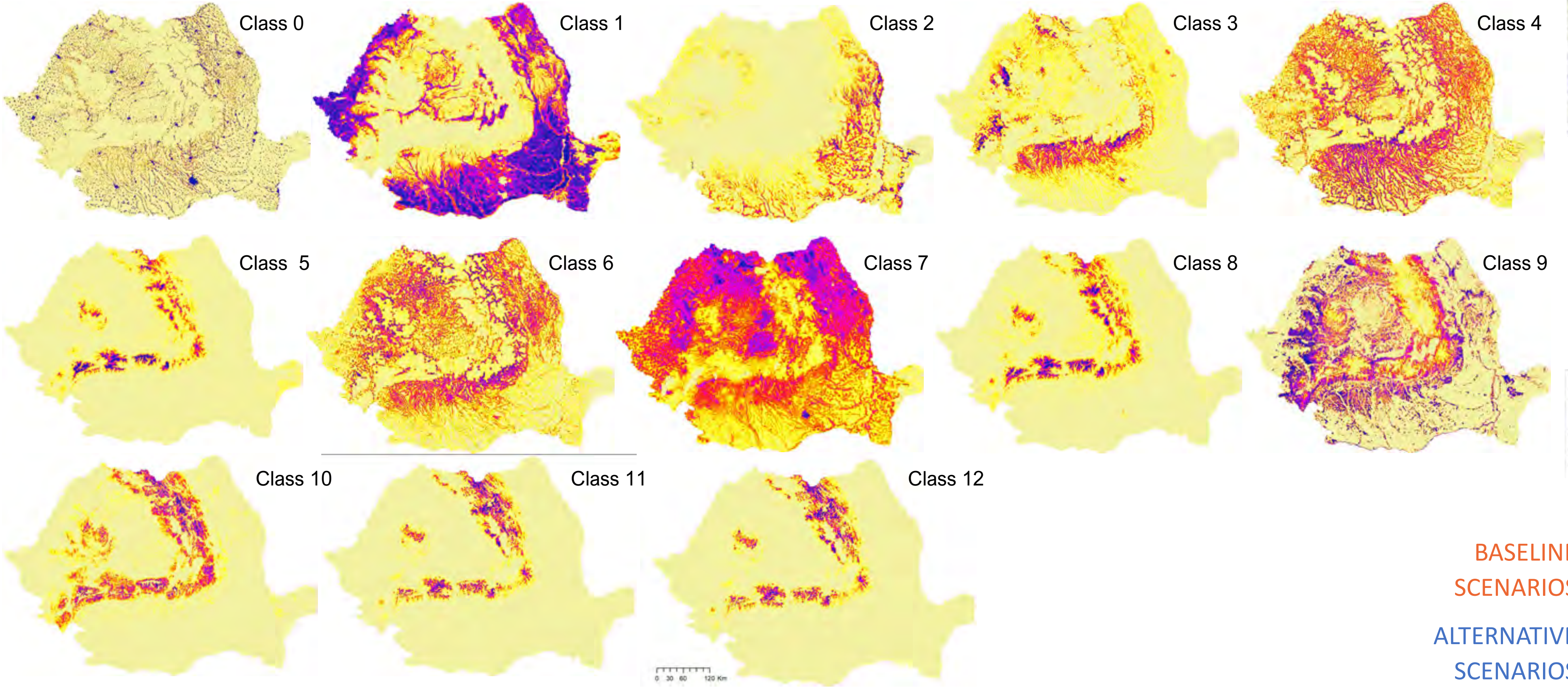
LU/LC	*Class 0*	*Class 1*	*Class 2*	*Class 3*	*Class 4*	*Class 5*	*Class 6*	*Class 7*	*Class 8*	*Class 9*	*Class10*	*Class11*	*Class12*
AUC	**0.867**	**0.890**	**0.816**	**0.755**	**0.732**	**0.692**	**0.626**	**0.858**	**0.787**	**0.779**	**0.903**	**0.956**	**0.801**

Statistical validation

3. CLUEs model: implementation for Romania

Developing two baseline scenarios + one alternative

LOCATION CHARACTERISTICS
(probability of transition)



DECISION RULES

The conversion matrix

class	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	0
3	1	1	1	1	1	1	1	1	1	1	1	1	1	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	0
5	1	1	1	1	1	1	1	1	1	1	1	1	1	0
6	1	1	1	1	1	1	1	1	1	1	1	1	1	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	0
8	1	1	1	1	1	1	1	1	1	1	1	1	1	0
9	1	1	1	1	1	1	1	1	1	1	1	1	1	0
10	1	1	1	1	1	1	1	1	1	1	1	1	1	0
11	1	1	1	1	1	1	1	1	1	1	1	1	1	0
12	1	1	1	1	1	1	1	1	1	1	1	1	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	1

0 = LU/LC type cannot be converted into any other LUC / 1 = LU/LC type can be converted into any other LUC

The conversion elasticity

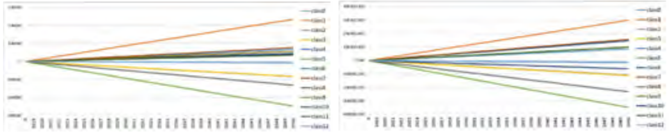
0	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.2	0.7	0.7	0.3	0.4	0.2	0.1	0.5	0.7	0.7	0.7	0.5	1

0 = easy to convert ..... 1 = irreversible change

+

+

LU/LC DEMAND



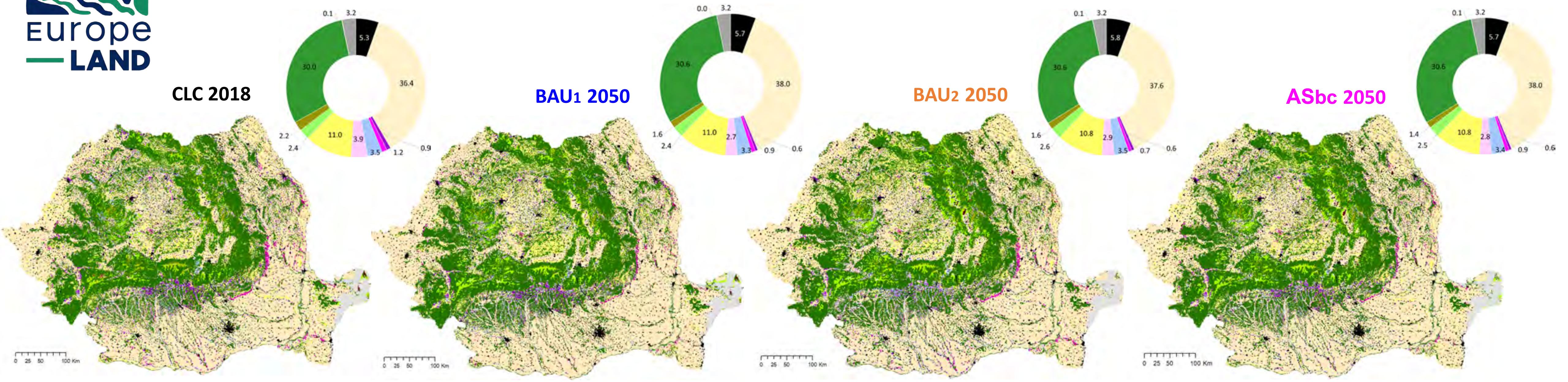
BASELINE SCENARIOS

ALTERNATIVE SCENARIOS

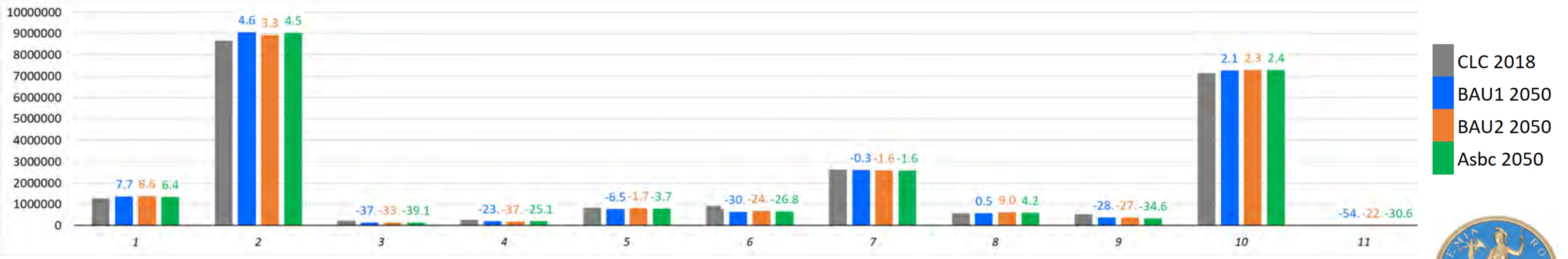
Future potential LU/LC pattern change (2019-2050)

4. RESULTS

The predicted LU/LC pattern in 2050



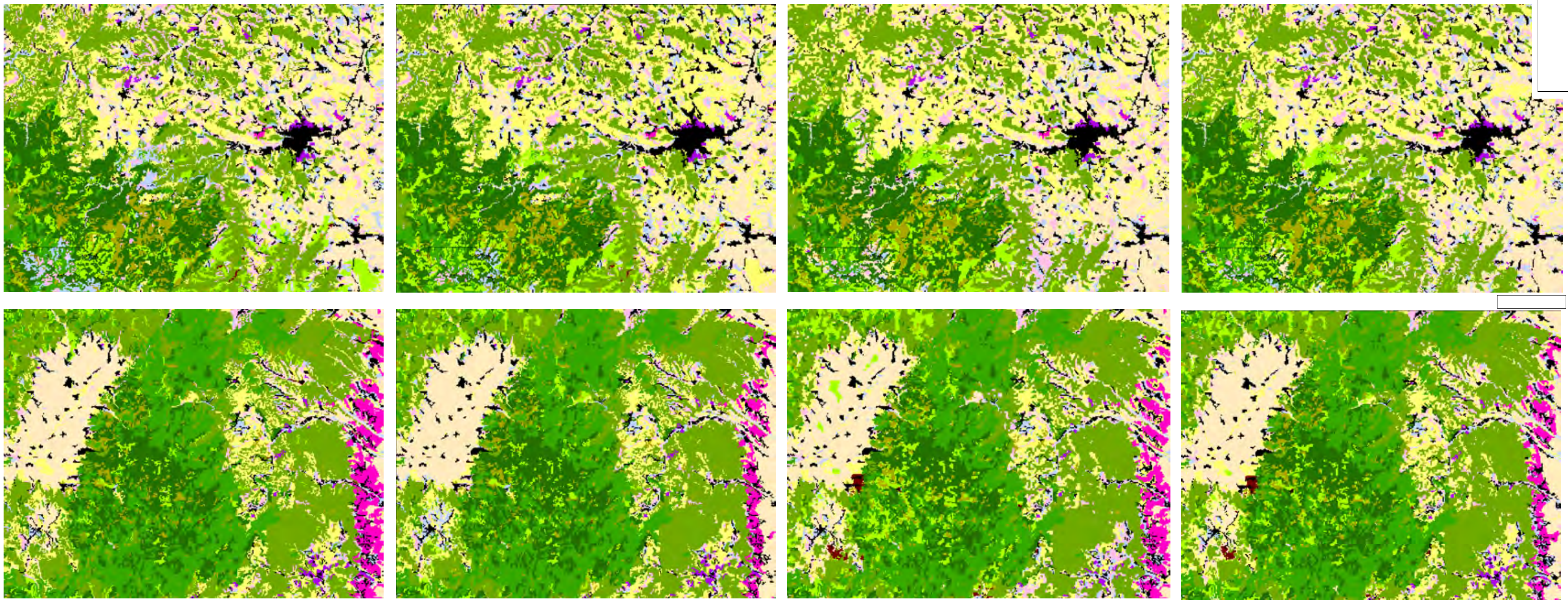
1 Built-up areas
2 Arable lands
3 Vineyards
4 Orchards
5 Agricultural complex cultivation patterns
6 Heterogenous agricultural areas
7 Pastures
8 Natural grasslands
9 Transitional woodland-shrub
10 Forest
11 Open spaces with little or no vegetation
12 Not simulated



4. RESULTS

The predicted LU/LC pattern in 2050

CLC 2018 | BAU1 2050 | BAU2 2050 | ASbc 2050



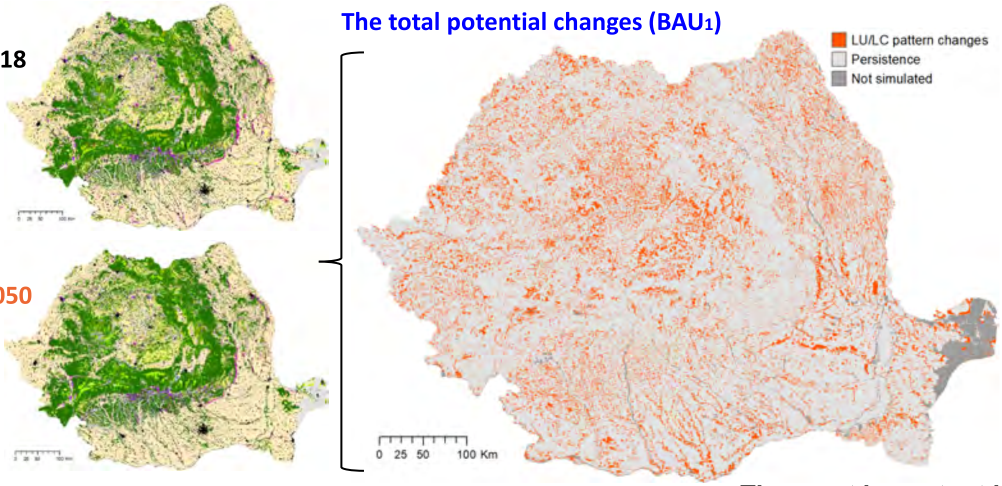
4. RESULTS

The predicted LU/LC pattern changes

CLC 2018

BAU_1 2050

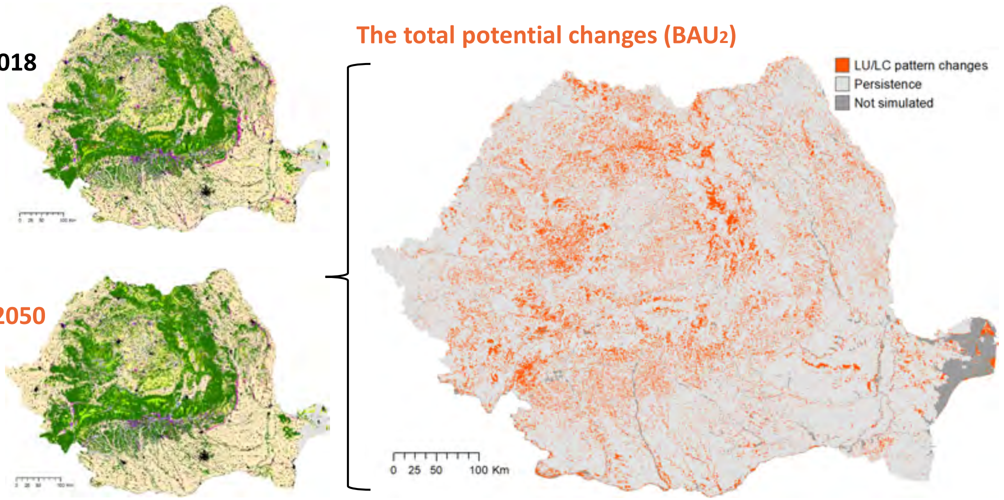
The total potential changes (BAU_1)



CLC 2018

BAU_2 2050

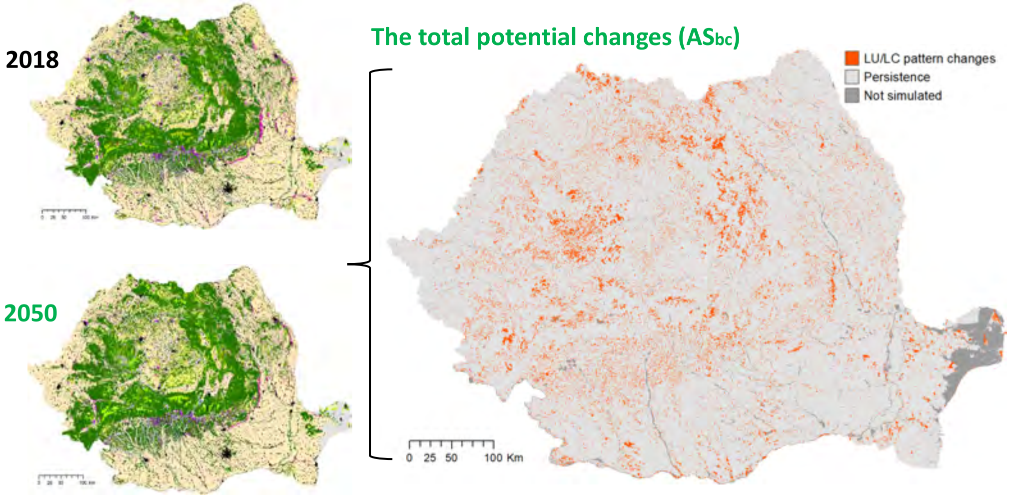
The total potential changes (BAU_2)



CLC 2018

AS_{bc} 2050

The total potential changes (AS_{bc})



The most important increases:

- **Arable lands** = +399,350 ha (BAU_1), +283,150 ha (BAU_2); +389,250 ha (AS_{bc})
- **Natural grasslands** = +2,700 ha (BAU_1), +52,100 ha (BAU_2); +24,000 ha (AS_{bc})
- **Forests** = +147,550 ha (BAU_1), +164,300 ha (BAU_2); +169,600 ha (AS_{bc})
- **Built-up areas** = +97,600 ha (BAU_1), +109,300 ha (BAU_2); +81,750 ha (AS_{bc})

➢ *Total predicted pattern changes*:

BAU_1 = 3,412,000 ha (14.8% of total simulated LU/LC)

BAU_2 = 3,005,600 ha (13.0% of total simulated LU/LC)

AS_{bc} = 1,723,300 ha (7.2% of total simulated LU/LC)

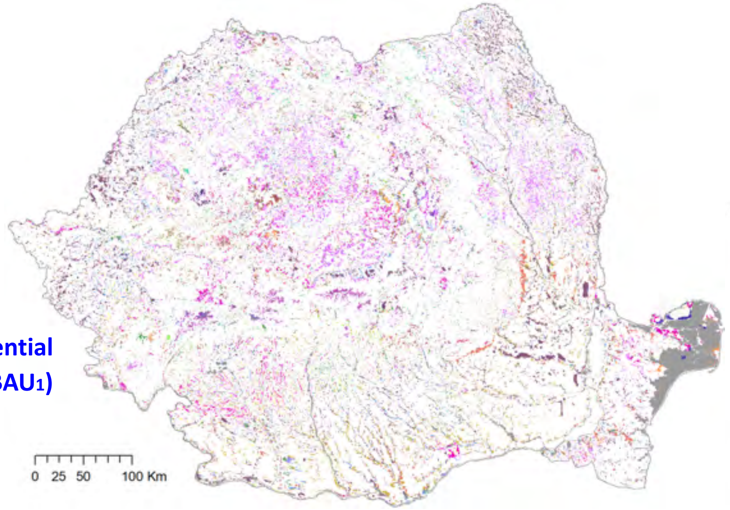
The most important decreases:

- **Heterogenous Agricultural areas** = –275,000 ha (BAU_1), – 224,200 ha (BAU_2); –245,388 ha (AS_{bc})
- **Transitional woodland-shrub** = –149,600 ha (BAU_1), –145,800 ha (BAU_2); –182,400 ha (AS_{bc})
- **Vineyards** = –83,100 ha (BAU_1), –73,900 ha (BAU_2); –87,800 ha (AS_{bc})
- **Orchards** = –66,150 ha (BAU_1), –103,300 ha (BAU_2); –70,000 ha (AS_{bc})
- **Agricultural complex cultivation patterns** = –53,900 ha (BAU_1), –13,900 ha (BAU_2); –30,600 ha (AS_{bc})

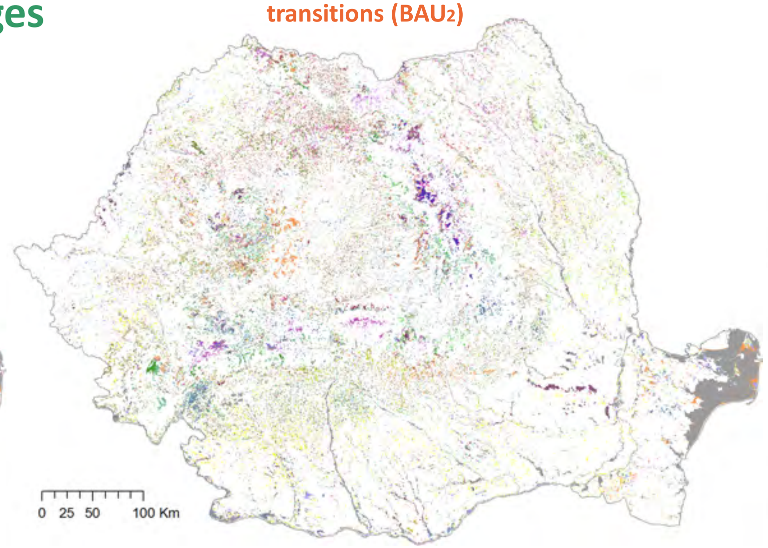
4. RESULTS

The predicted LU/LC pattern changes

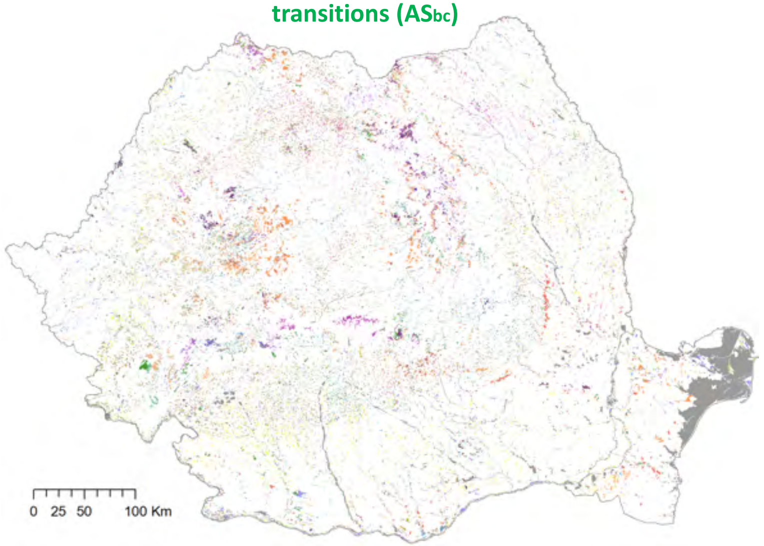
The predicted potential transitions (BAU_1)



The predicted potential transitions (BAU_2)

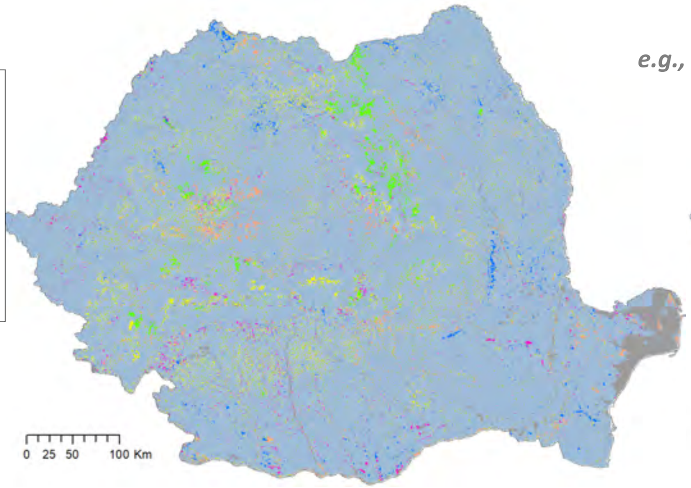


The predicted potential transitions (AS_{bc})

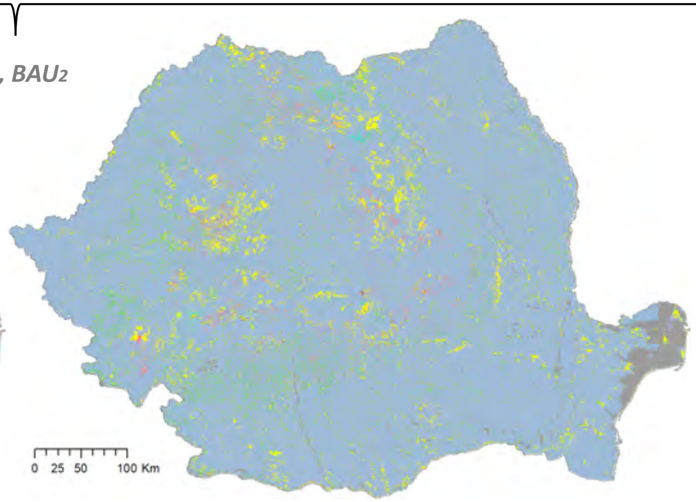


Total possible LU/LC transitions = 98 to 105

The specific FLOWS of LU/LC pattern changes



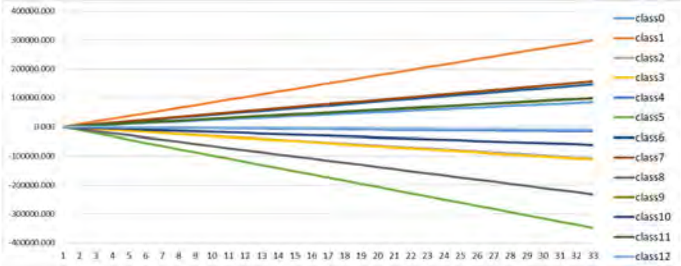
e.g., BAU_2



5. NEXT STEPS

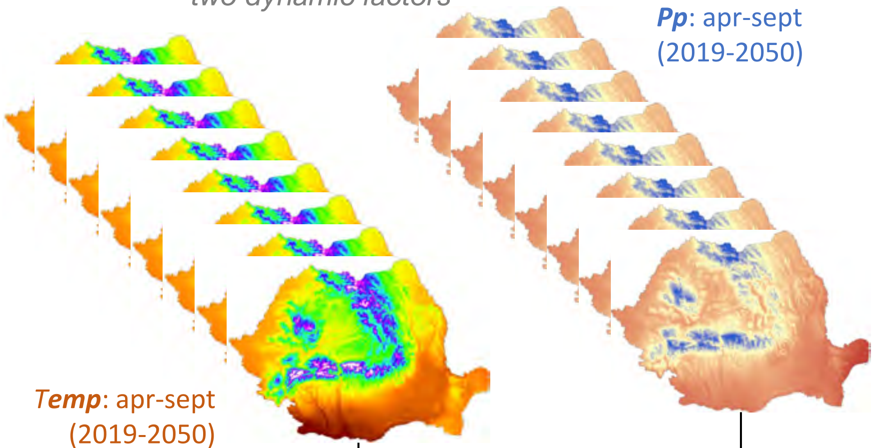
Predicting LU/LC pattern changes by integrating climate change scenario

Past LU/LC change (2006-2018)



+

two dynamic factors



Pp: apr-sept (2019-2050)

Temp: apr-sept (2019-2050)

Annual time-scale

CHELSA
(Climatologies at high resolution for the earth's land surface areas)

SSP1-RCP2.6 (optimistic)
SSP3-RCP7 (intermediate)
SSP5-RCP8.5 (pessimistic)

Pp	***Temp***
2019	2019
2020	2020
2021	2021
2022	2022
2023	2023
2024	2024
2025	2025
2026	2026
2027	2027
…	…
…	…
…	…
…	…
2049	2049
2049	2049
2050	2050

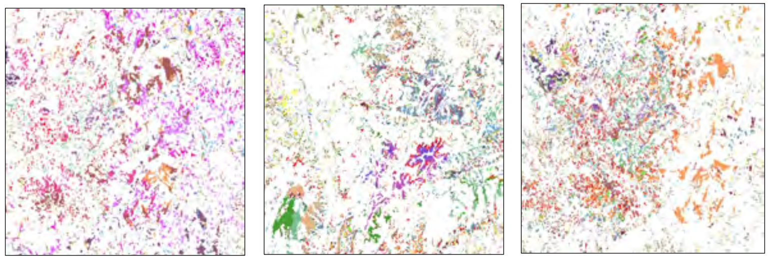
To develop three alternative scenario in relation to climate change (AScc)

AScco = alternative that simulated future LU/LC pattern change under the **c**limate **c**hange (**o**ptimistic scenario). The future demand is adapted to current trend of LU/LC pattern change, registered in the EU post-accession (>2006), and under the current condition of driving factors, except for the climate indicators.

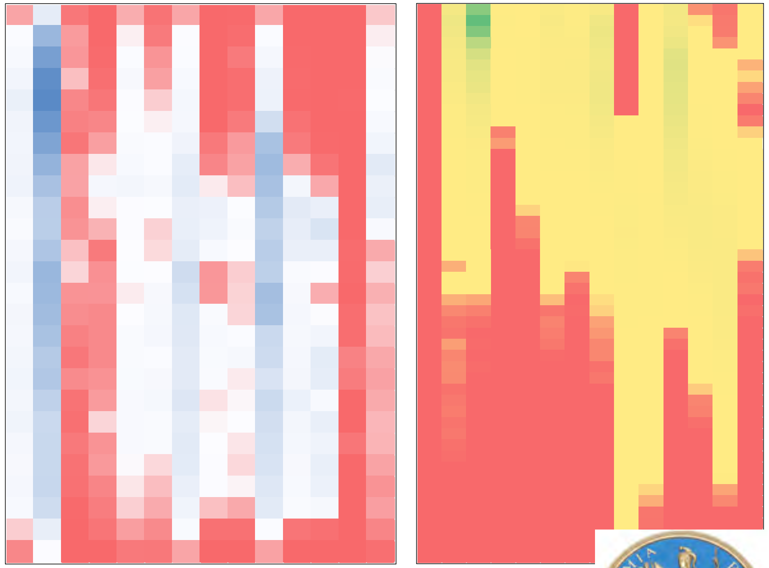
AScci = alternative that simulated future LU/LC pattern change under the **c**limate **c**hange (**i**ntermediate or in between scenario). The future demand is adapted to current trend of LU/LC pattern change, registered in the EU post-accession (>2006), and under the current condition of driving factors, except for the climate indicators.

AScсp = alternative that simulated future LU/LC pattern change under the **c**limate **c**hange (**p**essimistic scenario). The future demand is adapted to current trend of LU/LC pattern change, registered in the EU post-accession (>2006), and under the current condition of driving factors, except for the climate indicators.

type of transitions; location; magnitude



latitudinal & altitudinal potential variation



CONCLUSIONS

The used CLUEs model = a dynamic model, suitable to simulate near-future changes in LUC pattern at high resolution, by integrating different static/dynamic driving factors & in relations to the recent LU/LC pattern change;

The used CLUEs model = allows us to understand the most likely LU/LC transitions in the future, their location and amount;

The modelled scenarios = show a high heterogeneity of the possible transition in LU/LC in the simulated period, according to the demands proposed in relation to recent LU/LC pattern change in Romania;

The outcomes = show significant differences between the proposed baseline and alternative scenarios, in terms of total possible transitions, their location and total amount;

The outcomes = show how by integrating the protective measures in agreement with respecting the general principles of biodiversity preservation inside the already delineated protected areas in Romania (*As*$_{bc}$ scenario) may reduce the total amount of LU/LC pattern changes, with the results in slight increase of artificial areas, a relative stability of agricultural lands and, more important, an increase of afforested areas in the future;

Next steps = the integration of climate change scenarios (pp & temp in the growing season) as dynamic factors in order to see how climate warming will affect LU/LC pattern up to 2050 in terms of transitions, their location and magnitude;

Next steps = a more detailed analysis of all proposed scenarios at national and regional scale, by aggregating the resulting transitions into the main LU/LC change flows in line with the EUROPE-LAND project objectives.