Faculty of Environmental Sciences

RETROSPECTIVE ANALYSIS AND SCENARIO-BASED PROJECTION OF LAND-COVER CHANGE. THE EXAMPLE OF THE UPPER WESTERN BUG RIVER CATCHMENT, UKRAINE

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Dresden, July 23rd, 2019 Cornelia Burmeister

ABSTRACT

Land-cover and land-use change are highly dynamic and contribute to changes in the water balance. The most common changes are urbanisation, deforestation and desertification. This dissertation deals with the topic of projecting land cover (LC) into the near future with the help of the scenario technique. The aim of the thesis is the projection of the urban and rural land-cover change (LCC) till 2025. Two research questions are addressed in this work: (1) Which integrated concept can be developed to combine different methods to project urban and rural LCC into the future based on past LCC? (2) Is it possible to implement the developed concept and does the implementation deliver plausible results?

To answer the research questions, a 4-step concept is adopted which serves as workflow for projecting the LCC: (i) the definition of the scenario context, and with that the definition of the study area, (ii) the identification of spatial and dynamic drivers for LCC, consisting of spatial drivers that are location-dependent, such as slope or soil type, and dynamic drivers of LCC, such as demographic and economic development, (iii) scenario formulation and projection of identified drivers, and (iv) scenario-based projections of future LCC, which means its quantitative and spatial modification (demand and allocation).

For implementation and testing, the Upper Western Bug River catchment in Ukraine serves as the study site. The extent of the study area reaches from the source of the Western Bug to the Dobrotvir gauging station and is thus entirely located in Ukraine. This presents the first step of the developed concept of the projection of LCC. The existing geo-database for implementation is scarce. LC data is available for the territory of the EU (e.g. CORINE Land Cover) but not for Ukraine.

Therefore, the implementation of the second step had to focus on the derivation of LC data for three-time steps to get the basis for the LCC. A classification of satellite scenes of Landsat and SPOT are done for the time steps 1989, 2000, and 2010. The two decades show a huge development of LCC. The increase of ‘artificial surface’ and unmanaged ‘grassland’ is visible with the decrease of ‘arable land’ and ‘forests’.

An extended statistical analysis considering the systematic LCC reveals stable transition pathways, which in turn are the basis of the projection of future land cover. This refers to the second step of the concept: change detection.

One transition pathway is that ‘arable land’ is not used and converted in settlement areas, but rather changes into ‘grassland’. With the derived LC and the analysed LCC as a basis of the work, the search for spatial and dynamic drivers start at the third time step. A list of dynamic drivers is first compiled, via literature research, and then tested for effect on LCC with statistical analyses.

The dynamic driving forces are the ‘Gross Domestic Product’ (GDP) and ‘population development’. Spatial driving forces are laws/planning practices, fertility, slope, distance to the city Lviv, settlements, roads, or rivers. As a result, population development has an effect on the change in the LC class to 'artificial surface' from 'grassland' and 'arable land' from ‘grassland'.

The implementation of the third step is done with the help of four storylines where the overall development of the dynamic drivers are included towards 2025. With that it is possible to project them into the future.

The fourth step includes the calculation of the demand for each LC class with the projected dynamic drivers. The areas that have a high probability to change into another LC class are determined in suitability maps (allocation) which are derived by translating the transition pathways into GIS algorithms including the spatial driving forces. The class of 'artificial surface' changes the most under scenario A until 2025 and less under scenario D — the sustainable scenario. The LC class 'arable land' decreases in scenario A and B, but has the strongest development in scenario D. The LC class of unmanaged ‘grassland’ is quite stable under scenario A and B, but decreases in C and D.

The results of systematic changes in ‘arable land’ that changes into ‘grassland’ are different compared to developments in other countries like Germany. The protection and conservation of arable land is not seen as strongly in other Eastern European countries as it is in the Upper Western Bug River catchment. In turn, the identified spatial and dynamic drivers fit other studies in Eastern Europe.

The applied concept of projecting LCC with these steps are highly flexible for implementation in other study sites. However, the volume of work can differ within the steps because of the available databases. In Ukraine the available LCC data was not detailed enough to carry out a future projection. So, a main part of the work is dedicated to the derivation of past LC for different time steps. The involvement of regional experts helped to gain detailed knowledge of processes of LCC. The advantage of the presented concept with the mixture of quantitative (e.g. satellite analyses, statistical analyses) and qualitative methods can overcome methodological knowledge gaps. In addition, the retrospective analyses, as starting points, for the projection of future LCC carves out the site-specific allocation of change.

ZUSAMMENFASSUNG

Landbedeckungs- und Landnutzungsänderungen sind sehr dynamische Phänomene, die zu Veränderungen in der Wasserbilanz beitragen. Die häufigsten Formen des Landbedeckungswandels sind Urbanisierung, Entwaldung und Wüstenbildung. Diese Dissertation beschäftigt sich mit dem Thema der Projektion der Landbedeckung in eine nahe Zukunft. Dazu wird die Hilfe der Szenariotechnik genutzt. Ziel der Arbeit ist es, den städtischen und ländlichen Landbedeckungswandel ins Jahr 2025 zu projizieren. Zwei Forschungsfragen werden mit der Arbeit adressiert: (1) Welches Konzept kann entwickelt werden, um verschiedene Methoden zu kombinieren und zu integrieren, um den städtischen und ländlichen Landbedeckungswandel in die Zukunft zu projizieren, indem von der Vergangenheit ausgegangen wird? (2) Ist es möglich, das entwickelte Konzept umzusetzen und liefert die Umsetzung plausible Ergebnisse?

Zur Beantwortung der Forschungsfragen wird ein 4-stufiges Konzept adaptiert, das als Workflow für die Projektion des Landbedeckungswandels dient: (i) die Definition des Szenariofeldes, und damit und die Definition des Untersuchungsgebietes, (ii) die Identifikation der räumlichen und dynamischen Treiber des Landbedeckungswandels, bestehend aus räumlichen Treibern, die ortsabhängig sind, wie Hanglage oder Bodentyp, und dynamischen Treibern des Landbedeckungswandels, wie die demografische und wirtschaftliche Entwicklung, (iii) die Szenarioformulierung und die Projektion der identifizierten Treiber und (iv) die szenariobasierte Projektion des zukünftigen Landbedeckungswandels, in seiner quantitativen und räumlichen Veränderung (Bedarf und Allokation).

Für die Durchführung und Erprobung dient das obere Einzugsgebiet des Westlichen Bug Flusses als Untersuchungsgebiet. Die Ausdehnung des Untersuchungsgebietes reicht von der Quelle des Westlichen Bug bis zum Pegel Dobrotvir und liegt damit vollständig in der Ukraine. Diese Festlegung beinhaltet den ersten Schritt des entwickelten Konzeptes für die Projektion des Landbedeckungswandels. Die Datenbasis für die Implementierung des Konzeptes ist gering. Landbedeckungswandeldaten sind für das Territorium der EU verfügbar wie bspw. durch CORINE Land Cover (CLC); in der Ukraine gibt es diese Daten jedoch nicht.

Daher wurde bei der Testung des zweiten Schrittes des Konzeptes der Schwerpunkt auf die Ableitung von Landbedeckungsdaten für drei Zeitschnitte gelegt, um eine Ausgangsbasis für

den Landbedeckungswandel zu schaffen. Dafür wurde eine Klassifizierung von Satellitenszenen von Landsat und SPOT für die Zeitschritte 1989, 2000 und 2010 durchgeführt. Die beiden Jahrzehnte zeigen eine große Entwicklung des Landbedeckungswandels im Einzugsgebiet. Die Zunahme von 'bebauter Fläche' und unbewirtschaftetem 'Grünland' ist sichtbar und eine Abnahme von 'Ackerland' und 'Wäldern'. Eine erweiterte statistische Analyse der Landbedeckungsveränderung, die auch die systematische Landbedeckungsveränderung berücksichtigt, zeigt stabile Übergangspfade, die wiederum die Grundlage für die Projektion der zukünftigen Landbedeckung sind. Ein Übergangspfad ist z. B., dass 'Ackerland' nicht für Siedlungsflächen genutzt und umgewandelt wird, sondern in 'Grünland' übergeht. Nach der Ausarbeitung des Landbedeckungswandels beginnt die Suche nach räumlichen und dynamischen Treibern für den Zeitraum der drei Zeitschritte (ebenso Schritt zwei). Eine Liste von dynamischen Treibern wird zunächst per Literaturrecherche zusammengestellt und anschließend auf ihre Wirkung auf den Landbedeckungswandel durch Statistik überprüft. Dynamische Triebkräfte sind das 'Bruttoinlandsprodukt' und die 'Bevölkerungsentwicklung'. Als räumliche Triebkräfte sind Gesetze/Planungspraktiken, Fruchtbarkeit, Hanglage, Entfernung zu Lviv, Siedlungen, Straßen oder Flüsse identifiziert worden. So wirkt sich z. B. die Bevölkerungsentwicklung auf die Veränderung der Landbedeckungsklassen 'bebaute Fläche', 'Grünland' und 'Ackerland' aus.

Die Implementierung des dritten Schrittes erfolgt mithilfe von vier Storylines, die die übergeordnete Entwicklung als auch die Entwicklung der räumlichen Triebkräfte bis in das Jahr 2025 beschreiben. Damit ist es möglich, die dynamischen Triebkräfte in die Zukunft zu projizieren.

Die Implementierung des vierten Schrittes beinhaltet die Berechnung des Bedarfes der einzelnen Landbedeckungsklassen mit den projizierten dynamischen Triebkräften. Die Flächen, die eine hohe Wahrscheinlichkeit haben sich in eine andere Landbedeckungsklasse zu wandeln, werden in Eignungskarten ermittelt (Allokation). Diese Eignungskarten werden erzeugt, indem die Transitionspfade mithilfe der räumlichen Triebkräfte in GIS-Algorithmen übersetzt werden. Die Klasse 'bebaute Flächen' ändert sich am stärksten unter Szenario A bis 2025 und weniger unter Szenario D – dem nachhaltigen Szenario. Die Klasse 'Ackerland' nimmt in Szenario A und B ab und hat ihre stärkste Entwicklung in Szenario D. Die Landbedeckungskategorie unbewirtschaftetes 'Grünland' ist in Szenario A und B recht stabil und nimmt in C und in D ab.

Die Ergebnisse der systematischen Veränderungen, wie z. B. die Umwandlung von 'Ackerland' in 'Grünland', unterscheiden sich von den Entwicklungen in anderen Ländern wie Deutschland. Der Schutz und Erhalt von Ackerflächen wird in anderen osteuropäischen Ländern nicht so stark praktiziert wie im oberen Einzugsgebiet des Westlichen Bugs. Die identifizierten räumlichen und dynamischen Treiber passen wiederum zu anderen Studien in Osteuropa. Das angewandte Konzept zur Projektion des Landbedeckungswandels mit den vier Schritten ist hochflexibel und kann in anderen Arbeiten Anwendung finden. Der Arbeitsumfang je Arbeitsschritt kann unterschiedlich ausfallen je nach vorhandener Datenbasis. In der Ukraine waren Daten zum Landbedeckungswandel nicht ausreichend detailliert vorhanden, sodass ein Arbeitsschwerpunkt auf der Erarbeitung der Landbedeckung für die drei unterschiedlichen Zeitschnitte lag. Das Einbeziehen von regionalen Experten half detailliertes Wissen über die Landbedeckungswandelprozesse zu erhalten. Der Vorteil des vorgestellten Konzeptes liegt dabei vor allem in der Mischung aus quantitativen (Satellitenbildanalyse, statistische Analysen) und qualitativen Methoden (Experteninterviews), um Daten- und Wissenslücken zu überwinden. Aber auch der Start der Landbedeckungswandelprojektion in der Vergangenheit (retrospektiv) holt die vorortspezifischen Gegebenheiten hervor.

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ABBREVIATIONS

AL	Arable Land
AHP	Analytical Hierarchy Process
ANN	Artificial Neural Network
AS	Artificial Surface
BAU	Business As Usual
BLF	Broad-Leaved Forest
CF	Coniferous Forest
CLUE	Conversion of Land Use and its Effects Model
DEM	Digital Elevation Model
DPSIR	Driver-Pressure-State-Impact-Response Concept
ESA	European Space Agency
GIS	Geographic Information System
GEO	Global Environment Outlook
GIFPRO	Commercial and Industrial Land Forecast
GL	Grassland
GTAP	Global Trade Analysis Project
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
IWAS	International Water Research Alliance Saxony
IWRM	Integrated Water Resource Management
LC	Land-cover
LCC	Land-cover change
LU	Land-use
LUC	Land-use change
LUDAS	Land Use Dynamics Simulator
LUSim	Land Use Simulation Model

MOLAND	Monitoring Land Use/Cover Dynamics Model
NDVI	Normalised Difference Vegetation Index
SCENES	Water Scenarios for Europe and the Neighbouring States
SITE	Simulation of Terrestrial Environments Model
SRES	Special Report on Emission Scenarios
WB	Water Bodies

1. INTRODUCTION

1.1 BACKGROUND

Land cover (LC) describes the Earth's surface, the cover on the Earth with: green spaces such as agricultural land, grassland, or forest and also urban areas in a spatial explicit way (FAO & UNEP 1999, Verburg 2009). The information of LC and its change is needed for the steering of the development of the state, district, city and rural environment. It is one of the tasks of the state institutions with the aim to monitor the development. Thereby, the land cover change (LCC) is still highly dynamic in the world (Mousivand & Arsanjani 2019, Wulder *et al.* 2018).

Mousivand & Arsanjani (2019) made a global analysis of the last 24 years of the European Space Agency (ESA) Climate Change Initiative dataset of LC (ESA-CCI-LC). The result of their study is that the most common global processes of change are urbanisation, deforestation, and desertification.

First of all, urbanisation is an ongoing trend. In the year 2016 around 55 percent of the world's population lived in cities (United Nations Department of Economic and Social Affairs 2016). The prognosis is, that by 2030, 60 percent of the world's population will live in cities (United Nations Department of Economic and Social Affairs 2016), because there is a greater opportunity to find jobs and to have the supporting infrastructure. Cities are the places with working places, and they provide for their inhabitants mobility services, drinking water, food, schools, hospitals, leisure time facilities, and as already mentioned above housing. These needs and demands are fulfilled not only in the cities but also by the corresponding surroundings and rural areas. Thereby, the used area which is often sealed should be as little as possible to preserve the natural cycles as e. g. infiltration. In Germany the aim is to consume up to 30 ha per day of unsealed and undeveloped area only which is difficult to meet (Bundesregierung Deutschland 2002, Rid 2003).

So the development of cities has a big impact on the LC and its change, especially the surrounding rural areas are affected. Therefore, area-wide data of different temporal states of LC and its development are important. The ongoing development is seen in the current and past LC and its change. Data and information on the state and change of LC opens options. On the one hand, it is possible to monitor the development of the prosperity of a society and the cities and rural areas. On the other hand, the analysis of the past and current LC development allows to identify the processes of LCC and land consumption by planning policies. The identified mechanisms of LCC can lead to policy actions and in general to options for actions.

The LC data which is needed to monitor the development and to steer spatial planning is cadastral information e.g. in Germany ATKIS, ALKIS or real land use (LU) data sets. When such information is missing or outdated, the LC can be derived with remote sensing products as e.g. satellite or aerial images which offers objective information on LC for different time steps. A good example for this in Europe is the European CORINE Land Cover dataset which is a product upon the analysis of Landsat, IKONOS, and SPOT satellite scenes and which monitors the pan-European area since the 1990ies (Umweltbundesamt & DLR-DFD 2009). Also, the Copernicus project which results in the finer description of the CORINE levels as 'Urban Atlas' has to be mentioned (European Union 2018).

Remote sensing gained more and more importance with the launching of the Landsat satellites in 1972 and went on to the current satellites as e. g. SPOT, the Sentinel Copernicus Series or Rapid Eye with an increased spatial, spectral, and temporal resolution (Wulder *et al.* 2018).

With remote sensing it is possible to provide data which cover not only administrative areas but also cover natural regions like a river catchment. An assessment of the LC development of a river catchment is possible and with that initial statements on the water quality. If the water quality of a river catchment is poor and shall be improved, the spatial development processes of the LC and its changes have to be analysed. This is crucial to find the critical developments and their underlying drivers to have a starting point for steering and mitigation.

But not only the current situation is important for analysis, it is also of interest to show the impacts of the developments into the future and how special environmental developments or laws impact and change LC. For this purpose, scenarios are a valuable tool to show the possible results of different developments in the future e.g. of LC development pathways. Thereby, a broad range of possible expected futures are imaginable. The 'business as usual' (BAU) scenario which project the current development in the future or scenarios with development in different dimensions of human life like economic, demographic or societal development.

As mentioned above, possible future images are broad, it is not the main task to pick the most certain developments but to parameterise the future developments with logical and consistent assumptions. LCC is affected through different developments, on the one side by the autonomous not controllable developments as e.g. climate change, demographic change or economic prosperity. On the other side, there are future developments of political and spatial planning strategies which are difficult to grab and to predict (Rounsevell *et al.* 2012, Turner *et al.* 2007). It is very complex and difficult to project future developments of different parts of public life and sectors. But it is one opportunity to generate a possible prospective picture to make e.g. stakeholders and politicians aware of critical developments.

LCC needs an integrated perspective considering different views from the natural sciences as well as from the social sciences. This is rather complex and difficult and needs a sophisticated concept (Müller & Munroe 2014) what the work tries to offer.

1.2 OBJECTIVES AND RESEARCH QUESTIONS

This work aims to project LCC into the near future of 2025 in both urban and rural settings. To get a base of ongoing LCC processes, the analysis starts with the past LCC from 1989 to 2010. The aim of the retrospective analysis is to identify the transition pathways, mechanisms, and the key drivers for the LCC processes. Therefore, a stepwise approach is developed and tested to derive potential future LC projections in the Upper Western Bug River catchment (cf. section 2).

The following research questions are addressed (cf. section 3 and 4):

- Which integrated concept can be developed to combine different methods to project urban and rural LCC into the future based on past LCC?
- Is it possible to implement the developed concept and does the implementation deliver plausible results?

1.3 STRUCTURE

In chapter 1, background information, objectives, research questions, and the structure of the work are presented.

In chapter 2, the basics of the work are presented. The definitions of LC terms, LCC, driving forces and scenario methods are clarified.

In chapter 3, the conceptual framework is introduced with a stepwise approach. The framework is presented in Figure 2 with each step and methods being described afterwards (cf. Burmeister & Schanze 2018).

In chapter 4, the implementation and testing of the conceptual framework is shown and described in the Upper Western Bug River catchment showing the applicability. The chapter is based on the results of the articles of Burmeister & Schanze (2016, 2018). The study starts with the systematic past LCC where Landsat and SPOT scenes from 1989 to 2010 are analysed. This leads to the initial transition rules which are translated and operationalised with geo-data. Statistics of possible driving forces allow to identify them for the processes of LCC. In parallel, experts' interviews are included. After these steps it is possible to project the first identified driver into the future, and afterwards the LCC is projected in space.

In chapter 5, the discussion of the applied methods and the achieved empirical results of the implementation of the framework are presented.

In chapter 6, the achieved results are assessed in summary to answer the objectives and research questions. The chapter ends with an outlook towards the challenges and additional research demands.

2. BASICS OF THE WORK

The following subsections will clear the key terms. They range from differentiation of LC and LU and a proposed understanding of systematic and random change to the explanation of drivers of LCC and their future modelling.

2.1 LAND COVER, LAND USE, AND LAND-COVER CHANGE

Land cover is commonly understood as the biophysical condition of the earth surface (Mimler 2007, Verburg *et al.* 2009), including bare soil, vegetation, or crops and man-made constructions covering the surface like buildings or infrastructure. LC comprises everything that is directly detectable by earth observation on the ground or via remote sensing data.

Land use is often defined as human activities exploiting and utilising the land for a certain purpose (FAO & UNEP 1999, Heistermann *et al.* 2006, Lambin *et al.* 2001, Mimler 2007, Verburg *et al.* 2009). Examples are nature protection areas, arable land or grassland, recreational areas and residential or commercial areas. Geist & Lambin (2001) relate these purposes to social driving forces. In addition, Verburg *et al.* (2009) refer to the human exploitation of land resources for the supply of goods and services for living and designate it as 'LU functions' or 'ecosystem functions/services', respectively.

Since LU is not directly visible via observation methods, additional information is needed such as socio-economic data, statistics, or particular field surveys (Verburg *et al.* 2009). It is sometimes directly linked to the LC taking the human activities into account (FAO & UNEP 1999). Vice versa, certain activities often lead to a specific LC. As an example, when the LU class grassland is used as pasture or mowed several times a year, the LC class is still grassland.

Concepts, causes, and processes of LC, LU, their changes over time, and patterns are summarised under the term 'land change science' or 'LU science' (Turner *et al.* 2007, Verburg *et al.* 2009) and 'land system science' (Rounsevell *et al.* 2012) which arose in the 2000ies. They cope with different scales with the linkages of LC/LU; interactions between nature and society, e.g. politics, behaviour of the people, consumption, or ecosystem services. LC and LU are a product of the changes and impact of each sectoral component in the human-environment system. Therefore, land system science is an interdisciplinary research field, which couples natural sciences and social sciences (Rounsevell *et al.* 2012).

LC and LU changes occur over a time period through anthropogenic actions (as described above) or natural succession processes. Therefore, it is crucial to analyse a longer time period. Change may regard to *LC*, *LU or both*. Geist & Lambin (2006) differentiate LCC in conversion or modification. The former occurs when a LC type is substituted by another one. The latter is determined by a gradual change of the character of a LC class. Furthermore, changing human activities may change the LC but in particular the LU. While LC conversion is obviously visible, the modification of LU is not, because the attributes of LU have to be known to make the change visible (Geist *et al.* 2006).

LCC/LUC can be considered as either unintended and autonomous targeted interventions through policies (Luther & Schanze 2009). This differentiation makes particularly sense if changing boundary conditions of decision makers should be separated from their decision options. In line with that, the aforementioned authors treat demographic development as autonomous change and spatial planning as targeted intervention in a study. At the same time, they stress that differentiation between both classes depends on the scale and purpose of the consideration. Often the unintended change refers to the biophysical conditions at a place, such as climatic variability or succession (Geist *et al.* 2006, Veldkamp & Fresco 1996).

A transition is the changing of an LC class into another LC class. A transition pathway includes the underlying change processes dependent on the driving forces of LCC.

2.2 PROJECTION OF LAND-COVER CHANGE

When it comes to modelling the LCC, especially the projection of LCC into the future, the following key components have to be considered:

- The analysis of the past LC and the LCC to the current state,
- The calculation of the future development (demand) of a LC class, and
- The allocation of the future LCC in space.

To fulfil these three tasks, different methods and data have to be considered. First of all, it needs LC data of the past and current situation. Remote sensing has gained more and more importance, at all, with the launch of satellites, e.g. Landsat-1 in 1972 and the development of various analysis methods (Lambin & Geist 2006, Rounsevell *et al.* 2012). The Landsat data archive provides a consistent long-time series for analysing the LC data of an area of interest since 1972 (Griffiths 2013, Turner *et al.* 2007, Wulder *et al.* 2012, 2018). The technical improvement and progress of the satellite systems provide nowadays higher resolution and repetition rate. Satellite data provider services as the USGS Earth Explorer help to search and check for available images. More and more platforms offer the data for free as e.g. Landsat, Rapid Eye or the Copernicus System so that it is getting easier to use satellite images for own purposes.

There are different concepts of modelling LCC and LUC. These concepts are mentioned: empirical–statistical, rule-based/ process-based and economic LU approaches which are linked to models.

A short overview of the most common approaches is given here and some examples are named. Besides, there are a lot of classifications for model approaches. This subsection focuses here on state of the art LCC/LUC models with the possibility of future projections. The differentiation of the models is carried out according to two criterias: calculating areas which are prone to change (suitable for allocation) on the one hand and the estimation of change rates (demand) on the other hand.

Thereby, the site-specific suitability is a multi-criteria problem or decision problem (Malczewski 2006, Mendoza 2001) where several indicators affect the suitability of an area. The challenge is to consider or combine the different factors.

The most well-known rule-based models are cellular automaton models which transform LC classes in an adjacency of one LC class with the help of defined rules. Examples are MOLAND (Barredo *et al.* 2003), LUSim (Ströbl *et al.* 2003), CLUE (Veldkamp & Fresco 1996), and DINAMICA (Soares-Filho *et al.* 2009). As input data demand rates are necessary and sometimes also suitability maps.

Economic models, also called equilibrium models, calculate the supply and demand of the trade process with price mechanisms. Land is implemented there as a commodity (Rounsevell *et al.* 2012). They are used for calculating change rates and are not spatially explicit.

Another class considers the agent-based models where e.g. households or employees act as an agent which interact with other agents and utilise resources by that. The approach is used for simulating decisions (Rounsevell *et al.* 2012) which lead to typical LU patterns or their change. The Land Use Dynamic Simulator (LUDAS, Le *et al.* 2008) uses ranking algorithms for simulating the decision processes, where households are the smallest agents and politics are external drivers. Here a cellular automaton model is used as a sub-model.

Statistic models as regression models try to find a dependency between the change of spatial patterns and different numbered drivers (explanatory variables) to create probabilities which are used for suitability maps where areas are identified which are prone for change. Hoymann (2009) uses this approach to generate suitability maps to allocate urban growth and Dendocker *et al.* (2007) applied it to Belgium.

Multi-criteria assessments are also adapted for creation of suitability maps, and for identifying (ranking) the best site for change. Methods are Analytical Hierarchy Process (AHP, Saaty 1987, Thinh *et al.* 2004), compromise programming (Schanze *et al.* 2004, Vogel 2010) or ordered weighted averaging method (Malczewski 2004, 2006).

Integrated approaches try to consider a set of driving forces, as e.g. economy or demographic change as well as site-specific situation, e.g. biophysical factors as soil, exposition and climate and so forth. The integrated model SITE (Mimler 2007) works with multi-criteria analysis, rules, genetic algorithms and cellular automaton. The IMAGE model is also categorised as an integrated model (Alcamo *et al.* 1994).

The future development of LCC/LUC in numbers is defined as the demand of a LC class. There are different approaches for determining the demand required for LCC:

- Trend extrapolation of historical developments,
- Trend extrapolation via regression,
- External models or approaches
- Expert surveys or workshops,
- Assumptions.

Trend extrapolation analyses historical developments. Afterwards, they are extrapolated under the assumption that the retrospective development remains the same for the future. This method can be used for short-term projections, such as those made by Hoymann (2011) for the period of 10 years. In most cases, LU modelling programmes are calibrated on the basis of the historical development (Sohl *et al.* 2012).

Trend extrapolation via regression is also able to quantify the LCC. It uses the same drivers of LCC, which are also used to explain LC patterns (Verburg *et al.* 1999). If for example, population growth is accompanied by an increase of LC for artificial surface, population forecasts can also be used to determine future demand. This continuation of dependencies into the future from the past to the present is an intuitive concept, which is therefore widely used (Lantman *et al.* 2011).

Furthermore, external models or approaches can be used to calculate the demand. There is the approach of density measure, which, for example, uses the settlement, building, or population density as socio-economic variables to derive the demand for artificial surface (Hoymann 2011). However, this approach requires a lot of data, such as projections for population, households, and the housing market. When a threshold value for a density measure is exceeded, e.g. the city requires more 'new' built-up areas, it grows into the suburban areas. However, the calculation of land demand for LC classes can also be carried out by external models, mostly equilibrium models such as cellular automaton models as e. g. the Land Use Scanner (Beurden *et al.* 2002, Koomen & Beurden 2011). Heistermann *et al.* (2006) describe these external models as 'economic LU models'. An example of this is the GTAP (Global Trade Analysis Project) model, which keeps global economic data in a database (Narayanan & Walmsley 2008). It is developed as an equilibrium model, which is able to calculate demand for individual sectors of the economy on the basis of the national and global market situation.

The GIFPRO model (Commercial and Industrial Land Forecast, Stark *et al.* 1981), which was developed for the city of Arnsberg at the end of the 1970s, determines the commercial future (Bonny & Kahnert 2005) and was used for many urban development concepts in Germany (Wehmeier & Siegel 2007). The models examine the impact of LCC/LUC on economic well-being (Heistermann *et al.* 2006). They calculate the change due to demand and supply of raw materials or goods (food). In doing so, they are driven by the goal of achieving maximum wealth or profit. The land is seen as an input variable in the production process (Ronneberger 2006).

Expert surveys or workshops can be used to determine the demand of LC. Expert interviews are mainly part of the scenario technique and planning and serve to derive numbers from narrative qualitative storylines (Kemp-Benedict 2013). These derived numbers are used in models for simulation and the results are presented to the experts, so that an evaluation can take place and possible adjustments can be made. Sohl *et al.* (2012) derived the demand for individual LC classes from the IPCC scenarios via expert interviews in a workshop. The SCENES project (Water Scenarios for Europe and for Neighbouring States) and the scenario study Global Environment Outlook 4 (United Nations Environment 2007) also used expert interviews to identify the demand.

Furthermore, assumptions can be made to quantify the demand of a LC class. The CLUE model (Veldkamp & Fresco 1996) estimates the demand at the national level (Heistermann *et al.* 2006, Schaldach & Priess 2008). The cellular automaton 'Pimp Your Landscape' (Fürst *et al.* 2010) estimates the demand on the regional level.

Finally, the methods differ and have to be adapted to project the demand and allocation of LCC.

2.3 DRIVERS OF LAND-COVER AND LAND-USE CHANGE

A huge variety of *driving forces* cause LCC/LUC. Thereby, the drivers are site dependent or impact the development of a LC class in amount. In general, the drivers belong to a typical pathway of change for a LC class. Drivers are concluded as both environmental and societal factors (Heistermann *et al.* 2006). Whereat for example climate, freshwater availability, exposition, and soil conditions belong to the environmental drivers, societal transformation, demographic development, technological development, and alteration of lifestyle are typical societal driving forces of change. The latter are assigned to the demand-site of LC/LU patterns, because they imply demand for specific commodities which alters the LC/LU.

Environmental drivers affect the suitability of LC/LU patterns: the allocation and distribution in space, because of the given natural conditions at a place.

If different scales are considered, additional drivers have to be added as e.g. access to the market which is important for local and regional scales and the respective governmental frame.

Verburg *et al.* (2004) divide the driving forces into three groups, two of them are the same as mentioned by Heistermann (2006). An another one is named 'proximate causes', covering land management variables such as cutting or burning.

All those driving forces are used to explain LCC/LUC and the underlying processes in the first instance. Beyond, they allow modelling LCC/LUC (Verburg *et al.* 2004). The interrelations between the driving forces and the resulting change are represented by different approaches, ranging from empirical methods (regression/economic input-output analysis) to the involvement of expert knowledge e.g. for the simulation with cellular automatons (Verburg *et al.* 2004).

Hersperger *et al.* (2010) describe and assess four models to conceptualise and categorise the interrelations between driving forces, actors, and LCC/LUC in a more generic way exploiting regional studies and the literature. In the first model, the authors link driving forces directly to LCC/LUC, which is the most commonly applied approach in land change research and is often used to model future scenarios. The approach consists of the correlation between drivers, operationalised through explanatory variables (data sets), and LCC/LUC.

The second model provides the linkage between driving forces, actors and LCC/LUC. To combine data as driving forces (quantitative) and actors (qualitative), specific methods are required what in general is challenging, but valuable for LCC/LUC research because they explain causal chains.

The third model is characterised by the analysis of the interrelations between driving forces and actors with their impacts on LCC/LUC. The framework allows for investigation on how the driving forces influence the decisions of the actors. This is done by interviews and surveys, often integrating a policy analysis (Hersperger *et al.* 2010).

The last model links actors with LCC/LUC whereby elements in the environment are understood as driving forces. This framework is often used for the simulation with agent-based models and allows application for smaller geographical studies only. A huge variety of data (statistics or interviews) is needed.

Geist & Lambin (2006) and Turner *et al.* (2007) state that there is no overarching theory for explaining LCC/LUC, only parts are yet described by different theories. Theory building for the causes and processes of LUC is complex and still a difficult task because of the interrelations and dependencies that are divers, multiple, and confusing. The authors claim that three aspects have to be taken into consideration for the derivation of a theory: (i) the behaviour of people within the society and their linkages to the LU as well as their feedbacks; (ii) a multi-level or multi-scale approach, combining the people (individuals, households, villages) and pixels (watersheds, forests, districts, countries); and (iii) the influence of the people and pixels to the past and current situation. With these formal requirements LCC/LUC theoretically could be analysed and explained.

There are different approaches for dealing with LCC and the underlying processes. In general, the concepts which are used for determining LCC/LUC consider the amount and time horizon of change and their underlying causes. However, an investigation on random and systematic processes, which show the essential changes, is not the focus before modelling the LCC. Particularly, for future analyses it is very important to take this into account, because the impacts of the behaviour of the actors who alter the conditions (respective driving forces) in a landscape can be seen in the subsequent LCC/LUC.

For that, the perspective of a coupled human-environment system evolved (Turner *et al.* 2007). It involves research on the empirical linkages between causal variables towards the change, e.g. LCC related to population and economic development. For that, cellular automaton, agent-based models, regression techniques, and genetic algorithms are the most common approaches (Haase & Schwarz 2009, Heistermann *et al.* 2006, Schaldach & Priess 2008).

2.4 BASICS OF SCENARIO METHODS

The idea of modelling future states implies to design alternative scenarios which are contrasting and form a kind of funnel into the future showing a variety of developments. Based on this it may be expected that the real development will unfold within this funnel (Alcamo 2008).

LC/LU alter within the time due to human-made actions or through the natural succession of the landscape. Mid-term perspective of LCC/LUC should be considered which starts in the past, lasts till the present and shows developments in the future. Scenarios are able to provide images of possible developments of the future and are called 'alternative futures' (Dator 2019, Luther & Schanze 2009, Sauer *et al.* 2012). These alternative futures are a result of the combination of future developments as autonomous changes (climate change or demographic change), controllable alterations (spatial planning or political frameworks), and random conditions (events, reaching tipping points, assumptions) (Dator 2019, Sauer & Schanze 2012).

The first scenario methods originate from the military. The training situations of the soldiers reflected different threat scenarios which are running through. In the 1970ies the scenario methods expanded into the energy economy (oil industry) after a huge amount of money was wrongly invested (Kosow & Gassner 2008).

Meanwhile, scenario methods are applied in different branches, also in the environmental sector. The IPCC defines scenarios as pictures of alternative futures, which do not predict the future precisely but shows possible options of the future development (Alcamo *et al.* 2011).

A short overview of the different types of scenarios are given in the following paragraphs. Scenarios are differentiated in qualitative and quantitative scenarios, whereat the qualitative scenarios are based on so-called storylines. The storylines are developed in a manner that even non-experts can understand them. They tell a story about the future (Alcamo 2001). Quantitative scenarios are often used to parameterise models.

Furthermore, scenarios can be differentiated in explorative (describing) and anticipatory (normative) scenarios: Explorative scenarios start in the present and continue trends into the future. The underlying method is forecasting and as an example the 'business as usual scenarios' (BAU) can be mentioned. Anticipatory scenarios start with a vision of the future and go stepwise back to the present. They utilise the backcasting method (Alcamo 2001).

Another differentiation is made by baseline and policy scenarios. Baseline scenarios (business as usual) are the reference or benchmarking scenarios (Alcamo 2001). They extrapolate the current situation with the framework conditions without alterations into the future (Kosow & Gassner 2008).

Policy scenarios show the future under e.g. environmental policy restrictions and their impacts (Alcamo 2001).

Thereby, it is recommended to use an even number of scenarios, otherwise often the 'middle' scenario is chosen by stakeholders or politicians to orient themselves (Alcamo 2001). Scenarios fulfil different functions (Kosow & Gassner 2008): knowledge intermediation, communication, goal concretion and goal setting, decision-making, and strategy functions. The purposes of scenario development define the functions, besides not all functions have to be fulfilled.

Scenarios are often a mixture of qualitative and quantitative approaches, starting with qualitative storylines which are then parameterised. As an example, the Special Report on Emission Scenarios (SRES) from the IPCC is mentioned. The SRES are qualitative described and parameterised via expert workshops. The answers of the experts are then used for modelling (Alcamo 2001).

Scenarios are often structured by the scenario-axes approach (Nakicenovic & Swart 2000), whereat a coordinate system is developed by the x- and y-axis presenting different developments or scales. The end of each axis is linked towards low or high rates of a specific development to span a broad range of the scenario funnel. The resulting four quadrants in the coordinate system represent four distinct scenarios (Rothman 2008).

A lot of scenario studies as e.g. Global Environment Outlook (GEO) or Water Scenarios for Europe and the Neighbouring States (SCENES) use the Drivers-Pressures-State-Impact-Response-Concept (DPSIR), to represent, to describe, to systematise and to assess the human-environment system for the current and projected situation as e.g. the GEO4 scenarios do.

3. CONCEPTUAL FRAMEWORK

At the beginning, a coherent methodological framework is designed and a workflow is developed with the aim to project future LCC. Therefore, a literature review of studies and of scenario approaches which deal with the projection of LC and LUC were conducted. The Kosow & Gassner (2008) approach proved to be a valuable and transferable concept for doing a scenario study. They published a generic concept of conducting scenario-based projections by running through five phases (see Figure 1). This concept is taken as a basis for the dissertation and adapted. However, in this work only four phases are considered.

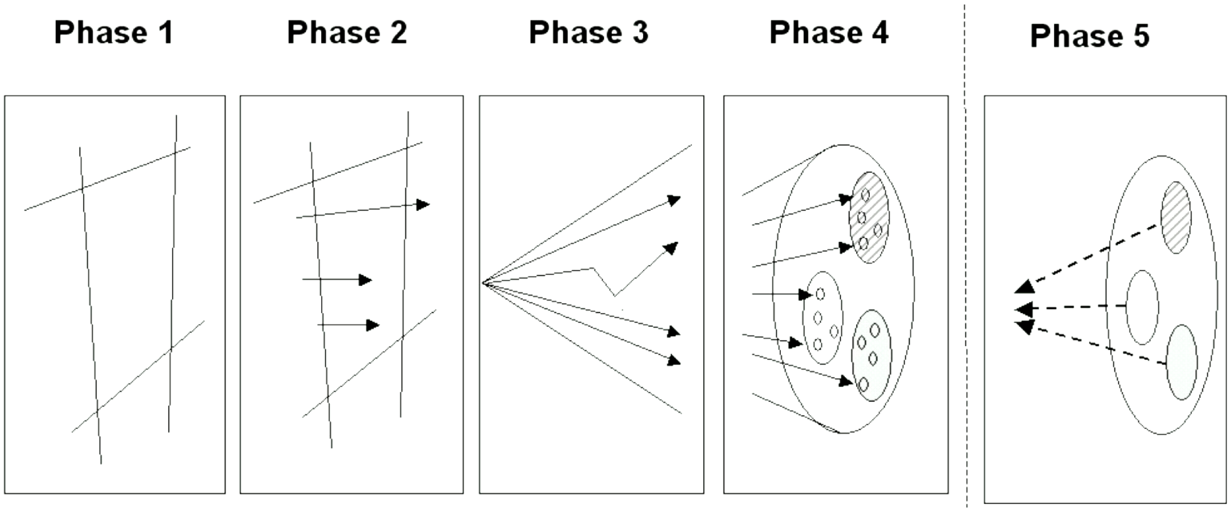


Figure 1: General scenario process in 5 phases. Source: Kosow & Gassner (2008, p. 20)

The *first phase* describes the context of the scenario theme including the definition stating the exact object for which scenarios are to be developed. Here, the topic and problem of a scenario study are addressed. The guiding questions for this phase are (a) what is considered and (b) where are the boundaries and limitations of the scenario process?

The *second phase* identifies the key factors which are the central variables that describe the scenario field. As key factors are understood, those variables, trends, developments, and events which have interrelations and/or an impact on the scenario field and which have to be considered in the scenario process. In consequence, knowledge about the scenario field and the interrelationships between the various key factors is required. The used methods, that Kosow & Gassner (2008) discovered, range from empirical to theoretical work as desktop research towards participatory approaches workshops or interviews to gain knowledge on underlying key factors.

The *third phase* involves the analyses of the future state of the identified key factors and addresses how they will develop. This means that the scenario funnel for each key-factor is stretched out and possible future states are elaborated on. Often this includes an intuitive-creative approach, stated by Kosow & Gassner (2008).

In the *fourth phase,* the alternating scenarios are extracted, condensed, and generated at the selected projection time in the future. Here, consistent factor bundles are selected and elaborated into scenarios which are the final product of this phase. This can be conducted with qualitative methods using narrative procedures vs. quantitative mathematical procedures.

Phase five describes the further application and use of the scenarios, it is the scenario transfer. Sometimes, this phase does not belong to the scenario process. This step consists of impact analysis, analyses of actors, or strategic assessment. Therefore, a vertical dashed line is included in the Figure 1 between phase four and phase five.

The five-phase approach described above is adapted for the projection of the LCC in this work. However, only four phases are truly considered, the fifth phase, scenario analysis, is not considered due to time resources. The phases are translated into four major methodological steps (see Figure 2):

I. Definition of the scenario context

II. Identification of spatial and dynamic drivers for LCC

III. Scenario formulation and projection of the identified drivers

IV. Scenario-based projection of future LCC in quantity and space

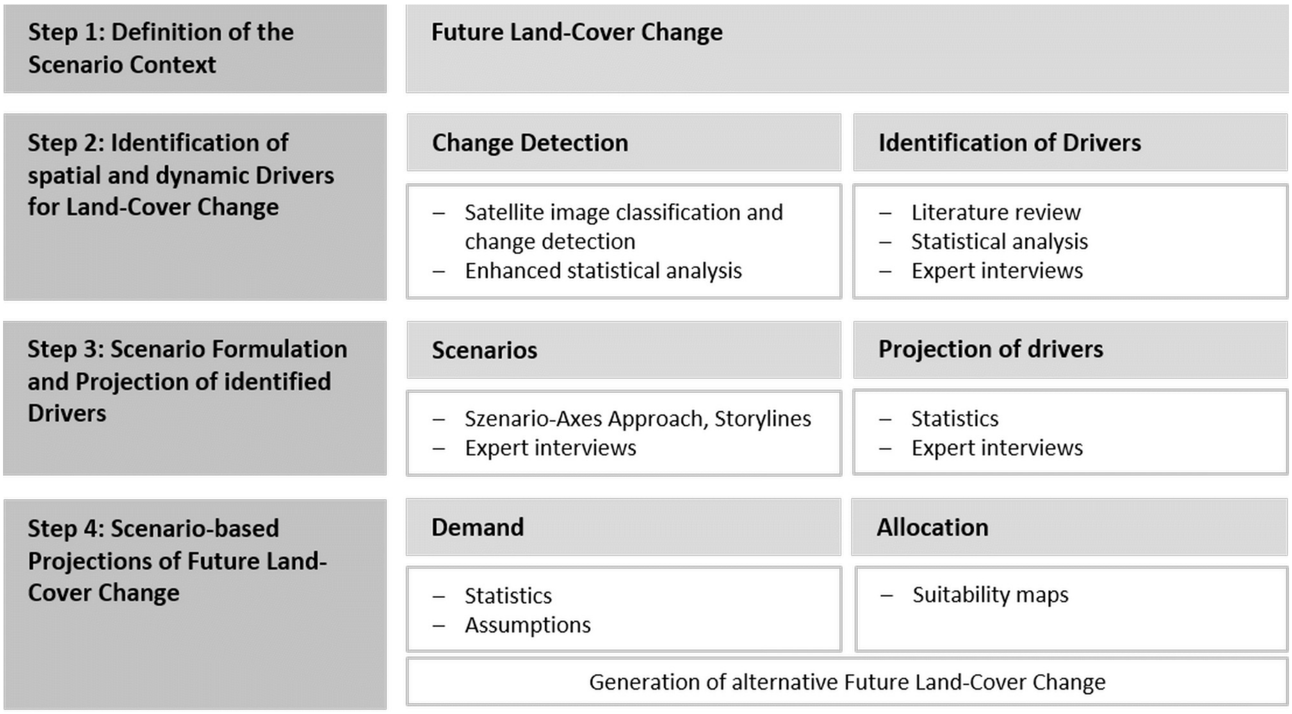


Figure 2: Methodological framework of the comprehensive scenario approach for projection of future LCC. Source: Burmeister & Schanze (2018, p. 3), adapted.

In Figure 2 the applied methods for each step are shown. Each of the four steps comprise two working tasks considering different amounts of work for projecting the future LCC. If little is known about the study area, it is valuable to involve regional experts at steps two and three. As Figure 2 illustrates, a mixture of qualitative and quantitative methods are involved for one working step. For quantitative methods, the following fall under this class: the satellite image classification and change detection, statistical analysis, and the GIS operations. Qualitative methods refer to literature review, expert interviews, and scenario generation. The qualitative and quantitative methods intertwine and investigate the same thing, e.g. expert interviews and statistical analyses are used to identify the driving forces.

In the following sections, each step with its methods is presented.

3.1 STEP1: DEFINITION OF THE SCENARIO CONTEXT

The first step is to define and explain the context of the topic in the scenario study. This is the projection of LCC to the near future in 2025 just for the testing. It is also important to clarify the limitations of the scenario approach (Burmeister & Schanze 2018). This step refers to the first phase defined by Kosow & Gassner (2008).

3.2 STEP 2: IDENTIFICATION OF SPATIAL AND DYNAMIC DRIVERS OF LAND-COVER CHANGE

The adaptation of the Kosow & Gassner (2008) concept to the problem of the LCC involves, in the second step, the elaboration of LC data for individual time steps as a basis for the analyses (Burmeister & Schanze 2016, 2018). This is a prerequisite for looking for drivers of LCC. After elaborating the satellite image classification, a change detection follows to make the underlying LCC processes visible by comparing the time steps with each other. The LCC is seen in persistence, gross gains, gross losses, net change, total change and swap of each LC class (Burmeister & Schanze 2016). Additionally, an enhanced statistical analysis allows to identify the systematic LCC (Braimoh 2006, Manandhar *et al.* 2010, Pontius *et al.* 2004) which serves as an initial transition rule for the future. The systematic LCC is identified with the gross loss and the gross gain. The random gross loss and gross gain are set in relation to the class size of a LC class. If a LC class systematically loses to another LC class which simultaneously gains from this class, it is a systematic LCC (see also Burmeister & Schanze 2016, p. 10f, equation 1 & 2). This allows to focus on the relevant processes of LCC.

After the basis of the change detection is worked out, the search for drivers of the LCC processes starts. This is done by a literature review to get an initial understanding of already identified drivers in other studies. Statistical analyses, like regressions can be used to determine the dependencies. The aim is to find variables (x, drivers) which are able to describe the LCC (y, dependent variable).

Experts' judgements have been included in the work with different tasks. Their knowledge is used to *identify* missing drivers in the second step of the workflow. The answers are gathered through semi-structured interviews.

3.3 STEP 3: SCENARIO FORMULATION AND PROJECTION OF IDENTIFIED DRIVERS

Scenarios are used to compose various states of the future. The discriminant-axis method is chosen to derive scenarios with differing developments in the dimensions: social (including demography), economy, and environment. For this purpose, a coordinate system is used which is spanned by the x- and y-axis. At the ends of each axis, the opposing development goals are plotted. The combination of the two axes forms four combinations of different scenarios representing the four quadrants of the coordinate system (Burmeister & Schanze 2018, Nakicenovic & Swart 2000).

The four scenarios include different developments of the above-mentioned dimensions, so that it is possible to transfer these developments to the identified dynamic drivers and project them into the future. Again, experts are involved in this step. They quantify the future development of drivers of LCC by interpreting the qualitative terms.

3.4 STEP 4: SCENARIO-BASED PROJECTIONS OF FUTURE LAND-COVER CHANGE

All the previous steps provide the base for the projection of future LCC. As described above in step 3, the *dynamic drivers* are projected via the detected statistical dependencies towards LCC. If there is no statistical dependency of the drivers to the LCC, assumptions are involved for the future development which are based on the answers obtained from the experts and literature. Afterwards, the amount of change of each LC class for the future is calculated – the demand.

The *spatial drivers* and the transition rules allow the projection of the LCC in space. All the gathered information is combined and operationalised into GIS algorithms. With the help of geodata it is possible to find suitable areas of LCC for every LC class. Therefore, a multi-criteria approach is used, which consists of reclassifying raster layers representing the spatial drivers. If spatial drivers have a high suitability of LCC for a LC class, they are assigned high values. If spatial drivers are not suitable for LCC, or even prevent it, they are assigned small values, or those excluded completely. Afterwards, the spatial drivers are summed up for each transition rule resulting in one suitability map for each LC class. The suitability map of the transition path of a LC class in the future shows the ranking of the most suitable areas (high numbers) towards the least suitable areas (low numbers or zero). The demand and allocation are finally brought together by changing the most suitable areas by the amount of the demand rates into another LC class (Burmeister & Schanze 2018).

4. IMPLEMENTATION AND TESTING OF THE FRAMEWORK

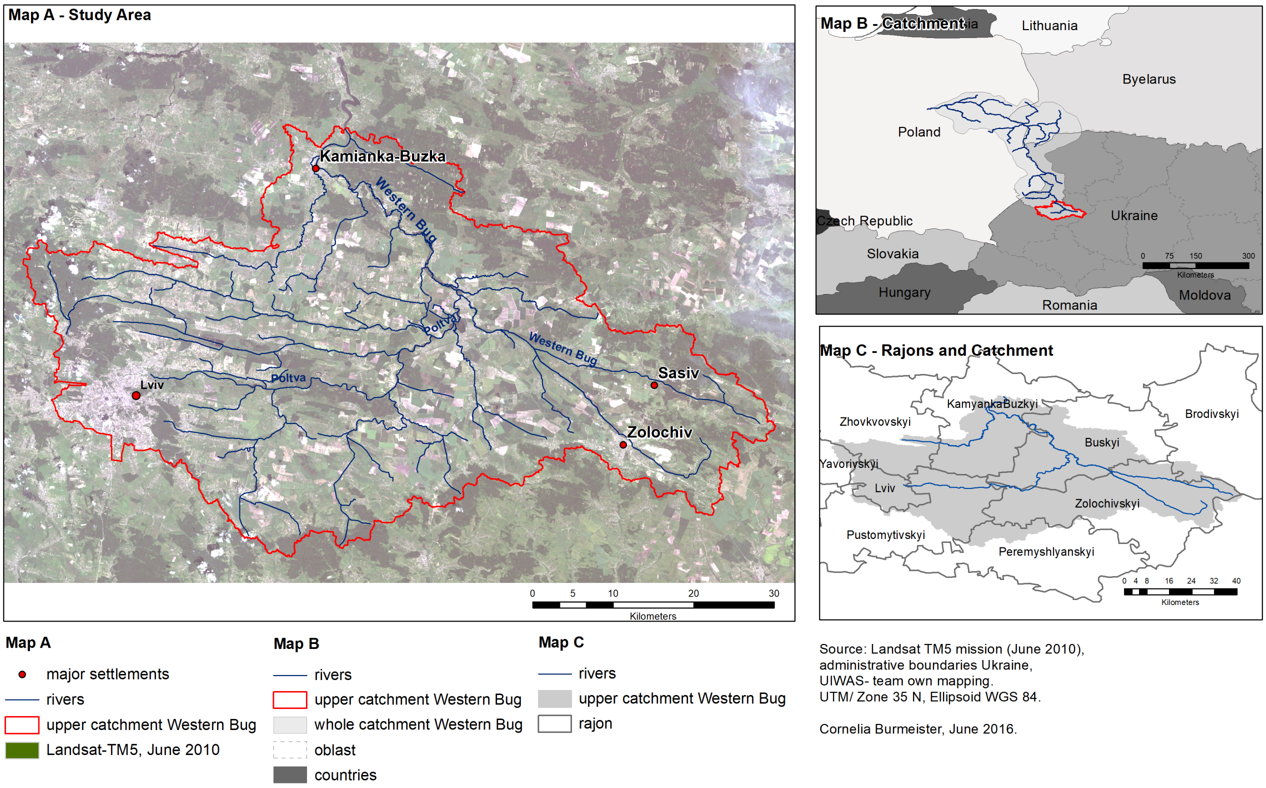
The third chapter presented the concept of projecting LCC. In the fourth chapter, the implementation and testing of the concept is described. For that, a single case study is used. The working resources were limited, therefore the research is closely linked to the BMBF funded research project ‘International Water Alliance Saxony’ (IWAS, FKZ 02WM1028) and fulfilled parts of this project for scenario generation for an Integrated Water Resource Management. One of the study regions of IWAS was situated in Ukraine, so that it served as the study site. The concept is implemented in the Upper Western Bug River catchment in Ukraine, with a focus on IWRM. The LC must consider not only the administrational units but the environmental system of the sub-basins of the river as well. Therefore, the spatial extent of the study refers to the borders of the Upper Western Bug River catchment.

4.1 STEP 1: DEFINITION OF THE SCENARIO CONTEXT

A more detailed view of the study site which is situated in Ukraine, is portrayed in Burmeister & Schanze (2018). The study deals with the future LCC in the Upper Western Bug River catchment, which is located in West Ukraine, close to the border of Poland. The focus of the study is LC, not LU. This is due to additional information to derive LU not being available.

The year 2025 is defined as the forecast horizon, 15 years from 2010. The main consideration behind this is to minimise uncertainty, which becomes larger the further view into the future. In addition, a long-term view into the future can lead to fewer changes in LC than a near future view, because processes have changed to such an extent that they correspond to the present again (Verburg *et al.* 2019).

When considering LCC in Ukraine, especially in a river catchment, the boundary conditions with its legal frameworks like laws must be known. This section provides some background information which is needed to understand the current state of the LC and LCC. Additionally, the river catchment is shortly described.



Source: Landsat TM5 mission (June 2010),
administrative boundaries Ukraine,
UIWAS- team own mapping.
UTM/ Zone 35 N, Ellipsoid WGS 84.

Cornelia Burmeister, June 2016.

Figure 3: Study area of the Upper Western Bug River catchment. Source: Burmeister & Schanze (2018, p. 7)

The starting point for LCC analyses in this work begins in the year 1989, when the political change took place. Ukraine is a young independent state which gained its independence from Russia in 1991 (Kudelia 2012). Ukraine is situated in Europe. After the independence in the 1990's the premise was to shape an efficient democratic state with functioning institutions and framework conditions. The development of the Ukrainian democracy is still an ongoing process.

The study area is situated in West Ukraine, between the districts of Lviv and Lutsk. In the following paragraphs the processes in Ukraine are described which have an impact on LC and LCC. This is especially true when it comes to the land management, real estate market, planning strategies, and environmental laws and policies which alter the LC.

To analyse the development of LC in Ukraine, it is crucial to know the laws, functioning of the property, and real estate market which have existed since 2001 (Lerman 2008, OECD & World Bank 2004, UNECE 2013, Verkhovna Rada of Ukraine 2001).

The agricultural area was collectivised in the Soviet period and after the independence of Ukraine, being distributed and privatised (Land Code 2001). Ex-kolchose workers had the option to get a piece of the kolchose land after the political change. Previous workers from industrial farms got a part of the farm (including buildings and technologies) for their own use. However, the workers didn't have the technological capabilities and financial resources to manage the entire area depending on the size and purpose (Csaki & Lerman 1994, Lerman 1999).

A set-up of land cadaster or mapping of land ownership would have helped to monitor the LC allocation, but this was not done. Result was a rag rug of small parcels of the kolchose workers land plots which evolved in the 90's and are still there in the 2010's. They were located as little parcels of agricultural plots around the settlements like a belt. The land plots were used for subsistence farming because after the independence of Urkraine, there were no longer subsidies and fixed prices for agricultural products and markets in the other socialist countries (Kuemmerle *et al.* 2009).

The rural areas still face depopulation in Ukraine, accompanied by trends of ageing, unemployment, and poverty. The rural areas provide poor infrastructure, low levels of housing conveniences, and limited access to education and medicine creating a depopulation. By the end of 1998, the sharing of collective land was finished. The state did not want to divide the huge areas of farmland into small parcels, therefore 6.7 million Ukrainian citizens received certificates which clarified the owner. The borders of the newly owned land were not clear so the farmers were only owners 'on paper' (Melnychuk *et al.* 2005).

Furthermore, the kolchose field plots could not be sold or traded because they were officially not found on maps or in the cadaster (OECD & World Bank 2004). This issue will be eliminated with the creation of a pan-Ukrainian cadaster incorporating information on owners and borders, which should be available for all citizens. In regard to this task, a law called the State Property Cadaster was passed to meet the needs for a functioning land market (Dykunskyy 2011).

The focus of the law is to fix the selling right of agricultural land with pre-emption of state administrations and the delamination of the size of sold land to protect the Ukrainian state for outselling land. Foreign companies with headquarters overseas are forbidden to buy agricultural land in Ukraine, because the soil is a big resource and very fertile (Gozujenko & Gozujenko 2011, Zaturjan 2009).

However, there are other ways to set up an agricultural business in Ukraine as a foreign company. Big agricultural companies rent plot of land for a long period of time (e.g. 49 years) (Gozujenko & Gozujenko 2011, Zaturjan 2009) and grow lots of industrial crops which depletes the soil of nutrients (Rudenko *et al.* 2017). In the Western part of Ukraine, there is another speciality in the agricultural sector. There is a high groundwater table that impacts soil creating a need for a functioning drainage system. After the Soviet breakdown, the system was not maintained due to less resources.

Urban development is characterised by growth, which comes along with less controlled suburbanisation, resulting in regional disparities and unbalanced urban development (UNECE 2013). The regional capital, Lviv, with around 750,000 inhabitants[1] (HUSuLo 2015) has different spatial plans on a different scale level to preserve and improve the quality of life and ecosystems. They are used for spatial steering of the urban land consumption. On a local level, the general city, zoning and detailed plans must be mentioned (Dells *et al.* 2006, UNECE 2013). Laws and spatial plans exist for steering growth, seldom they are coordinated and harmonised between the neighbouring municipalities, so that the suburbanisation is difficult to control. For rural space, the spatial plans are in a development state and implementation is still lacking (Rudenko *et al.* 2017).

In the administration at a local level, it is common to replace all stakeholders of all hierarchical levels after an election. This hinders the collaboration and the long-term implementation of projects and concepts, also sustainable concepts (Gorobets 2008, Riabchuk 2008).

This study area covers the sub-catchment of the Poltva River and the upper part of the Western Bug River catchment. The water quality is poor (Blumensaat *et al.* 2011, Ertel *et al.* 2011, Tavares Wahren *et al.* 2012) and the pollution (microbiological, heavy metals) originates from the main tributary: the Poltva. It carries the industrial and settlement wastewater of Lviv. Diffuse sources come from the strong agricultural use. The water quality of the Poltva river has worsened exponentially in the last 20 years (Tavares Wahren *et al.* 2012).

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[1] 750,382 for the whole city council, 1.03.2015

4.2 STEP 2: IDENTIFICATION OF SPATIAL AND DYNAMIC DRIVERS FOR LAND-COVER CHANGE

As it is described in chapter 3.2, LC data has to be elaborated as a base for the analyses. For that, satellite image classification is performed for three time steps: 1989, 2000, and 2010 (cf. Table 1). The time steps are meant to represent the socialist period in 1989, the development after the revolution in 2000 and the present state in 2010. This chosen time periods are highly dynamic with the political and economic developments.

Table 1: Satellite scenes used for the three time steps. Source: Burmeister & Schanze (2016, p. 11).

Time step	Data	Satellite Sensor	Geometric Resolution
1989	1989-07-07 1989-08-16 1993-04-21	Landsat-TM 5	30 x 30 m
	1989-07-12 1989-08-18 1989-08-30	SPOT-1	10 x 10 m
2000	2000 -05-02 2000-08-22 2001-04-03	Landsat-7 ETM +, band 1 to 5, 7 band 8 (pan)	30 x 30 m 15 x 15 m
2010	2010-04-04 2010 -06-07 2010-11-14	Landsat-TM 5	30 x 30 m
	2007-08-23 2009-04-19 2009-07-18	SPOT-4 SPOT-2 SPOT-5	10 x 10 m 10 x 10 m 5 x 5 m

Each time step is represented by three inner-annual satellite scenes which cover the beginning, middle, and end of the vegetation period (cf. Table 1). Figure 4 provides an example of an inner-annual satellite image (brick) of the time step 1989 (cf. also Table 1). This approach is used to distinguish arable land, managed grassland, natural grassland, bare soil on arable land, and urban areas.

The satellite images are classified by a supervised classification using the statistical classifier, *Maximum Likelihood,* which assigns the pixel to the class with the highest probability based on training pixels. The Maximum-Likelihood Classifier was chosen because there was very little existing data and knowledge about LC and change in the study area. The resolution of 15 x 15 m supports the choice as well.

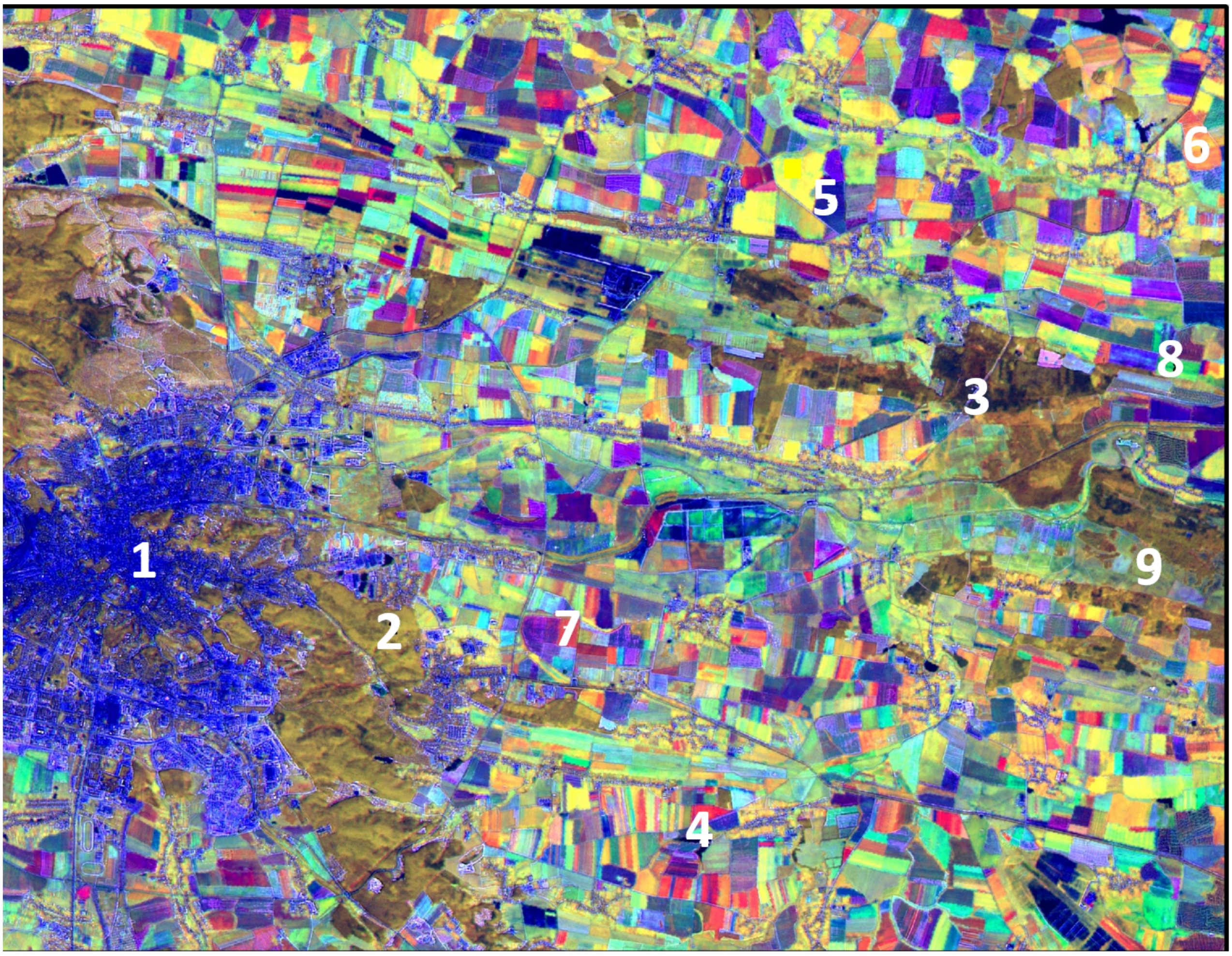

Figure 4: Detail of an inner-annual satellite scene from July and August for the time step 1989, covering the surroundings of the regional capital, Lviv. Presented is the near infrared (nIR) band. July = red, August = green, July = blue.

1 – urban, 2 – coniferous forest, 3 – broad-leafed forest, 4 – water, 5 – arable land, abandoned, 6 – cultivated arable land in July and August, 7 – arable land, cultivated in July, harvested in August, 8 – arable land, abandoned in July, cultivated in August, 9 – year-round vegetation

For the Maximum-Likelihood Classifier, training data for the predefinition of classes is needed. To delineate training samples for each class, ground truth data from the field campaigns are taken. Google Earth is used to complete the data for 2010. The rural part of the catchment is presented in Google Earth with SPOT scenes. The reference data for 1989 are collected using topographic maps in the scale of 1:100,000, which is available for the whole investigated catchment, and 1:10,000 which is available for a sub- catchment. Additional visual image interpretation of the Landsat and SPOT scenes is done for the derivation of reference data. Only visual image interpretation of the Landsat and SPOT scenes can be made for the collection of reference data for time step 2000.

The collected ground truth data reference points are randomly divided into two parts. One part is used for the training samples to delineate each LC class. The other part is used for assessing the accuracy of the classification afterwards.

The results of the satellite image classifications are seen in Figure 2 in Burmeister & Schanze (2016, p. 13). The numbers of the LCC between the time steps are shown in Table 2.

Table 2: Results of LCC between 1989, 2000, and 2010. Source: Burmeister & Schanze (2016, p. 12)

[2] AS = artificial surface, AL = arable land, BLF = broad-leaved forest, CF = coniferous forest, GL = grassland, PB = peat bogs, WB = water bodies

LC Classes		**AS[2]**	**AL[2]**	**BLF[2]**	**CF[2]**	**GL[2]**	**PB[2]**	**WB[2]**
∑ [%]	**1989**	10.7	47.2	15.0	5.1	20.6	1.2	0.1
	2000	11.3	47.2	17.0	4.3	19.9	0	0.3
	2010	13.3	44.3	13.9	4.8	23.5	0	0.3
1989 - 2000 [%]	**persistence**	9.2	39.0	13.7	3.2	11.5	0	0.1
	gross gain	2.1	8.2	3.4	1.1	8.4	0	0.2
	gross loss	1.5	8.2	1.4	1.9	9.1	1.2	0.0
	net change	0.6	0.0	2.0	0.9	0.7	1.2	0.2
	total change	3.6	16.4	4.7	3.0	17.5	1.2	0.2
	swap	3.0	16.4	2.7	2.1	16.8	0	0.1
2000 – 2010 [%]	**persistence**	10.7	36.0	12.5	3.1	11.3		0.2
	gross gain	2.5	8.3	1.4	1.7	12.1		0.1
	gross loss	0.6	11.2	4.5	1.2	8.6		0.1
	net change	1.9	2.9	3.2	0.6	3.6		0.0
	total change	3.1	19.5	5.9	2.9	20.7		0.2
	swap	1.2	16.6	2.7	2.3	17.1		0.2

The classes with the highest changes are grassland (GL) and arable land (AL) for both decades. Artificial surface (AS) increases over the two decades, mostly until 2000 with 3% swap. Broad-leaved forests (BLF) first increase and then decrease afterwards. The trend for coniferous forest (CF) is opposite to BLF. All in all, the forest classes are almost the same after the two analysed decades. This is mainly due to there not being so many extensive forest areas in the study area. Peat bogs (PB) are detected in 1989 and then diminished afterwards. The analyses of the systematic LCC revealed for the study site the following transition rules (transition pathways) (Burmeister & Schanze 2016):

- New AS is mostly developing on GL and not on AL because it is strictly protected.
- AL has *not* transformed into forest, but the GL class that develops, through succession, into forest.
- Both forest classes, BLF and CF, have decreased since 1989. An interchange between the classes has been identified. (The forest areas are not that big in the study region, so this is not a general trend for Ukrainian forests.) The high interchange of AL and GL could be related to location and fertility issues.

With this knowledge, potential drivers are sought, starting with the literature review. Table 3 in Burmeister & Schanze (2018, p. 9) shows the results of the collected potential driving forces and available data sources. In this work linear regression is used for the identification of interrelationships between the retrospective LCC and dynamic drivers. Equation 1 presents the formula of the linear regression.

$$y=\alpha+\beta_1 x_1+\varepsilon \qquad \text{Equation 1}$$

Different tests are carried out to check the requirement for linear regression. This included checking for random sampling, linear independence between the independent variables (multicollinearity), exogeneity of the independent variables, homoscedasticity and normally distributed disturbance terms.

The limitation of linear regression for the identification of dynamic drivers is due to the low availability of statistical data. As available data source serves the State Statistical Service of Ukraine (HUSuLO 2000), most of the variables show a temporal change. They either show the change between 1989 and 2010, or a shorter time period of change from 2000 to 2010. As dynamic drivers are identified, the ‘population development’ for the changes of the LC classes AL and GL (cf. Table 5 in Burmeister & Schanze 2018, p. 11).

The spatial drivers are shown in Table 4 in Burmeister & Schanze (2018, p. 10). Results for the spatial driving forces are the distance to the city Lviv, settlements, roads, streams, slope, soil, and biotic yield (cf. Table 4 in Burmeister & Schanze 2018, p. 10).

Due to the data availability being so poor, 11 experts are interviewed in February 2012 and March 2012 for additional identification of dynamic and spatial drivers. The selected experts represent different societal sectors and hierarchical administrative levels (cf. Table 1 in Burmeister & Schanze 2018, p. 5). The expertise, position, and affiliation of the experts can be seen in the Appendix, Table 6. The guiding questions for the interviews are designed for each LC type, LCC transition rule, and boundary condition. As result, the experts identified as additional dynamic and spatial drivers the economic development, spatial policies, laws, specific soil types, and slope (cf. Table 6 in Burmeister & Schanze 2018, p. 12).

4.3 STEP 3: SCENARIO FORMULATION AND PROJECTION OF DRIVERS

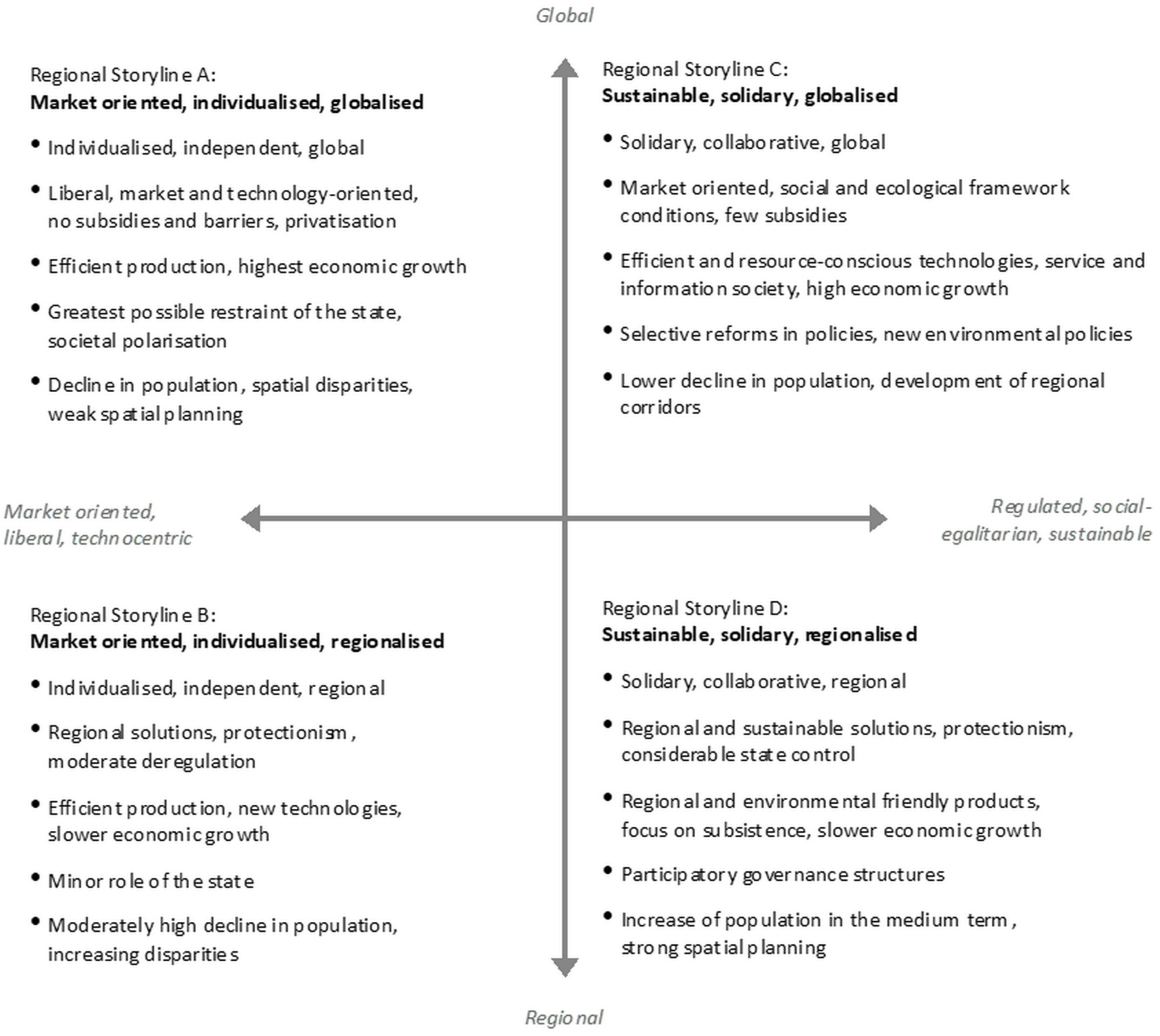

Figure 5 : Storylines for regional change in the study region. Source: Schanze et al. (2012, p. 1410)

Figure 5 shows the four different scenarios which are developed by the project team and show the different developments of the future. As described in section 3.3 the scenario-axes approach is used. Thereby, the development of the axes reaches from a 'regional' to a 'global' development and from a 'market oriented, liberal, technocentric' perspective to a 'regulated, social-egalitarian, sustainable' perspective. The keywords in the quadrants refer to different dimensions such as economy, technology and production, as well as spatial planning, supports of the state, and population development. They are combined with a qualitative development of terms like 'minor/low/weak', 'moderate', and 'high/strong'. These terms are assigned to the overall developments of the storylines. Scenario A has the highest economic growth and population declines with weak spatial planning. In contrast, scenario D has a slower economic growth, but the population increases and strong spatial planning institutions.

Table 3: Regional storylines with principal developments of selected dimensions for the Western Ukraine.

	Storyline A	**Storyline B**	**Storyline C**	**Storyline D**
Principle Characteristics	**Market oriented, individualised, globalised**	**Market oriented, individualised, regionalised**	**Sustainable, solidary, globalised**	**Sustainable, solidary, regionalised**
Policies				
Overall policy	minor intervention	moderate intervention	moderate intervention	strong intervention
Principal economic policy (e.g. market mechanisms)	liberal	liberal with minor regulation (protectionism)	regulated	regulated (including protectionism)
Energy policy			expansion of water-power use	expansion of water-power use
Subsidies	no subsidies	minor	moderate	moderate
Water supply policy (e.g. privatisation, costing)	privatisation, decrease of water costs	privatisation, decrease of water costs	public, increase of water costs	public, increase of water costs
Waste water policy (e.g. privatisation, costing)	privatisation, minor increase of waste-water costs	privatisation, minor increase of waste-water costs	public, moderate increase of waste-water costs	public, moderate increase of waste-water costs
Housing and infrastructure policy	liberal	liberal	regulated	regulated
Agricultural policy	production for world	production for re-	(ecological) produc-	(ecological) produc-

	Storyline A	**Storyline B**	**Storyline C**	**Storyline D**
Principle Characteristics	**Market oriented, individualised, globalised**	**Market oriented, individualised, regionalised**	**Sustainable, solidary, globalised**	**Sustainable, solidary, regionalised**
	market	gional market	tion for world market	tion for regional market
Forestry policy	production for world market	production for regional market	(ecological) production for world market	(ecological) production for regional market
Planning system	no regulations	minor regulations	moderate regulations	strong regulations
Disparities in spatial development	high	moderate (slowly growing)	moderate (corridors)	moderate (corridors)
Economy				
Unemployment rate	low	low	moderate	moderate
Gross domestic product	strong	strong	moderate	weak
Overall crop yield	high	moderate	high	low
Technology				
Technological system	fast innovation	moderate innovation	moderate innovation	moderate innovation
Production efficiency	high	moderate	moderate	moderate
Energy consumption	high	high	low	low
Social				
Way of life	individual	individual	families and groups	families and groups
Level of education	not considered			
Health				
Hygienic				
Demography				
Population development	decrease	decrease	stagnant	stagnant till weak increase
Environment				
Environmental pollution	high	high	medium	low
State of the environment	decline	decline	constant	improving

Experts quantified the development of future scenarios for the identified driving forces: 'population development' and 'GDP development', for the dimensions economy and demography. However, these drivers are only some key factors of future developments for an Integrated Water Resource Management. Additional trends and developments which have an impact on IWRM must be considered in the scenario process. Table 3 briefly shows the total underlying assumptions of the dimensions for politics, economy, technology, social, demography, and environment under the four storylines.

All in all, twelve experts are involved in this work. Selected experts quantified the drivers of 'GDP' and 'population development' for the future (see Table 4). The quantifications of the dynamic driver 'population development' are very similar between the experts. The quantification of the driver 'GDP' varies stronger between two experts; the third expert declined to quantify the 'GDP'. Storyline B shows a strong economic growth but at a lower rate than in scenario A. That's why the average quantification by experts is reduced to the average deviation and leads to rate of 7.5% GDP for scenario B.

Table 4: Drivers under scenarios A - D for the Upper Western Bug River catchment. Burmeister & Schanze (2018, p. 14)

	Storyline A	**Storyline B**	**Storyline C**	**Storyline D**
Principle Characteristics	Market oriented, individualised, globalised	Market oriented, individualised, regionalised	Sustainable, solidarity, globalised	Sustainable, solidarity, regionalised
Economy				
GDP [%/yr]	Strong	Strong	Moderate	Weak
Expert 1				
Expert 2	6 to 10%	6 to 10%	3 to 6%	0- to 3%
Expert 3	9 to 12%	9 to 12%	6 to 9%	1%
Average	9.3%	7.5%*	6%	1.3%
Society/ Demography				
Population Development [%/yr]	Decrease	Decrease	Stagnant	Stagnant to weak increase
Expert 1	-1.1 till to -0.5%	-1.1 till to -0.5%	0%	0 till to 0.2%
Expert 2	-0.2 to- -0.5%	-0.2 to -0.5%	-0.2 to -0%	0%
Expert 3	-0.5%	-0.5%	0%	0.2%
Average	-0.6%	-0.6%	-0.1%	+0.1%

*reduction of the average deviation.

4.4 STEP 4: SCENARIO-BASED PROJECTIONS OF FUTURE LAND-COVER CHANGE

All the previous steps are concluded in the fourth step, estimating the *demand* of the future LC class and the areas in which will change, the *allocation* of the LCC in space.

The quantitative change (demand) of the LC classes, AL and GL, is calculated with the dynamic driver 'population development'. AS is projected with the future state of the 'GDP development'. BLF and CF are projected by the driving forces of the experts and literature. The demand differs between the four scenarios, Figure 6 shows all rates until 2025.

The LCC transition rules (see section 4.2) are used as a starting point for the development of future suitability maps allocating the LCC. The rules present the systematic changes but not all observed changes (Burmeister & Schanze 2016). They are enriched with the information of the spatial driving force analysis (see Table 4 in Burmeister & Schanze 2018, p. 10), the experts' answers (cf. Table 6 in Burmeister & Schanze 2018, p. 12) and available planning documents. As a result, future suitability maps for each LC class are developed (cf. Table 5). Each dataset is classified according to the transition rule in rates between high and low suitable. Afterwards, the datasets are summed up with the Raster Calculator Tool (ESRI 2012) and that results in one suitability map for each transition rule.

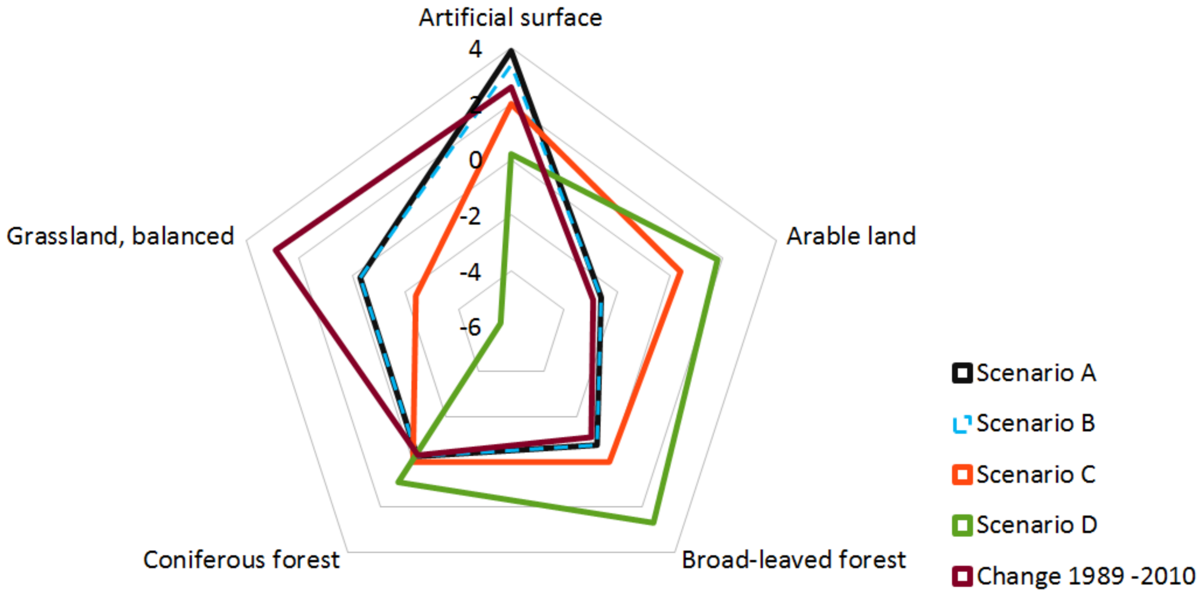

Figure 6: Demand rates for all LC classes and scenarios A - D between 2010 and 2025 for the Upper Western Bug River catchment. Source: Burmeister & Schanze (2018, p. 17)

Table 5: Derivation of suitability maps of LCC presenting the transition pathways and rules, data, and resulting map (see Appendix 8.2) for the Upper Western Bug River catchment. Source: Burmeister & Schanze (2018, p. 15f)

→Future LC Class Developments	**Transition Rule and GIS-Algorithms**	**Data**	**Suitability Map**
AS develops on…	• GL and not on BLF/CF or AL • Within the vicinity of settlements and roads (different functionalities/sizes of cities refer to different buffer distances) • Mainly in the suburban region of Lviv, the closer to Lviv the more GL change into AS • Not in riparian zones (buffer of distances) • Not on fertile soils with GL	LC data, rivers, soils, biotic yield	Figure 8
AL develops on…	• GL, not on AS • Areas with a declination of <12% • Not in flood plains • On more fertile soils (Chernozem, Gleysoils)	LC data, SRTM-DEM, soil data, biotic yield, rivers	Figure 9
GL develops on…	• Less -fertile AL • In areas with declination of >12% • On flood plains (buffer distances)	LC data, SRTM-DEM, soil data, biotic yield, rivers	Figure 10
BLF/CF develop on…	• GL, not on AL • In areas, with declination of >12%, and on less fertile soils and sandy soils • In the vicinity of existing forests • Within forests on in clearings • Exchange of forest kind types (from/to BLF and CF) • On flood plains For BLF: • Higher BLF development if areas are closer to Lviv	LC data, SRTM-DEM, soil data, biotic yield	Figure 11 and Figure12

The combination of the demand rates for each LC class, which change the suitable areas, lead to four different scenario results. Details for AS (above, surroundings of Lviv) and for AL (below, rural part in the Southeast of the catchment) can be seen in Figure 7.

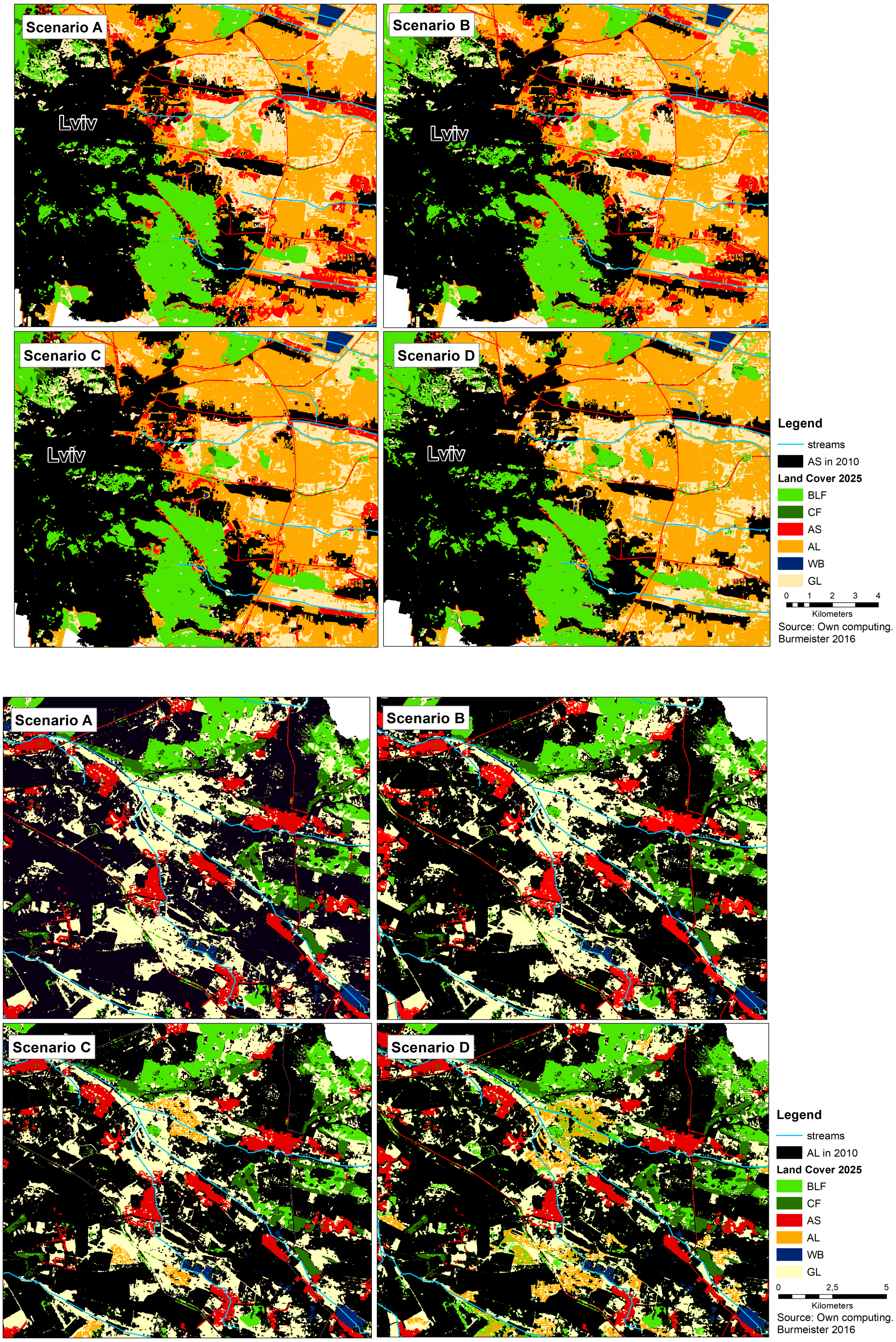

Figure 7: Projections A - D of LCC in 2025 Above: Focus on AS, Lviv. Below: Focus AL, rural areas in the Southeast of the Upper Western Bug River catchment. Source: Burmeister & Schanze (2018, p. 17)

In Figure 7, above the AS from 2010 is shown in black, and new AS (in 2025) is coloured red. Scenarios A and B are the scenarios with the highest growth of AS in comparison to C and D (cf. previous subsection 4.3). AS is growing mostly on the fringes of Lviv, in the Northeast, as well as close to roads and other settlements based on the transition rules. In scenario D, the forest classes grow mostly in the Northwest and Southeast of Lviv (lower right).

AL is also seen in Figure 7 (below) where it is shown in black, and where the new AL (coloured orange) is accompanied by new BLF/CF patches (light and dark green) which present a multi-structured agricultural area. This can particularly be found in scenario D. AL is mixed with BLF patches, which are sustainable regarding to wind erosion and biodiversity. In scenarios C and D, AL (orange) grows, especially on GL.

5. DISCUSSION

The papers already comprise the specific discussions of the used methods and results. Here, the whole work is discussed, the critical points are derived, and reflected with reference to the current literature and existing studies.

5.1 DISCUSSION OF THE METHODS

The framework ensures a consistent projection of urban and rural LCC till 2025 for the Upper Western Bug River catchment in Ukraine, considering both the allocation and demand of certain LCC pathways. The framework was developed, implemented and tested in the Upper Western Bug River catchment which is a first feedback loop to validate the approach with its steps and methods. The particular method selection and sequence ensured the applicability of the approach and their combination to a methodological framework overcome the weaknessess of the individual methods implied. Divers checks of the results are integrated in the framework as e.g. the: systematic LCC, identified dynamic and spatial drivers and so forth. The mixture and meshing of quantitative and qualitative methods are a great benefit to the aim of projecting LCC. The quantitative methods comprise to the satellite image classification and change detection, the statistical analysis of the driving forces and the projection of the LCC in amount (demand) and space (allocation). These steps which are almost done as desk research are accompanied by qualitative methods as e.g. the interviews which are undertaken in Ukraine in 2012.

Kosow & Gassner (2008) stated in their study that scenario approaches often consists of five phases. They divided the phases: scenario field identification, key factor identification, key factor analysis and scenario generation, and (sometimes) the scenario transfer. The main result of the studies they reviewed finish with the scenario generation. The application of the scenarios (phase scenario transfer) is often missed. Kosow & Gassner (2008) understand the key factor identification as the finding of descriptors of the scenario field and the key factor analysis as the development of the factors in the future to generate with the developed factors the scenarios. The here presented approach presents the first four phases.

The discussion of the steps of the framework structure the following paragraphs of the discussion section.

Step 1: Definition of the scenario context

The *first step: definition of the scenario context* of the framework is equal to Kosow & Gassner's first phase, but considers the whole human-environment system with urban and rural LC and its change. Other studies have (of course) different thematic coverages. They often concentrate on a small part of LCC/LUC, as e.g. settlement growth *or* rural change *or* the amount (demand) of LCCs (Barredo *et al.* 2003, Kozak *et al.* 2007, Kuemmerle *et al.* 2009, Thapa & Murayama 2011). They do not consider the whole urban and rural LCC starting with the analysis of the retrospective change to identify the transition rule of every LC class. Other studies concentrate on the detection of the driving forces of specific LCC processes as e.g. agricultural land abandonment in Eastern Europe (Baumann *et al.* 2011, Prishchepov *et al.* 2013), forest development (Kozak *et al.* 2007, Kuemmerle *et al.* 2009) or urban growth (Hoymann 2011, 2012).

The view into the future was set to 2025 for the Upper Western Bug River catchment - when the work started in 2010 this comprises 15 years which is a manageable time horizon and not a too short time span so that apparent LCC can occur because it takes several years to detect the LCC.

Step 2: Identification of spatial and dynamic drivers of LCC

The here presented approach for the *second step: identification of spatial and dynamic drivers* starts to analyse the past to understand the site-specific processes and dependencies which cause the LCC. This is done to be sure to focus on the real and important processes. Sohl *et al.* (2016) state in their article that it is hard to compare models and results of model projections because the underlying LCC processes and transition rules depend on the specific model paradigms (e.g. Logistic Regression) which analyse the site-specifics of the current time step or a time step in the past (Sohl *et al.* 2016). Often, the models are used to analyse the past LCC processes to calibrate the model and to check the model performance of distributing the LCC afterwards (Rounsevell *et al.* 2012, Sohl *et al.* 2010, 2016, Verburg *et al.* 2013). In this work this is done without using a model, the focus is laid on the derivation of a sound database and that's why an analysis of the retrospective systematic LCC and an enhanced statistical analysis on systematic change of past LC developments is performed. The past LCC analysis is made before the usage of a model. Also, it is difficult to include socio-economic developments like qualitative data into the models (Sohl *et al.* 2010).

As starting point, the LC data has to be derived for the time steps beginning with the classification of satellite images. Other data sources as the CORINE LC data sets are not available for Ukraine and do not provide data for the time step 1990ies which covers the political change. The results of the Maximum Likelihood Classifier algorithm are presented in Burmeister & Schanze (2018). The Maximum Likelihood classificator is a pixel-based statistical classificator. Of course, other classificators could have been applied but the initial database and ancillary data did not allow a more complex approach as e.g. object-based classification. There are restrictions to deal with, which means a low ancillary data availability, cost-value ratio and the intended assurance of a consistent analysis of LC over more than two decades that have to be fulfilled. That's why the Landsat and Spot satellite series are used which provide long-term time coverage. Besides, Jogun *et al.* (2019) applied the same approach using Landsat images from 1985 to 2013 which are classified by the Maximum Likelihood Classifier and achieved also good results.

Because of the combination of inner-annual images for one time step the results are improved and the separation of LC classes is achieved. On the one hand, the differentiation between 'AL' and unmanaged 'GL' are improved. On the other hand, a higher accuracy of description between AL and AS is achieved. Thereby, errors and uncertainties of the classification algorithm are minimised.

The subsequent analysis of random and systematic change proved that the approach concentrates on the relevant changes. Nevertheless, using satellite images provided an objective database. All the results of each particular method contribute to the understanding and verification of the LCC results and the underlying reasons of change.

Although each of the used methods in the *second step: identification of the spatial and dynamic drivers* are all well-known and widespread, the combination of them as e.g. the usage of systematic LCC processes (Braimoh, 2006, Manandhar *et al.* 2010) deliver a valid base for the projection of future LCC. The identification of the systematic change allows to overcome the state-of-the-art methods with their implied particular weaknesses as e.g. the Maximum Likelihood Classifier. The following change detection delivers mistakes in the classification results and also in the LCC detection. E.g., the change of arable farming on the fields is highly dynamic within a year, but this is not in focus when considering a decade where it is interesting where new AL develops or where it is abandoned. So, a plus of this work is to consider the systematic change of urban and rural LCC and the translation into transition rules afterwards.

Also, the statistical analysis using linear regression is a well known method. The identification of the drivers used different sources and methods to get a sound base: literature review, expert interviews and statistical analysis. The latter considered linear regression and the Weights of Evidence method to come to the driving forces of LCC and to quantify the demand of each future LC class later. Again, a common well-known method is combined and enriched with the answers of the experts to close knowledge gaps and systemic method weaknesses. Also, a complicated statistical approach like multivariate regression which considers a set of factors (explanatory variable) to explain the dependent variable, in this case the LCC, is neglected because it is difficult to understand the importance of each factor. And the task to quantify the factors/drivers by the experts would have been too difficult (Bahrenberg *et al.* 2010).

Step 3: Scenario formulation and projection of identified drivers

In Kosow & Gassner (2008), as mentioned above, phase four deals with the scenario analysis and the outwork of the differences between the scenarios and the key factors. This work also partly involves this step, but here in the *third step: scenario formulation and projection of identified drivers*. In this work there are four different scenarios covering different LCC developments until 2025. The narrative storylines which define the development in the scenarios are very general and could also fit to other countries. The focus is laid on the translation of the qualitative - into quantitative developments.

Karner *et al.* (2019) showed in their article that it is possible to consider the future urban and rural LCC by global storylines which are translated to the scale of different European regions. The scenarios are related to land-sharing, land-sparing and management practices showing the impact on ecosystem services. In the study they work with the LU classes built-up, ‚cropland, and forests. Their approach is totally different: they involved a huge amount of stakeholders for quantification of the developments in the future. The local experts should also describe where the future LCC should be allocated or they agreed on transition rules with precise thresholds on fertile soil, slope, etc. which was site-specific for the different study areas.

This underlines that LCC is always site-specific based on the country's spatial politics and programs, on the management practices, and the bio-physical situation. This is also considered in this work: the systematic site-specific LCC processes in the Upper Western Bug River catchment, the analysis of the dependent site-specific spatial driving forces of LCC, and the involvement of experts with their regional knowledge and experiences. Both studies, Karner *et al.* (2019) and the presented work deduced expert interviews. This work is more focused on the identified transitions for future developments because the finding of the driving forces and transition rules was made before the interviews started. Karner *et al.* (2019) let the experts define the scenarios and the LCC in the future.

The selection of different experts of different hierarchical levels of administrations and also research institutes reveal a good spectrum of different perspectives of the environment and the planning system and allowed getting answers for urban processes and rural developments.

Step 4: Scenario-based projections of future LC

The translation of the identified LC transition rules into future suitability maps used also the expert interviews for validation. The individual suitability maps for each LC class is afterwards implemented into the cellular automaton model DINAMICA, but the results are not reasonable and so the usage of DINAMICA failed after long trials to model the study site. One reason of the implementation failure of DINAMICA is, that the expert answers contain concrete thresholds for LCC developments. These answers and the results of the transition rules are brought together in the suitability maps, which are afterwards implemented in the model. The suitability maps are translated into input data of DINAMICA. The transition pathways and demand rates are as well implemented in the cellular automaton model, but the model produced no future LC maps with these specifications. Unfortunately, the consultation of the model developers delivered no solution of the problems.

The used alternative: a multi-criteria approach in GIS is the solution and delivered sound results and is easier to control and flexible enough to include all the experts thresholds. Furthermore, it is possible to implement the transition rules as future development pathways. With that it is e.g. possible to integrate a biotic yield layer which is calculated with the soil data, digital elevation model and derived slope (see Table 5). The result of the LCC transition pathway is known: one specific LC class. Therefore, the method AHP is not usable, because AHP finds the best decision/aim based on different indicators and comparison of them (Saaty 1987, Vogel 2016). In this work, the LCC 'aim' is defined: a future LC class, so the method is not applicable.

To apply the multi-criteria algorithms the ArcGIS Raster Calculator Tool is utilised to derive the suitability maps by combining the individual data sets like biotic yield layer, LC classification of 2010, slope, distances to rivers, settlements, and infrastructure which is defined in the transition pathways. This approach and the results are easier to control than e.g. the approach of an Artificial Neural Network (ANN) which would have resulted in that what Jogun *et al.* (2019) showed in their work. They stated, that ANN is a ‘black box', searching for dependencies between LCC and the underlying variables. The ANN algorithm creates complicated equations and calculations in a 'black box' which is hard to understand and difficult to follow. This is certainly usable for scenario studies where no precise thresholds are defined and implemented. In contrast to this work, where great efforts are made to determine precise thresholds by conducting interviews, analysis of laws like the Water Code (1995) or the Land Code (2001).

The derived transition pathways represent the LCC of the Upper Western Bug River catchment. E.g., AS will only develop on GL which is a result of the retrospective systematic change analysis. The concentration of the transition rules narrow down the possible combinations of LCC and with that the uncertainties. In this work is not a global development trajectory assumed which would have only considered the gain or decrease of a LC class and would have led to a high model uncertainty (Sohl *et al.* 2016). Instead, site-specific transition pathways are identified with the base of the retrospective changes.

A suitability map for each LC transition pathway allowed an individual suiting approach and diminish incoherent developments, also of other transition pathways. This is the base for the future developments: to allocate the demand rates of the LC classes to get future LCC maps.

Sohl *et al.* (2016) compared six different scenario models results for the United States to assess quantitative, spatial, and conceptual inconsistencies. They found very little agreement in projected future LULC trends and patterns among the different models. So, the projection results of the 6 models varied not only between the different scenarios used, also the difference between the models for one scenario simulation is very large. They concluded that the model choice has a strong influence on the spatial patterns of LCC. It can be stressed, that the here presented approach yields in more regional reliable LC results and narrow the uncertainties of LCC analysis. Deduction of transition rules reflects the individual specifics in a region than considering classical transition matrices only (Braimoh 2006).

The operationalisation of the transition rules into GIS-algorithms produce differences between the suitability maps, so that the future LCC are compatible and do not conflict or compete with each other to avoid the non-allocation of future LCC. Competition exists between the transition pathway of new AS (change into AS) and the growth of the forest classes because both LCC will develop on less fertile GL. For this competition a ranking of the future LCC is developed: at first is GL changed into AS and afterwards the change of future AL is applied. The allocation is based on each suitability map and in the end the results of each future LCC transition is brought together in one scenario map.

The decision of changing the area in the future is still random when areas with the same suitability value exist. These areas are changed randomly until the amount of the future demand rates of one LC class is met. The demand calculation in a first step is performed by projecting driving forces and afterwards the projection of the associated LC class is calculated. If a statistical dependency is missing, the expert judgements and information of the literature/other studies are taken into account. So it is possible to find the suitable dynamic driving forces for one LCC class to project their development into the future in order to get a LCC number of a LC class in the year 2025 in result. The combination of the dynamic drivers which led to the demand rates and the spatial drivers which led to the suitability maps generated the four distinct scenario maps. They are able to show a possible development of the future of the Upper Western Bug River catchment.

The modular structure of the stepwise approach allows to use this methodology as a pattern for other case studies. Also, there is the possibility to use or adapt a part of the framework.

5.2 DISCUSSION OF THE EMPIRICAL RESULTS

In this sub-chapter the empirical results of the work are discussed. The structure of his section follows the framework (cf. Figure 2).

Step 1: Definition of the scenario context

The definition of the scenario context was done in the IWAS project. The analysed part of the catchment covers Ukraine and not Poland or Belarus. The Ukrainian catchment borders are different to the administrative borders which is always a challenge (Hagemann *et al.* 2014). It is difficult to get consistent data for different countries, even it is difficult to get data on the level of municipalities as e.g. statistics of Ukraine. This lead to the decision, that the Ukrainian part is considered, primarily the rayon level, where the methodology is tested and implemented.

Step 2: Identification of spatial Drivers of LCC

The presented results of LCC are reliable and fit to the findings of e.g. Baumann *et al.* (2011). The authors published a very high rate of farmland abandonment for the Lviv Oblast (up to 30 to 45 % from the mid/end of the 1980ies to 2008), which is at first not visible in the results of this work. Because of the different delineations and definitions of the LC classes. Baumann *et al.* (2011) delineate farmland as arable land, pastures, and meadows. Abandoned farmland is defined by unmanaged GL and successional shrubs. In this work, managed grassland is also summarised in the LC class 'AL' (see subsection 4.2, and Table 2 in Burmeister 4.2 Schanze (2016), although, shrubs are not considered as own LC class. The amount of change of 'AL' to 'GL' between 1989 and 2010 is around 12%, which is around a quarter of the whole LC class in the year 1989. Moreover, the transition of 'GL' to 'forest' has to be considered (related to Baumann's shrubs) which is around 1% from the year 1989 to 2010, this is 5% of the total LC class forest. In sum, this would be around 30% of farmland abandonment. The rest of the delta is related to different time periods (Baumann *et al.* 1986-1989 to 2006-2008, in contrary, this study 199*0 to 2*010), different definitions of the LC classes, and different spatial distribution of the study areas.

Systematic changes between 1989 and 2010 showed that there are differences compared to developments in other countries, such as Germany, where LCCs like new AS grew mostly on

AL (Hoymann 2009, Kretschmer 2012). This is contrary to Ukraine, where new AS develop mostly on ‘GL’ as these results show.

Current studies emphasise the results of this work. Cegielska *et al.* (2018) analysed the farmland abandonment and LCC in the region Pest in Hungary and in the province Malopolskie in Poland with CORINE LC data (2002 to 2016). They found out, that the change from the communist system towards a market-oriented economy can be seen in the LC patterns. Especially, an increase in 'uncultivated' land and forests and a decrease in agricultural land are recognisable in Hungary and Poland from 2006 to 2012.

These results emphasise, that the institutional and political framework with its laws and economic system have a great impact, e.g. restructuring the agricultural sector and privatising the land in Eastern Europe.

The results in this work, show also a high dynamic (swap) for the change of AL and GL which is not seen if the absolute numbers of the change from 1989 to 2000 to 2010 is in focus. But the trends coincides with the results of Cegielska *et al.* (2018) like the decrease of AL and the increase of ‘uncultivated land’, in this work ‘GL’. Also, an increase of AS from 1989 to 2010 is seen. Cegielska *et al.* (2*018) detected* a decrease of arable land between 5% for the Hungarian study site and 3% for the Polish study site. This range fits to the total change of AL from 2000 to 2010 of -2.9% in this work whereat Ukraine is a neighbouring country to Poland and Hungary. Thereby, the changed AL in Hungary and Poland is turned into AS, CF/BLF and semi-natural areas like GL. This is different, because in the Upper Western Bug River catchment AL changes almost into GL (cf. Table 2) and the forest classes show a decrease in the Upper Western Bug River catchment. Cegielska *et al.* (2*018) fo*und out that the WB are stable during the time and do not change their boundaries which is also one result of this work.

The literature review on drivers of LCC delivered a broad base from other studies (cf. subsection 3.2). The used methods in this work deliver spatial and dynamic drivers also for the LCC in the Upper Western Bug River catchment like GDP and population development or the distance to the regional capital Lviv. Thereby, the different used methods verified the same driving forces for the transition pathway of *AL* and *GL*, *e.g. th*e impact of the city of Lviv (expert answers and statistical results), the distance of settlements and roads (statistical and spatial analysis of the drivers, expert answers).

“[…] The date of the available driver statistics differed. Only population statistics are available for 1989, and the others are only available from the year 2000 or even later. That is why not all changes from 1989 could be explained, but for this gap the expert interviews are used, as well as the analysis of the systematic LCC (cf. Burmeister & Schanze 2016). Population and economic development are identified as dynamic drivers. Special location features, such as soil, slope, distances to infrastructure, and environmental laws like protection zones, are identified as spatial drivers. The results fit to the findings of other studies. Baumann *et al.* (2011) found a dependency between the number of villages and the farmland abandonment. In this study, the number of villages per rayon can explain the change of agricultural land (positive relation) and as well the change of BLF (negative relation). So, the findings of Baumann *et al.* (2011) fits to the presented results here. […]” (Burmeister & Schanze 2018, p. 19).

Step 3: Scenario formulation and projection of identified drivers

Burmeister & Schanze (2018, p. 19): “[…] A general criticism belonging the expert interviews is the low number of involved experts for scenario quantification (three experts for demographic development, two experts for GDP development, and 12 experts are interviewed for the identification and validation of drivers). Nevertheless, the advantages of involving regional experts prevail (Sleeter *et al.* 2012). Pahl-Wostl (2008) described these advantages of involving stakeholders in scenario building as follows: “*it ensures that the different perspectives are considered and, as possible users of the scenarios, it ensures a higher level of understanding and first of all acceptance of scenarios”*. Additionally, it is common to have a small sample when using qualitative methods — the contents of the expert answers are important. The questionnaires were produced with the knowledge on the results of the systematic LCC, so that the questions are purposeful and selective.[…]”

The expert quantifications are very similar for the qualitative terms ‘weak’, ‘moderate’, ‘strong’ etc. This shows that Ukrainian development is understood and estimated in the same way and that it was suitable to ask only three persons.

Step 4: Scenario-based projections of future LC

The derivation of the suitability maps followed multi-criteria GIS algorithms. The usage of the cellular automaton model DINAMICA failed as it is described in section 5.1. The suitability maps (cf. Table 5 and Appendix 8.2) is produced for each LC class. The differentiation of the future developments is caused by the different growth rates of demographic or economic development (GDP) in the storylines. Scenario A and B represent the future developments with the highest urban growth (AS) and show a high sealing, especially in the surroundings of Lviv (suburbanisation) and the regional capitals as e.g. Zolochiv or Kamianka Buzka.

The central dataset for the generation of the suitability maps are the digital elevation model (DEM) respective slope, the biotic yield layer and the LC of the year 2010. The biotic yield layer describes the fertility of the soil. E.g., fertile soil is suitable to change GL in AL and low fertile AL is suitable to change into GL. Less fertile GL is prone to change into AS and so on. This detailed definition of the transition rules makes the transition pathways compatible to each other.

On specificness in Ukraine is, that AL is protected, so the transition rule results in: AL does not change to another LC class. The forest areas are also stable in their development in the Upper Western Bug River catchment, that’s why they are only slightly changed. AS grows in the scenarios as it is a common trend in Europe (Cegielska *et al.* 2018, Noszczyk *et al.* 2017). In scenario A it grows strongest, in scenario D it has the smallest growth rate with 0.2% per year.

6. CONCLUSIONS AND OUTLOOK

The methodological framework and implementations in this case study to project the LCC in the Upper Western Bug River catchment revealed that the approach is valid to project rural and urban LCC. The focus is LC with its systematic change to derive transition rules from the retrospective LCC.

Firstly, this work answered the following research questions (cf. section 3 and 4):

- What integrated concept can be developed to combine different methods to project urban and rural LCC into the future based on the past LCC?
- Is it possible to implement the developed concept and does the implementation deliver reliable results?

The derived 4-step approach answers the first research question which concept can project LCC. The implied methods of the 4-step concept showed their practicability and complemented each other, different methods identified the same driving forces (step 2). A key component of the approach is the identification of the *systematic* changes. The prospective transition pathways in the future are set up and used as an initial base of suitability maps. The consideration of different sources for identification of the underlying dynamic and spatial driving forces increased the reliability and narrowed down the uncertainty. This work is designed as an integrated approach, covering both the future demand rates and the spatial distribution of future LCC where growth or shrinkage is considered. Thus, the work includes the expert knowledge in the different steps of the approach.

All the used methods are well known, the combination of them in a 4-step concept which is introduced in chapter 3 is a new aspect and the first main result of the work.

The implementation of the concept answered the second research question. The approach is applicable and delivered four plausible scenario results of the LCC development in the future for the Upper Western Bug River catchment. The retrospective analysis allows to identify the site-dependent transition pathways, mechanisms, and the key drivers for the LCC processes in the Upper Western Bug River catchment. The involvement of experts and statistical analysis verified the findings of the past LCC processes and made it possible to overcome the data and knowledge gaps.

The initial data availability was not that satisfying due to missing data, outdated data, non-existing spatial explicit data or missing metadata information on the data sets. The involvement of local experts helped to overcome these disadvantages.

This work also shows, that it is crucial to analyse the past developments of LCC if a projection into the future is conducted. Every country or region has its own history, laws, and restrictions which is readable in the LC and change over time. The handling of agricultural land plots and real estate can largely differ between countries, but it is a main factor of influencing the LC and its change. As these results show, agricultural land is very valuable in Ukraine, therefore it is well protected. This example is typical for Ukraine and may not be valid for other countries. Considering the past LCC makes it easier to detect the relevant LCC processes and their underlying driving forces which provides the mechanisms of future LCC.

The presented scenarios must not be fulfilled in the real future. The aim is to show developments and their impacts on the future LCC. Thereby, the scenarios range from a more sustainable, regulated development towards a more market-oriented, liberal development which can be found in different definitions of economic and population growth and their influence on LCC.

This generic 4-step approach provides flexibility for other case studies to adopt and to modify the approach as needed. It is possible to only use some steps of the approach which is dependent on the particular task and database. This approach allows scenario-based analysis from past to be found using the underlying LCC processes and driving forces to project future LCC. It is applicable in projects where the data availability is scarce, as well. One of the reasons why LU change is not considered for this study is because huge amounts of additional information is needed. The results of this work could be a reliable base to start additional research on the LU of the area.

The deduced results of future LCC can be used in an IWRM context to model and analyse the impacts of LCC on the water balance. It is possible to quantify the changes in the matter balance, to derive options, or actions for river management.

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8. APPENDIX

8.1 POSITION AND AFFILIATION OF THE INTERVIEWED EXPERTS

Table 6: Interviewed Experts.

No.	Position	Affiliation
1	Chief	Lviv City Council, Department of Town-Building, Unit of Town-Building and *Marketing*
2	Chief	Lviv City Council, Department of Town-Building, Unit of Environment and *Improvements*
3	Deputy Chief	Administration of Water Resources in Lviv Oblast
4	Chief	Administration of Water Resources in Lviv Oblast, Consultation Centre, Hydrological and Land-Improvement Expedition
5	Head	National Forestry University of Ukraine, Department of Ecology
6	**Chief**	Institute of Regional Studies, National Academy of Sciences of Ukraine, Department of Spatial Social Systems and Spatial Development
7	Research Officer	National Academy of Sciences of Ukraine, Department of Forecasting and Modelling of Regional Development, Institute of Regional Studies
8	Deputy Chief	Lviv Oblast State Administration, Main Administration of Agro-Industrial Development
9	Chief	Lviv National Agrarian University, Faculty of Economics, Department of Statistics and Analysis
10	**Associated Professor**	Franko University of Lviv, Faculty of Geography
11	Research Officer	Franko University of Lviv, Faculty of Geography
12	**Research Officer**	Leibniz Institute of Ecological Urban and Regional Development

*Experts in **bold** quantified the future developments.*

8.2 SUITABILITY MAPS

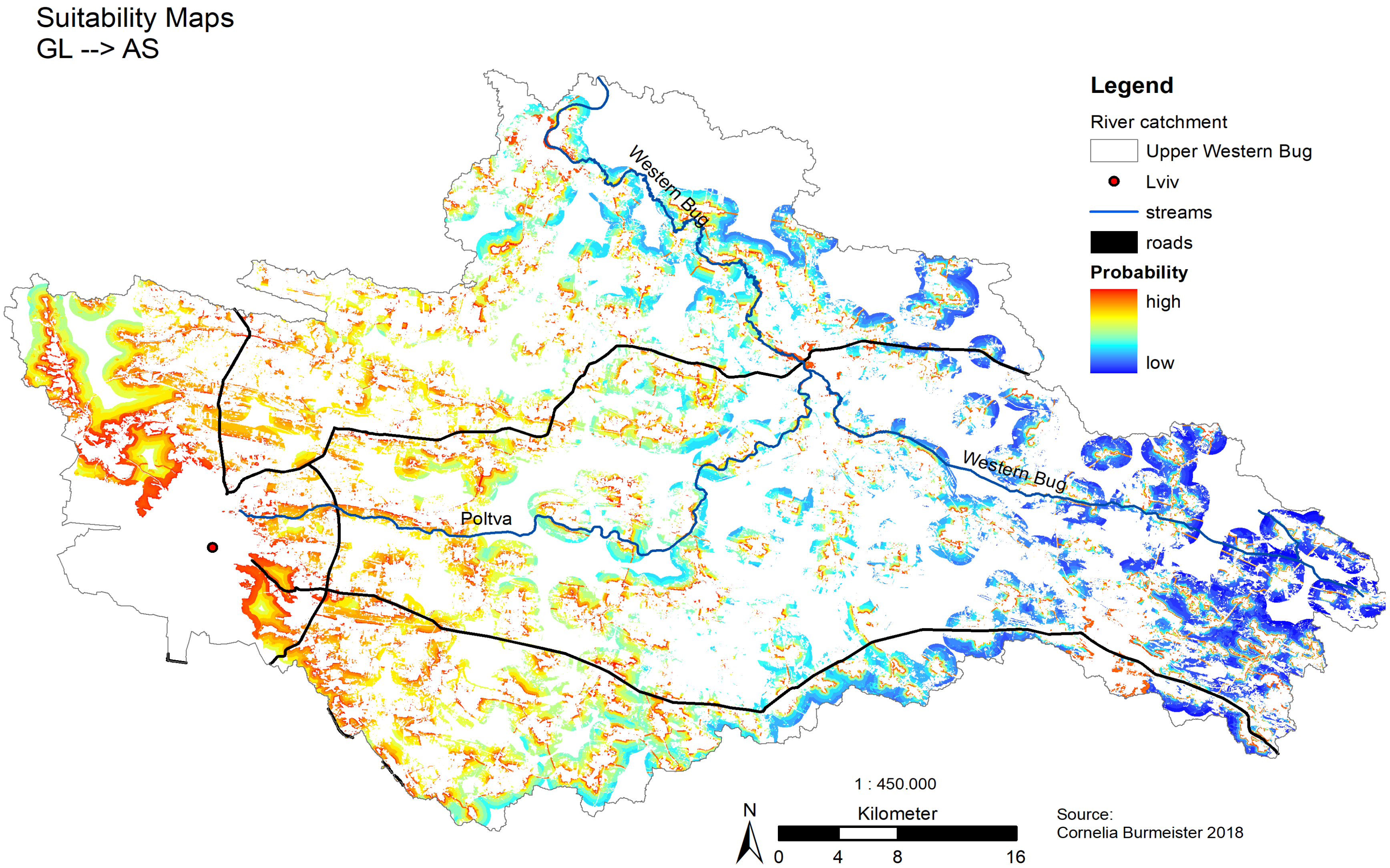
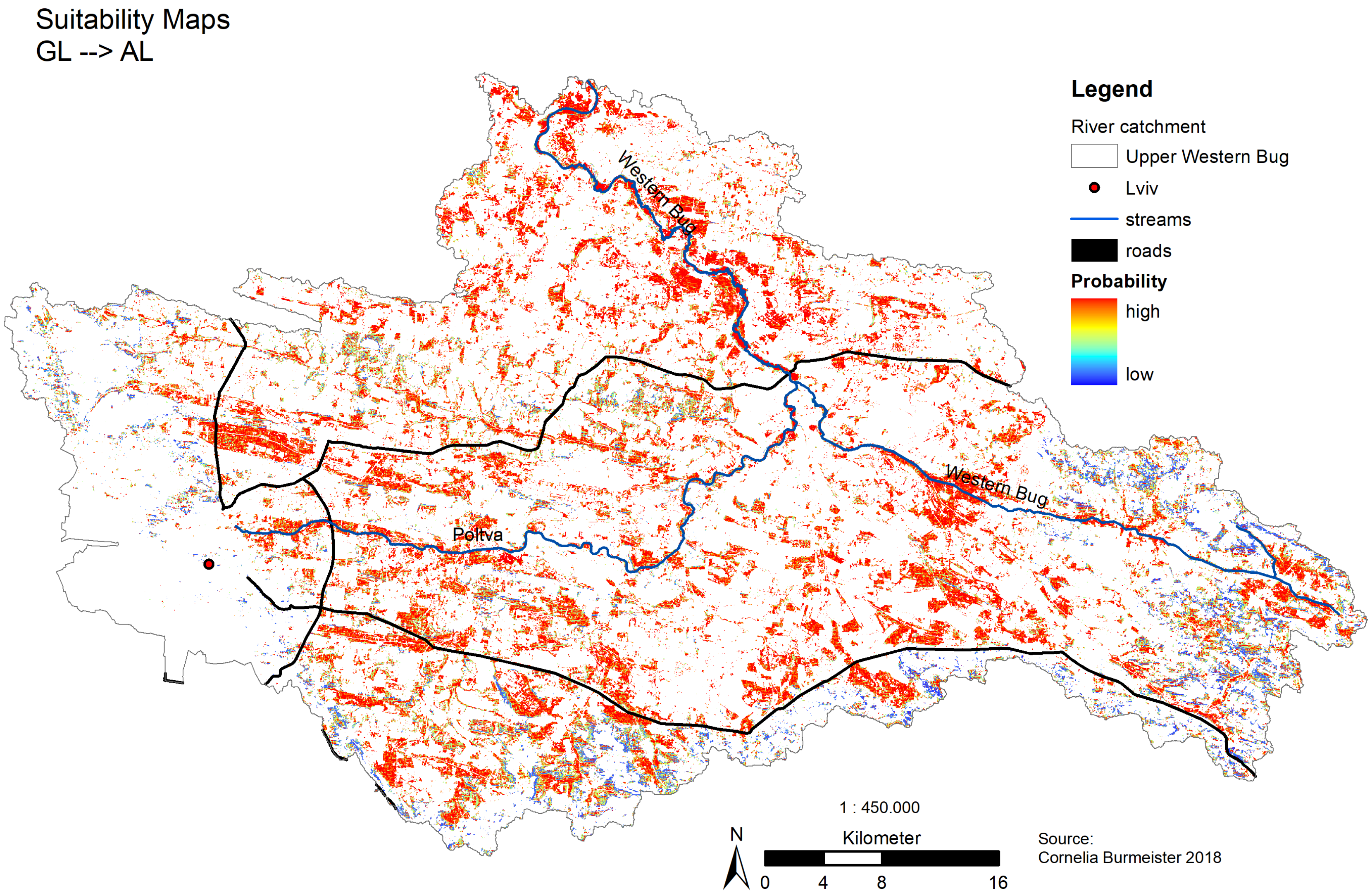
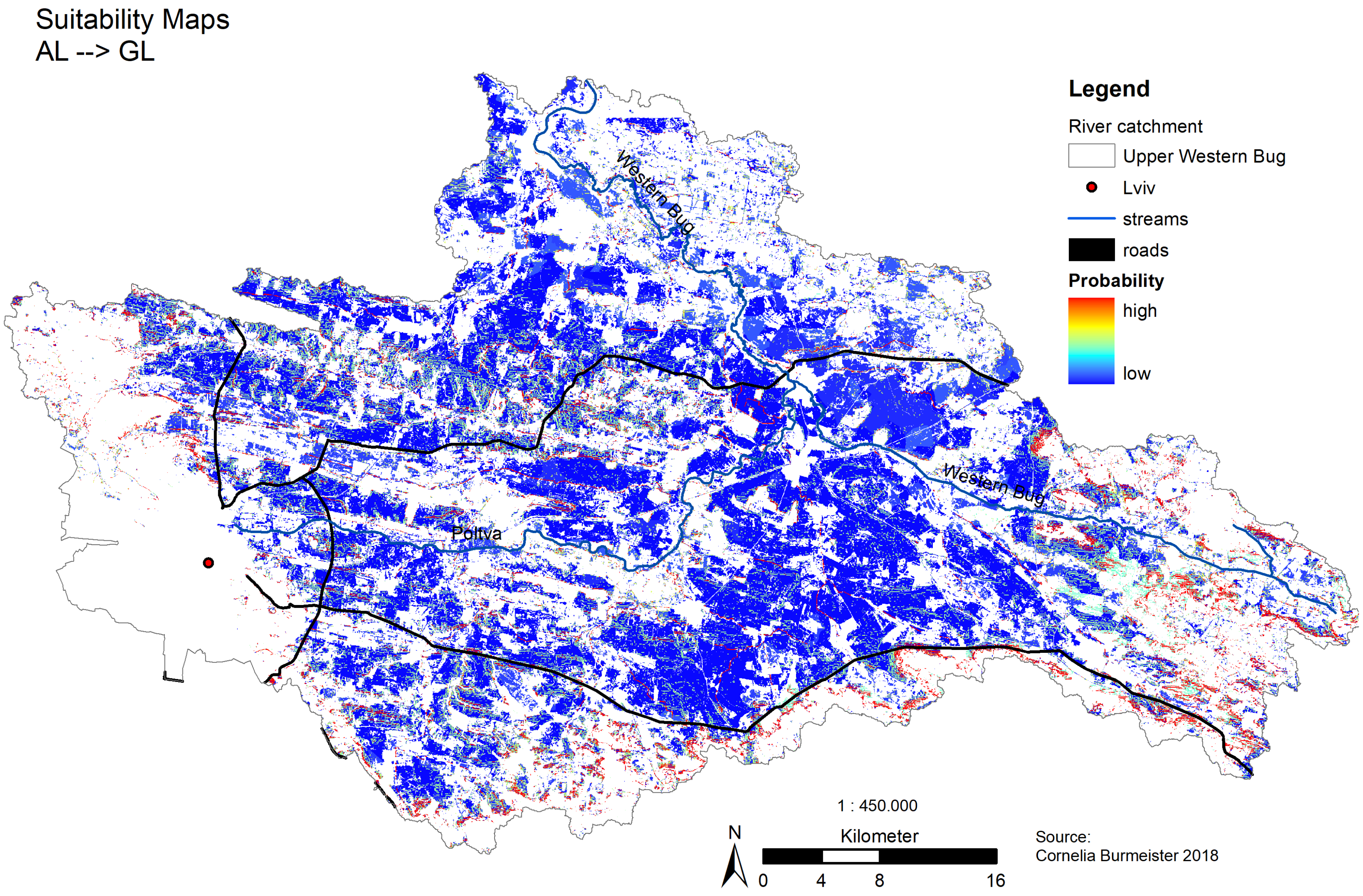


Figure 8: Suitability map for the transition pathway from grassland to artificial surface.



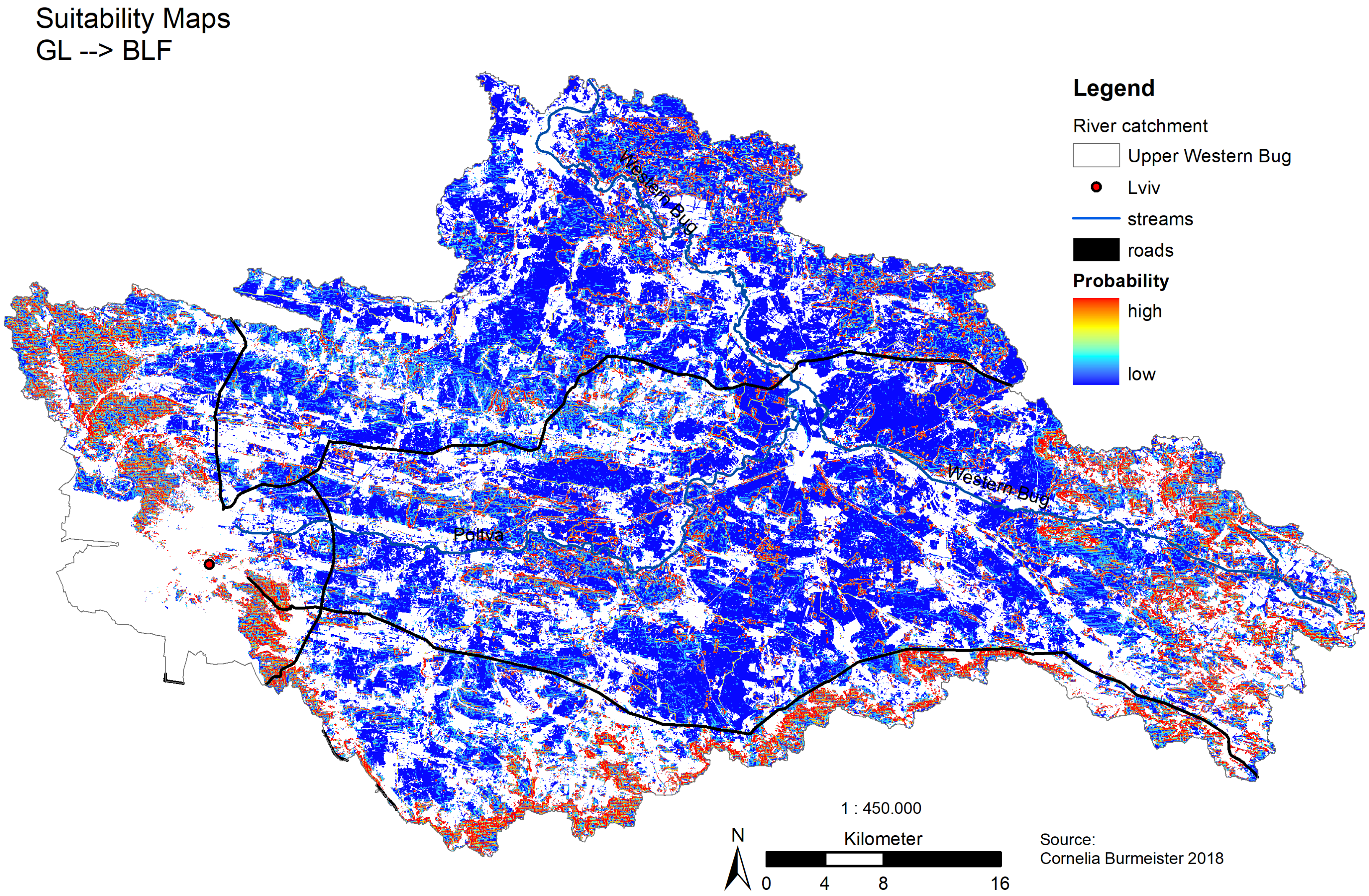
Source:
Cornelia Burmeister 2018

Figure 9: Suitability map of the transition pathway from grassland to arable land



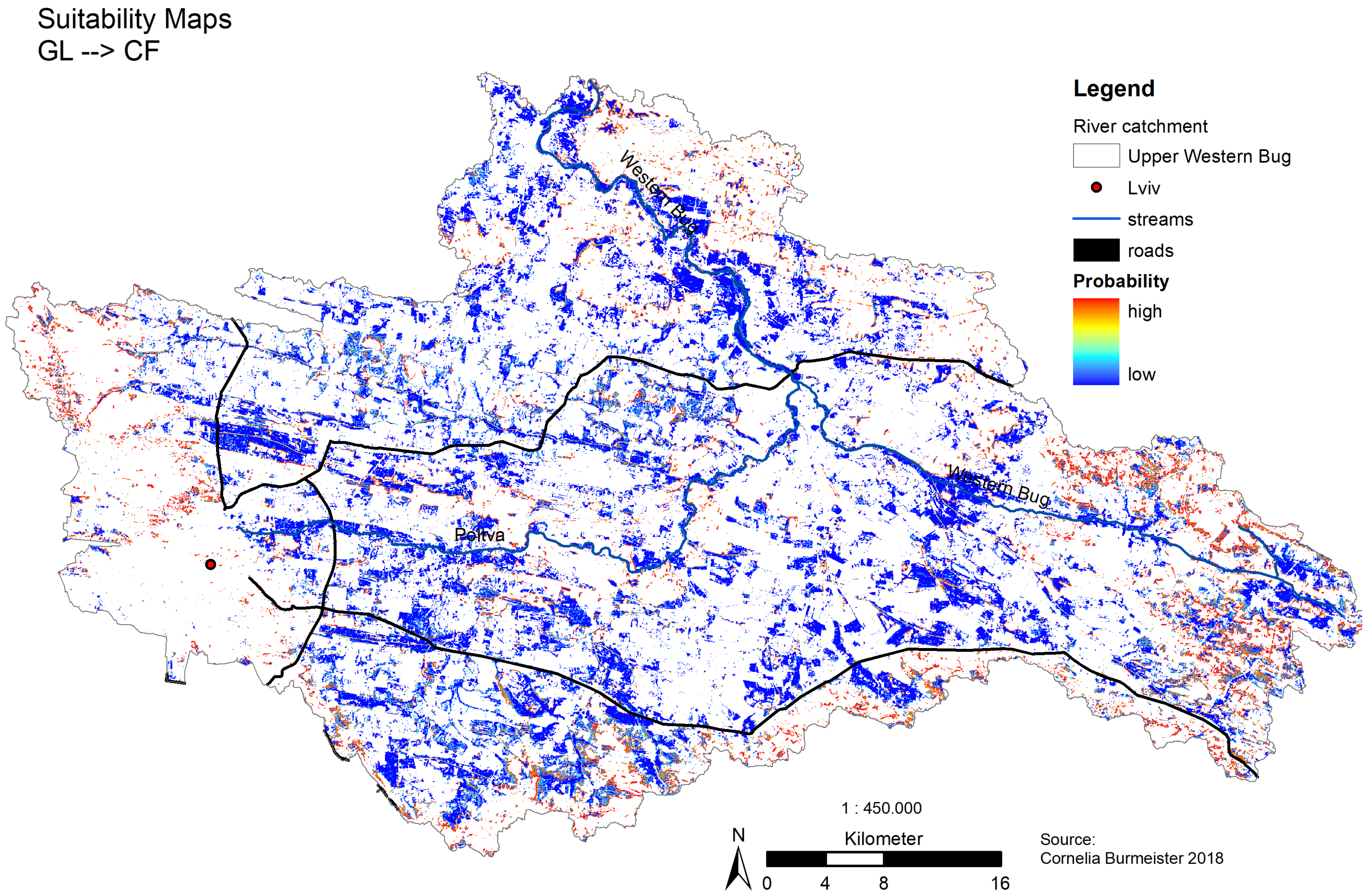
Source:
Cornelia Burmeister 2018

Figure 10: Suitability map of the transition pathway from arable land to grassland



Source:
Cornelia Burmeister 2018

Figure 11: Suitability map of the transition pathway from grassland to broad-leaved forest.



Source:
Cornelia Burmeister 2018

Figure 12: Suitability map of the transition pathway from grassland to coniferous forest.

8.3 RESEARCH ARTICLES

BURMEISTER, C. & SCHANZE, J. 2018. Cross-sectoral projections of future land-cover change for the Upper Western Bug River catchment, Ukraine. *Environmental Earth Sciences*, **77**, 194, doi:10.1007/s12665-018-7338-1.

BURMEISTER, C. & SCHANZE, J. 2016. Retrospective Analysis of Systematic Land-Cover Change in the Upper Western Bug River catchment, Ukraine. *ACC Journal*, **22**, 7–18, doi:10.15240/tul/004/2016-1-001.

8.3.1 Research Article 1: Retrospective Analysis of Systematic Land-Cover Change in the Upper Western Bug River catchment, Ukraine

by C. Burmeister, J. Schanze

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RETROSPECTIVE ANALYSIS OF SYSTEMATIC LAND-COVER CHANGE IN THE UPPER WESTERN BUG RIVER CATCHMENT, UKRAINE

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Abstract

The paper presents the approach and empirical findings of a study on systematic land-cover change in the upper Western Bug River catchment in Ukraine. Landsat and SPOT images as remote sensing data are used for land-cover classification for the time steps 1989, 2000 and 2010. Thereby, three inner-annual scenes represent the vegetation development for each time step and facilitate classification with the Maximum Likelihood Classifier. Six classes are detected: artificial surface, broad-leaved and coniferous forests, arable land, grassland and water bodies. After this step, land-cover change detection over two decades is conducted. The observed against the expected gross loss and gross gain are statistically analyzed to identify the systematic and random land-cover changes in the study region. Results show that arable land changes not into artificial surface. Arable land changes into grassland and vice versa. This systematic change is very strong. The forest classes interchange whereat broad-leaved forest gains more from coniferous forest in the last decade.

Keywords

Land cover; Systematic land-cover change; Western Bug River; Ukraine.

Introduction

When a comprehensive terrestrial database is lacking, remote sensing data as satellite images or aerial photographs from different dates may visualize changes in land-cover (LC) and to a certain extent in land use (LU). LC is commonly understood as the biophysical condition of the earth surface [1, 2, 3], including e.g. bare soil, vegetation or crops and man-made constructions covering the surface like buildings or infrastructure. It comprises everything that is directly detectable by earth observation on the ground or via remote sensing data. Besides, LU is often defined as human activities exploiting and utilizing the land for a certain purpose [1, 2, 3]. Typical examples are nature protection, recreational and commercial areas. Since LU is not directly visible via observation methods, additional information such as socio-economic data, statistics, or particular field surveys are needed [2, 3].

Change may refer to LC, to LU or to both. Geist et al. [3] differentiate LC change into conversion or modification. The former occurs when one LC type is substituted by another one and is easily detectable. The latter is distinguished by the gradual change of the character of a LC class and the change is hardly visible [3].

Various techniques of remote sensing and GIS allow LC/LU change to be quantified, e.g. when LC/LU maps from different time steps are compared with each other. The product of the comparison is mostly a transition matrix, which presents the change of one LC category to another. This two-dimensional table fails to show all information, like e.g. the relevant changes [4, 5] or the existence of multiple possibilities of land-cover transitions [6]. Braimoh [7] introduced a method to differentiate between random and systematic (categorical) change by enhancing this transition matrix. They understand random transitions as a change that occurs once between two time steps because of abrupt changes, whereas a systematic change is recognized as a transition that is recurrent due to regular or common processes of change.

In this article, the systematic LC change detection is shown for the Upper Western Bug River catchment in Ukraine which was one of the tasks of a more comprehensive integrated water resource management (IWRM) study [8]. LC change in addition to climate change served as a driver for modelling a long-term change of the water and matter balance [9, 10, 11].

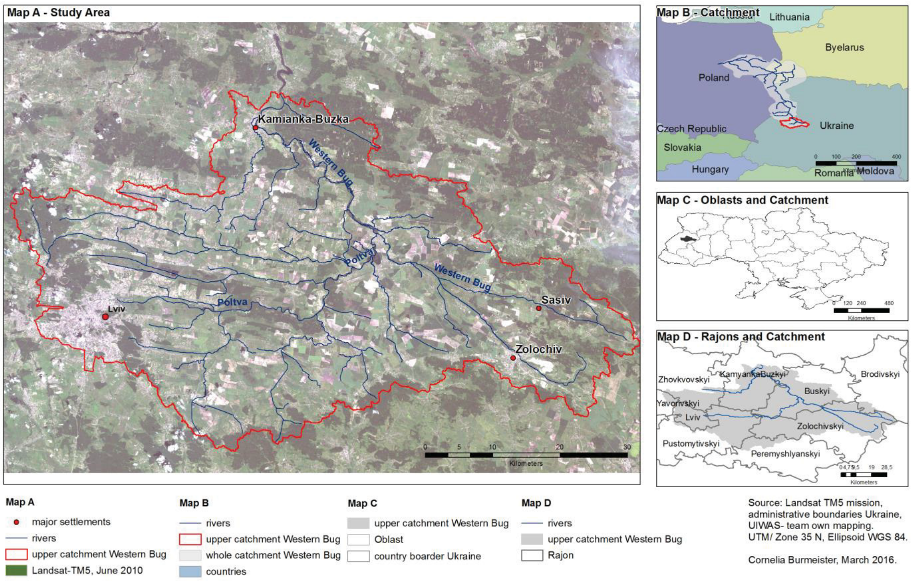
The research presented in this article consists of the following steps: (i) generation of comprehensive land-cover maps for the years 1990, 2000 and 2010 based on the classification of satellite data for urban, arable and forest land-cover classes; (ii) change detection for these land-cover maps with contingency tables to show LC change; and (iii) enhanced statistical analysis to depict systematic LC change.

1 Study Region

The upper part of the Western Bug River catchment is situated in the west of Ukraine, with its spring in the Podolian Highlands as can be seen in Fig. 1, Maps A to D. Thereby, map A shows the rivers and main towns of the study region. Map B presents the whole Western Bug River catchment. Map C covers the delineation of the study area within the administrational Oblast units and Map D depicts the study area within the administrational Rayon units. The river flows via Belarus to Poland and leads to the Narew River. The latter then flows into the Vistula River which ends in the Baltic Sea (see Fig. 1, Map B).

The study region is around 2,550 km² large [8] and reaches to the gauge of Dobrotvir in the North (see Fig. 1, Maps A, C and D). The western upper part is strongly influenced by the regional capital Lviv with about 734,000 inhabitants (year 2010, [12]). There, the Western Bug tributary Poltva River has its spring (see Fig. 1, Map A). The Poltva is determined by the discharge of the wastewater treatment plant of Lviv and various industries which lower the water quality of the tributary tremendously [13]. Other important cities of the catchment area are Zolochiv in the South, Buzk and Kamianka Buzka (see Fig. 1, Map A). The investigated catchment is characterized by agricultural activities and dense settlement structures in the rural areas [9].

The study region lies completely in Ukraine as a post-Soviet country which gained its independence in 1991. In Soviet times the state was characterized by rich natural resources, a highly qualified population and intensive agricultural production. With the change of the political and economic system from communism towards capitalism, a rapid societal and demographic change took place [14-16]. The population is shrinking because of low birth rates, high death rates due to diseases like cardiovascular diseases [14], and poverty caused by high unemployment rates and broad migration of workers into the EU or Russia. Gorobets [17] states that after getting independence Ukraine failed to ensure a successful transition and sustainable development mainly due to inefficient economic structures which are still resource intensive and the usage of old technology which pollutes the environment. Moreover, limited functioning of institutions, not only for environmental management and education is visible, but also a weak decision-making is present. There is still no functioning land-market to buy and sell land because of the fear of "outselling" the land [18, 19]. Today, Ukraine has been in political struggles with separatists since 2014, which lowers the living conditions and planning reliability.



Source: Own calculation, see lower right corner of Fig. 1.

Fig. 1: Study region with the upper Western Bug River catchment

2 Methods and Data

2.1 Data and Pre-processing

Satellite scenes from Landsat (WRS 186/26) and SPOT are used to derive reliable LC maps via classification with the necessary scale for subsequent parameterization of the water and matter balance models [10, 11]. The Landsat and SPOT platforms are chosen because they provide a continuity over a long time horizon [20]. The three time steps 1989, 2000, 2010 (cf. also Tab. 1) are meant to represent the socialist period in 1989, the development after the revolution from 2000 to 2010, and the present state before the struggles with separatists took place. Additionally, this time step was used to model the water and matter balance of the catchment [10, 11].

Each time step is represented by three inner-annual scenes covering the beginning, mid and end of the vegetation period (cf. Tab. 1) to distinguish arable land, managed grassland, natural grassland, bare soil on arable land and urban area.

All satellite images are atmospheric corrected, georeferenced (SPOT to Landsat) and pan-sharpened to 15 x 15 m. Furthermore, the Normalized Difference Vegetation Index (NDVI) is calculated. This is used to differentiate between vegetated areas and sealed surfaces to facilitate classification.

The data for ground truthing are scarce. Topographic maps at the scale of 1:100,000 from the year 1984, and some selected topographic maps with a scale of 1:10,000 for some parts of Lviv and the Sasiv sub-catchment are available. Usability of the latter is very limited since they are without any dates of production or actualization. As an additional data source, the GeoEye scenes in Google Earth are used for gaining ground truth data, especially for the time step 2010 (cf. section 2.2). These data are complemented in field campaigns in the years 2009, 2010 and 2012.

2.2 Classification Process

A supervised classification is performed with the statistical classifier Maximum Likelihood which assigns the pixel to the class with the highest class probability based on training pixels.

For the Maximum-Likelihood Classifier, training data for the pre-definition of classes are needed. To delineate training samples for each class, ground truth data from the field campaigns are taken. Google Earth is used to complete the data for 2010 where some GeoEye scenes are available for the city of Lviv. The rural part of the catchment is presented in Google Earth with SPOT scenes. The reference data for the time step 1989 are collected with the topographic maps in the scale for 1:100.000 which are available for the whole investigated catchment and 1:10.000 which is available for a sub-catchment (see section 2.1). Additional visual image interpretation of the Landsat and SPOT scenes is done for the derivation of reference data. For the time step 2000 only visual image interpretation of the Landsat and SPOT scenes can be made for the collection of reference data.

These collected ground truth reference points are randomly divided into two parts. One part is used for training samples for the delineation of each LC class and the other part for assessing the accuracy of the classification afterwards.

A post-classification enhancement is undertaken for the LC class AS with a settlement layer which is acquired by editing in different time steps on the satellite images.

2.3 Change Detection for Differentiation between Random and Systematic Change

Post-classification change detection is undertaken by calculating the contingency table (transition matrix) from one time step to another, so that class i changes in a percentage rate to class j. An enhanced calculation of indicators, which describes the change in more detail, is carried out with the *persistence*, *gross loss* and *gross gain*, *net change*, *total change*, and *swap* [4, 5, 7]. The *persistence* is the consistent unchanged percentage of one LC class between two time steps. The *gross loss* is the total sum of the LC category in time step one minus the *persistence*. The *gross gain* is calculated by the total amount of the LC category in the second time step minus the *persistence*. The *net change* is calculated by the difference of *gross gain* and *gross loss*. In contrast, the *total change* is derived by addition of the two. Finally, the *swap* is the difference of the *total change* and the *net change* [5] and provides information about the changes (gains and losses) of a LC category on different spatial sites. It presents the real change of a LC class, because the gain and loss of a category do not always take place at the same location, e.g. a loss of a specific LC class can be balanced by a gain of this specific LC class in another place, so the net change would be zero and indicate no change, which of course does not represent the truth [4]. With these numbers no assumptions of systematic change can be derived. Therefore, the assumption is made that the random process of the gross loss and gross gain is set in relation to the class size [5, 7]. If the *gross gain* or *gross loss* is not random, it is called a systematic transition (process). A systematic transition occurs when the deviation between the *observed gross loss*/*gross gain* minus *expected gross loss*/*gross gain* is either negative or positive.

The calculation for the random *expected gross gain* is in equation (1) [5, 7]:

$$G_{ij} = \left(p_{+jn} - i_n j_n\right) \cdot \frac{p_{in+}}{100 - p_{jn+}} \text{ where } i \neq j. \quad (1)$$

G_{ij} is the expected gain within the transition of the category i to the category j. The first paragraph expression ($p_{+jn} - i_n j_n$) is the observed gross gain, p_{in+} is the sum of the row of the category i and p_{jn+} is the sum of the row of category j in the contingency table.

The calculation of the random *expected gross loss* is in equation (2) [7]:

$$L_{ij} = \left(p_{in+} - i_n j_n\right) \cdot \frac{p_{+jn}}{100 - p_{+in}} \text{ where } i \neq j. \quad (2)$$

L_{ij} is the expected loss within the transition of the category i to the category j. The first paragraph expression ($p_{in+} - i_n j_n$) is the observed gross loss, p_{+jn} is the sum of the column for category j and p_{+in} is the column sum of category i in the contingency table.

Finally, the deviation between *observed and expected* ***gross gain*** has to be interpreted and assessed: a positive deviation between category i and j means that category i is systematically *gaining* from category j; a negative deviation between category i and j *impedes systematic gains* from category i to category j.

The difference of the *observed and expected* ***gross loss*** has to be interpreted too: a positive deviation between category i and j results in the systematic *losing from* category i to category j; a negative balance indicates that category i is *losing to* category j systematically.

A systematic transition is given, if class i systematically gains from class j and class j systematically loses to class i.

3 Results

3.1 Classification Results and Land-Cover Change between 1989, 2000, and 2010

Tab. 1 presents the used satellite images for the classification process. Images with high cloud coverages are rejected.

Tab. 1: *Satellite scenes used for the three time steps*

Time step	Data	Satellite sensor	Geometric resolution
1989	1989-07-07 1989-08-16 1993-04-21	Landsat-TM 5	30 x 30 m
	1989-07-12 1989-08-18 1989-08-30	SPOT-1	10 x 10 m
2000	2000 -05-02 2000-08-22 2001-04-03	Landsat-7 ETM +, band 1 to 5, 7 band 8 (pan)	 30 x 30 m 15 x 15 m
2010	2010-04-04 2010 -06-07 2010-11-14	Landsat-TM 5	30 x 30 m
	2007-08-23 2009-04-19 2009-07-18	SPOT-4 SPOT-2 SPOT-5	10 x 10 m 10 x 10 m 5 x 5 m

Source: Own

On the whole, six classes are detected: ‘artificial surface’ (AS), arable land’ (AL), ‘broad-leaved forest’ (BLF), ‘coniferous forest’ (CF), ‘natural grassland’ (GL), and ‘water bodies’ (WB). Additionally, the class ‘peat bogs’ (PB) is detected for the time step 1989, which disappears in the time step 2000 (cf. Tab 2).

Tab. 2: *Classification scheme*

Land-cover class	Description of class and detection
artificial surface (AS)	Settlement, infrastructure such as road etc. and impervious surface.
arable land (AL)	Agricultural area and mowed grassland (managed). It is detected through the different phenological states using the inner-annual satellite images representing the vegetation period. With this procedure it is possible to achieve a high quality of identification of a single field plot and in subsequence of this LC class because the farming plots are vegetated in at least one satellite scene during the vegetation period. Managed grassland is also subsumed in this LC class, allowing it to be distinguished from natural grassland.
broad-leaved forest (BLF) coniferous forest (CF)	Forest is divided on the basis of different spectral signatures.
Natural grassland (GL)	Vegetation cover through the whole year (unmanaged), with the three inner-annual scenes.
peat bogs (PB)	Specific spectral signature of non-vegetated areas.
water bodies (WB)	Specific spectral signature.

Source: Own.

The classification of the three time steps resulted in the aforementioned 6 LC classes AS, AL, BLF, CF, GL, and WB (cf. section 2.2 and Tab. 3), with the addition of one more LC class in the year 1989: PB.

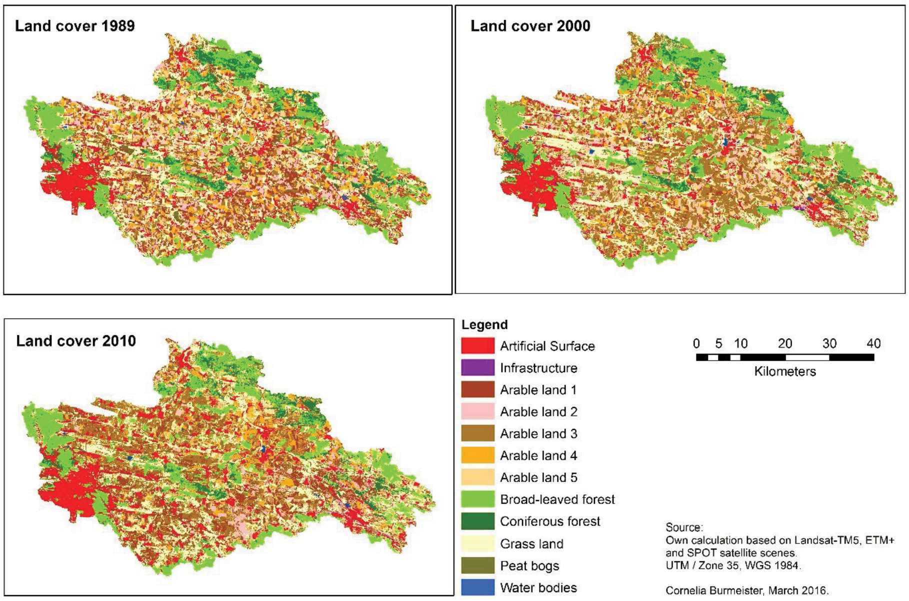
Tab. 3: *Results of land-cover change between 1989, 2000 and 2010*

LC classes		AS	AL	BLF	CF	GL	PB	WB
∑	1989	10.7	47.2	15.0	5.1	20.6	1.2	0.1
	2000	11.3	47.2	17.0	4.3	19.9	0	0.3
	2010	13.3	44.3	13.9	4.8	23.5	0	0.3
1989-	persistence	9.2	39.0	13.7	3.2	11.5	0	0.1
	gross gain	2.1	8.2	3.4	1.1	8.4	0	0.2
	gross loss	1.5	8.2	1.4	1.9	9.1	1.2	0.0
	net change	0.6	0.0	2.0	0.9	0.7	1.2	0.2
	total change	3.6	16.4	4.7	3.0	17.5	1.2	0.2
	swap	3.0	16.4	2.7	2.1	16.8	0	0.1
2000 -	persistence	10.7	36.0	12.5	3.1	11.3		0.2
	gross gain	2.5	8.3	1.4	1.7	12.1		0.1
	gross loss	0.6	11.2	4.5	1.2	8.6		0.1
	net change	1.9	2.9	3.2	0.6	3.6		0.0
	total change	3.1	19.5	5.9	2.9	20.7		0.2
	swap	1.2	16.6	2.7	2.3	17.1		0.2

AS = artificial surface, AL = arable land, BLF = broad-leaved forest, CF = coniferous forest, GL = grassland, PB = peat bog, WB = water body

Source: Own

There is an expansion of AS (new built-up areas) observable but not that high as it might have been expected. There is a shift of abandonment of old collection farms and the demand of land for newly developing industries and family houses, especially at the arterial roads and on the edges of settlements.



Source:
Own calculation based on Landsat-TM5, ETM+ and SPOT satellite scenes.
UTM / Zone 35, WGS 1984.
Cornelia Burmeister, March 2016.

Source: Own calculation, see lower right corner of Fig. 2.

Fig. 2: *Land-cover classification results for the three time steps.*

AL decreases from 1989 with 47.2% to 2010 with 44.3% in total. In contrast, GL increases by about almost 3% from 1989 to 2010. This total number changes, as also the net change suggests, showing only low change rates (0...2.9% for AL as well as for GL with 0.7...3.6%). However, the total change with 20% (2000-2010) and swap present a high dynamic within these two classes, especially in space – as it can also be seen on the maps (cf. Fig. 2). That means that areas less suitable for agriculture are abandoned and GL with good properties as e.g. location or fertility are brought back into the agricultural cycle. This is also supported by Tab. 4 where a strong systematic change occurs between AL and GL. For the last decade 2000 to 2010 the gaining of GL from AL is stronger than in the decade before (3.0/5.4 to 1.8/3.3). Once again, this reflects on the one hand the concentration on suitable areas for cultivation and on the other hand the uncertainty which is caused by a non-functioning land market.

Other changes are seen around the settlements (500 m buffer). A lot of GL areas changed into field plots for subsistence farming after the break down of the socialistic system (which can be seen in the satellite scenes of 2000) and consequent a different parcelling to 1989 (also seen on Fig. 2). The change from GL to AL in the 500 m vicinity is higher than the change of AL into GL compensates. This is the reason for the increase of subsistence farming on close plots to the dwellings for the cultivation of food and fodder and also an indicator of poverty. The LC map of 1989 shows the intensive cultivation of AL with the huge amount of different field plots. After 2000, more importance was attached to big enterprises which cultivate the large fields now, and is visible in the changing of the field sizes and the connections of the fields (Fig. 2). Other systematic changes for the category AL are that it is not systematically transformed into BLF or CF and for the category GL, that it is not systematically changed into CF (Tab. 4).

Tab. 4: *Systematic changes 1989 to 2000, and 2000 to 2010*

		Categories 2000					
Categories 1989		AS	AL	BLF	CF	GL	WB
AS	ΔO – GG		-1.2	-0.2	0.0	-0.4	0.0
	ΔO – GL		-0.3	-0.1	0.0	0.4	0.0
AL	ΔO – GG	-0.7		-1.3	-0.3	1.8	0.0
	ΔO – GL	-1.6		-2.4	-0.5	3.3	0.0
BLF	ΔO – GG	-0.2	-2.0		0.3	-1.1	0.0
	ΔO – GL	-0.1	-0.5		0.4	0.2	0.0
CF	ΔO – GG	-0.1	-0.6	1.4		-0.4	0.0
	ΔO – GL	-0.2	-0.7	1.3		-0.3	0.0
GL	ΔO – GG	1.1	3.2	0.1	-0.2		0.0
	ΔO – GL	0.3	1.0	-1.0	-0.4		0.0
WB	ΔO – GG	0.0	0.0	0.0	0.0	0.0	
	ΔO – GL	0.0	0.0	0.0	0.0	0.0	

		Categories 2010					
Categories 2000		AS	AL	BLF	CF	GL	WB
AS	ΔO – GG		-1.6	-0.1	-0.2	-1.4	0.0
	ΔO – GL		-0.1	0.0	0.0	0.1	0.0
AL	ΔO – GG	-0.9		-0.4	-0.5	3.0	0.1
	ΔO – GL	-2.2		-2.4	-0.7	5.4	0.0
BLF	ΔO – GG	-0.2	-1.4		1.0	-1.0	0.0
	ΔO – GL	-0.4	-1.0		1.0	0.4	0.0
CF	ΔO – GG	0.0	-0.2	0.2		-0.4	0.0
	ΔO – GL	-0.1	-0.1	0.1		-0.1	0.0
GL	ΔO – GG	1.1	3.1	0.2	-0.3		0.0
	ΔO – GL	0.2	1.2	-1.0	-0.4		0.0
WB	ΔO – GG	0.0	0.0	0.0	0.0	0.0	
	ΔO – GL	0.0	0.0	0.0	0.0	0.0	

Abbreviation: ΔO – GG = delta observed – expected gross gain; ΔO – GL = delta observed – expected gross loss; AS = artificial surface; AL = arable land; BLF = broad-leaved forest; CF = coniferous forest; GL = grassland; PB = peat bog; WB = water body.
Blue-colored cells show a negative systematic change, a change is impeded.
Green-colored cells show a positive systematic change, the LC category gains from the other.
Source: Own

The classes BLF and CF decline over the 21 years of the study period (see Tab. 3). The forest class BLF depicts a gain higher than a loss in the period from 1989 to 2000. After the next decade, the gross loss for BLF is higher than the gross gain but the swap is with 2.7 the same for both decades. For the category CF, it is the other way round. The swap of 3% for CF (two thirds of the whole LC class) also shows a high dynamic for the forest classes. The systematic change (Tab. 4) depicts a systematic interchange of the forest classes and that it is impeded by BLF changes in AS and AL. The only difference that occurs between the time periods is that the exchange of the forest classes is more one-sided to CF.

3.2 Accuracy Assessment

Accuracy assessment is performed using statistical measures which are based on the calculation of the error matrix that consists of the correct and misclassified pixels of the LC classes. The classification algorithm shows different accuracy results for the three time steps: 1989 displays an overall accuracy of 84.5% with an overall kappa of 0.8, 2000 has an overall accuracy of 92% with an overall kappa of 0.89, and 2010 demonstrates overall accuracy of 92.6% with an overall kappa of 0.89.

Conclusion

The paper shows how an enhanced statistical analysis of past land-cover developments can help to identify the relevant changes. Although the Maximum Likelihood classifier is a straight forward approach, it has delivered good results. The Landsat and Spot satellite series are able to provide long time coverage of a single service. By means of them, the selection of inner-annual time steps of the satellite images in one year was possible even for 1989. The inner-annual scenes support the differentiation between arable land and grassland and bare arable land and artificial surface a lot.

The enhanced analysis of the LC change shows main change trajectories:

- the high interchange of arable land and grassland due to location and fertility issues which is stronger in 2000 to 2010 for grassland
- the interchange of the forest kinds
- the protection of arable land and broad-leaved forest /coniferous forest because it is not systematically changed into artificial surface. This is different to developments in other countries, e.g. Germany, where new built-up areas (category artificial surface) develop mostly on arable land.

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Retrospektivní analýza systematických změn zemského povrchu v povodí horního Západního Bugu na Ukrajině

Článek popisuje přístup a empirické výsledky systematických změn v povodí horního Západního Bugu na Ukrajině. Z teledat satelitu Landsat a SPOT je určen zemský povrch v období 1989, 2000 a 2010. Každý časový úsek je přitom zastoupen třemi obrázky z různých ročních období s cílem integrovat vývoj vegetace a opravit klasifikaci pomocí metody maximální věrohodnosti. Jako výsledek bylo detektováno celkem šest tříd: zastavěná plocha (městská), listnatý les, jehličnatý les, zemědělská půda, zeleň a vodstvo. Po učení povrchu v jednotlivých časových úsecích jsou zkoumány změny vzniklé za poslední dvě desetiletí. Pozorovaný pokles a růst je statisticky analyzován, aby mohly být stanoveny systematické a náhodné změny zemského povrchu ve zkoumané oblasti. Výsledky ukazují, že orná půda není přeměněna na zastavěné plochy. Orná půda se mění v travnaté porosty a naopak. Tato systematická změna je velmi silná. V klasifikaci lesních porostů jde především o vzájemnou záměnu, přičemž více dochází k přeměně lesů jehličnatých na listnaté.

Retrospektive Analyse des systematischen Landbedeckungswandels im Einzugsgebiet des oberen Westlichen Bug, Ukraine

Der Artikel zeigt die Herangehensweise und empirische Ergebnisse des systematischen Landbedeckungswandels im Einzugsgebiet des oberen Westlichen Bugs in der Ukraine. Aus Fernerkundungsdaten der Satelliten Landsat und SPOT wird die Landbedeckung für die Zeitschritte 1989, 2000 und 2010 bestimmt. Dabei wird jeder einzelne Zeitschritt mithilfe von drei innerjährlichen Bildern repräsentiert, um die Vegetationsentwicklung zu berücksichtigen und die Klassifikation mit dem Maximum Likelihood Classificator zu verbessern. Als Ergebnis wurden sechs Klassen detektiert: versiegelte bebaute Fläche (städtisch), Laubwald, Nadelwald, Ackerfläche, Grünland und Wasser. Nach der Ermittlung der Landbedeckung in den einzelnen Zeitschritten wird der Wandel über die zwei Jahrzehnte untersucht. Der beobachtete Rückgang und Zuwachs wird statistisch analysiert, um den systematischen und zufälligen Landbedeckungswandel für das Untersuchungsgebiet zu identifizieren. Die Ergebnisse zeigen, dass Ackerfläche nicht in bebaute Fläche umgewandelt wird. Ackerfläche geht in Grünland über und umgekehrt. Dieser systematische Wandel ist sehr stark ausgeprägt. In den beiden Waldklassen gibt es hauptsächlich einen wechselseitige Nutzungsänderung, wobei in den letzten zehn Jahren mehr Nadelwald in Laubwald umgewandelt wird.

Retrospektywna analiza ukierunkowanych zmian pokrycia terenu w dorzeczu górnego Zachodniego Bugu, Ukraina

W artykule przedstawiono podejście do tematyki ukierunkowanych zmian pokrycia terenu oraz empiryczne wyniki badań przeprowadzonych w zlewni górnego Zachodniego Bugu na Ukrainie. Pokrycie terenu zostało określone przy pomocy danych Teledetekcji Landsat i SPOT dla lat 1989, 2000 i 2010. Każdy krok czasowy reprezentowany jest przy pomocy trzech zdjęć satelitarnych służących uchwyceniu rozwoju roślinności oraz poprawie klasyfikacji metodą największej wiarygodności. W rezultacie wyodrębniono sześć klas: teren zabudowany (miejski), las liściasty, las iglasty, grunty orne, łąki oraz wody. Na podstawie badań pokrycia terenu dla poszczególnych etapów czasowych określono zmiany w nim zachodzące na przestrzeni dwóch dekad. Obserwowany spadek i wzrost analizowanych klas poddany został statystycznej analizie w celu identyfikacji ukierunkowanych i losowych zmian pokrycia terenu na badanym obszarze. Wyniki pokazują, że grunty orne nie zostają przekształcane w tereny zabudowane. Grunty orne zamienia się w łąki i odwrotnie.

8.3.2 Research article 2: Cross-Sectoral Projections of Future Land-Cover Change for the Upper Western Bug River catchment, Ukraine

by C. Burmeister, J. Schanze

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ORIGINAL ARTICLE

Cross-sectoral projections of future land-cover change for the Upper Western Bug River catchment, Ukraine

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Abstract

Projections of future land-cover (LC) change are challenging because of the multitude of spatial and dynamic drivers involved, such as politics, economics, demographics, and the environment. This paper presents a combined qualitative and quantitative scenario approach for giving consistent projections of urban and rural land-cover change (LCC), considering both the demands of certain LC types, and their allocation. The approach has been implemented in the Upper Western Bug River catchment in Ukraine in the context of integrated water resource management. Special attention is paid to the identification of spatial and dynamic drivers of LCC, the scenario formulation and projection of the identified drivers, and the projections of alternative plausible LCC. The identification of spatial and dynamic drivers is based on the detection of retrospective LCC, statistical analysis of interrelations between LCC and drivers, and expert validation of transition rules. The scenario formulation and projection of the drivers involve storylines with inputs from expert interviews. The creation of future LC change projections followed four steps: suitability maps from retrospective LCC detection, expert validation, the future development of drivers, and the allocation of LCC. Results indicate demographic change and GDP development as dynamic drivers mainly influencing the LCC, as other studies have implied. Furthermore, there are spatial drivers influencing the local allocation such as the regional capital of Lviv, and they are shaped by, for example, environmental laws, distances to roads and settlements, slope, and soil fertility.

Keywords Land-cover projection · Scenarios · Drivers · Demand rates · Allocation · Ukraine

Introduction

Land-cover (LC) and land-use (LU) change play an important role in the development of human–environmental systems in general, and the water balance and matter fluxes in the catchments of rivers and lakes in particular (e.g. Schanze et al. 2012). Therefore, LC is understood as the directly detectable biophysical condition of the Earth's surface, e.g. bare soil, vegetation, or buildings. LU is defined as human activities exploiting and utilising the land for a certain purpose, like nature protection or commercial areas. LU is not directly visible and requires additional information for its determination, such as statistics or field surveys (FAO and UNEP 1999; Lambin et al. 2001; Verburg et al. 2009).

LC and LU changes such as the increase in impervious surface area lead to a rise in run-off, reduction in infiltration, and change in evapotranspiration. This change in the water balance also influences the matter fluxes of nutrients and other substances. Since there is no way of predicting future LCC due to the multitude of drivers involved, the scenario approach is broadly accepted as a tool for specifying possible futures. Up to now, there has been no well-defined methodology that is capable of dealing with the particularities of LCC in river catchments in the integrated water resource management (IWRM) context. Among others, there is still a gap of knowledge about factors influencing LC patterns and drivers of change. There are spatial drivers that are supposed to additionally shape LCC such as politics and laws, but also environmental conditions belong to this category—for instance, such as geomorphology and soil. And, there are also some drivers which show a long-term dynamic with a

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potential to influence LCC, such as climate change or demographic development. However, there is still a lack of clarity regarding how to involve the different spatial and dynamic drivers of LCC relevant to IWRM in considering *rural and urban* land cover and a wide range of different data, such as statistics for economic or demographic development, geodata like satellite data or "municipal" shape files, or qualitative data as expert answers.

Existing scenario studies on LCC/LUC (Rounsevell et al. 2005; Kosow and Gassner 2008; Sohl et al. 2010; Sleeter et al. 2012; Sohl et al. 2012; Ramírez and Selin 2014; Malek and Boerboom 2015; Wilson et al. 2016) reveal some common key components of scenario studies in this field: the analysis of past LCC/LUC, the analysis of drivers of LCC/LUC, scenario generation, and the calculation of the future LCC/LUC (demand) and its allocation. Differences are found mainly regarding the level of detail of the examinations of single components (Alcamo 2001; Bürgi et al. 2004; Houet et al. 2010; Sohl et al. 2010; Sleeter et al. 2012; Sohl et al. 2012; Wilson et al. 2016).

In this article, a scenario approach for LCC is presented that combines qualitative and quantitative components for consistent projections of urban *and* rural LC, considering both the demand of certain LC types and their allocation. Expert judgements on storylines and developments of unprojectable drivers are qualitative, while transition rules and algorithms retrieved from retrospective change detection, suitability maps, and cellular automaton applications are quantitative. Driver developments are the focus, with their influence on the future demand rates (transition rates) as well as allocation algorithms for modelling future LC. IWRM is the thematic and methodological context of the research. Empirical work is carried out in the Upper Western Bug River catchment in Ukraine for a time horizon from 1990 up to 2025, due to significant societal transformation.

The following research questions are addressed:

- How can the urban and rural LCC of river catchments be consistently projected in the future?
- Which spatial and dynamic drivers of LCC can be identified for the Upper Western Bug River catchment?
- What are plausible scenarios with projections of future LCC for this catchment, considering both the allocation and demand of LC types?

Methodology

To ensure the envisaged consistent projections of urban and rural LCC, considering both the allocation and demand of certain LC types, an advanced scenario approach has been developed (Fig. 1). The left column (dark grey) of the figure depicts the major methodological steps of this approach. They are explained in more detail in the subsequent sections. The middle and right columns show the methods and data applied during each step. The methodology has been implemented at the case study site in the Upper Western Bug River catchment with a thematic focus on IWRM.

Step 1: Definition of the scenario context

For a river catchment and the focus of IWRM, LC has to be considered as part of a human–environment system along with processes of the water balance, water-related matter fluxes, and the hydro-ecological system of the waters. Boundary conditions with the potential to change are the climate and the societal system. Climate change may affect temperature, precipitation, etc. Societal change plays a particular role via LCC with its manifold impacts on the water balance and matter fluxes. Examples of LCC influences are the impacts of impervious surfaces on infiltration and surface run-off, the use of fertilisers on the matter fluxes, and the urbanisation on changing amounts and pollution of wastewater discharge. Together, climate and societal change can lead to significant alterations of the hydrological regime and status of waters, and thus need to be treated in a comprehensive and consistent way as, for example, Schanze et al. (2012) show.

The spatial extent of the river catchment should represent the biophysical river catchment independent from administrative borders, even though this involves a variety of difficulties, as Hagemann et al. (2014) show. For this paper, the change of rural and urban LC is analysed for the study site with the full scope of relevant spatial and dynamic drivers. Spatial drivers are seen as environmentally local site characteristics that shape, for example, the distribution of LC due to a long-term persistence of the earth system's elements like slope or soil. Dynamic drivers underlie changing conditions like demographic or economic development.

The definition of the scenario context comprises the spatial extent of the system under consideration and the temporal horizon of the retrospective and prospective investigations.

Step 2: Identification of spatial and dynamic drivers of lcc

An incremental and combined quantitative and qualitative procedure supports the determination of spatial drivers shaping the spatial distribution of LC types and dynamic drivers delineating the demand (future development).

Retrospective change detection for the identification of spatial drivers of LCC

The procedure starts with retrospective change detection, based on remote sensing and GIS methods, to reveal spatial

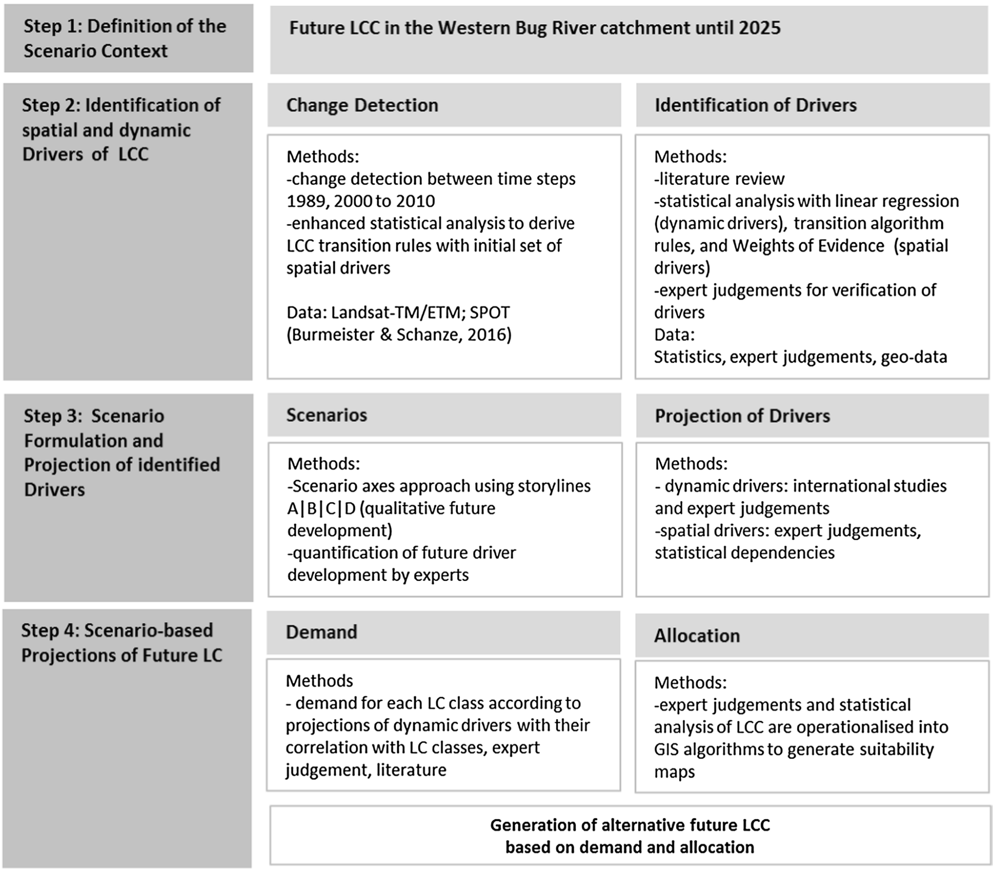

Fig. 1 Methodological framework of comprehensive scenario approach for projection of future LCC. *Source* own design

drivers and transition rules for the spatial distribution of LC (see step 2.4.1 and Schanze et al. 2012). Change detection is based on inter-annual multi-temporal remote sensing data using Landsat5/7 and SPOT data for the time steps 1989, 2000, and 2010. This allowed a resolution of 10 m to be used (Burmeister and Schanze 2016). The change detection method (two study periods 1989–2000 and 2000–2010) was enhanced with GIS analyses using the approach of Pontius et al. (2004). With this method, it is possible to differentiate between *systematic* and *random* LCC because it opposes the observed and expected LCC and gives, as a result, only the systematic processes (cf. Burmeister and Schanze 2016). The identified *systematic* LCC in the Western Bug River catchment region are translated into geo-data-based transition rules afterwards (Burmeister and Schanze 2016). Experts' interviews validated and enriched the transition rules. These rules are used for the future allocation of LCC (see step 4).

Literature review for the identification of potential dynamic drivers of LCC

An initial broad literature study was used to search for the driving factors of rural and urban LCC, which lead to the LC/LU patterns and their change.

Most studies which deal with the LCC of artificial surface (*AS*) and its projection concentrate primarily on population development or economic development (e.g. GDP development) as drivers or both (Niehoff et al. 2002; Rounsevell et al. 2006; Verburg et al. 2006; Narayanan and Walmsley

2008; Petrov et al. 2009; Boarnet et al. 2011; Hoymann 2012).

Boarnet et al. (2011) analysed the influence of the spatial planning politics of the past on the growth and speed of urban areas with an equilibrium model (regional adjustment models) for Florida. As dependent variables, the population density per acre and the employment density per acre are used. Rounsevell et al. (2006) estimated the demand for the LC category "urban land use" upon population development with the request/demand for housing and economic development. The change is allocated following specific rules which vary between the scenarios and were based on expert judgement regarding: accessibility of the transport system, land-use planning restrictions, attractiveness of cities, and competition with other land uses as, e.g. protected areas. Hoymann (2012) used a variety of variables (for describing AS change) like population, area of the administrative unit, floor area, household size, GDP, and the position of the settlements within the spatial planning units. She found out that a new built-up area is dependent on the ratio of single-family dwellings and to total residential dwellings. Another dependency was detected for the change of built-up areas with population and household size. Sohl et al. (2012) used expert interviews as their approach, on the basis of the Special Report on Emissions Scenarios (SRES) to estimate new settlement area.

Rounsevell et al. (2006) stated that it is hard to find a common trend for the development of agricultural areas. They estimated the future demands for the LC category arable land (AL) with the drivers: world supply and demand, market intervention, rural development policy, environmental policy, EU enlargement, and climate change. Rounsevell et al. (2005) used the results of the global trade calculations of the IMAGE (Integrated Model to Assess the Global Environment, Alcamo et al. 1994) model. Agricultural areas grow when the demand for food increases, but areas decline if the supply (productivity) increases. Busch (2006) produced a review of scenario studies for AL change within Europe and found out that all analysed future studies correspond at least to the drivers of GDP and population.

Farmland abandonment as an LU change (AL changes to various categories) can be explained with: elevation, slope, distance to the district capitals, measure of cropland fragmentation, distance to dwellings, cost distance to the road network, livestock units, cambisol content, urban proportion change, number of villages, distance from the nearest forest edge, isolated agricultural areas within the forest matrix, average grain yields, population counts from settlements, and distance from the nearest settlements or municipality centres (in Albania, Müller and Munroe 2008; in Romania, Lakes et al. 2009; in Western Ukraine, Baumann et al. 2011; and in post-soviet European Russia, Prishchepov et al. 2013).

For the LCC of *forest categories with* broad-leaved forests (BLF) and coniferous forest (CF), Rounsevell et al. (2006) took trend extrapolation of today as a basis for the future development of forest, because forest systems react slowly to changing circumstances and trees planted now take a lot of time to reach their harvesting age. Besides, forest policies take place at national and sub-national level. A literature review of trends and modelling with the IMAGE model calculated the demand for the forest class for country groups which have the same properties. The growth of forest classes is allocated to abandoned arable land or grassland, dependent on the scenario. They stated that the qualitative descriptions of drivers are sometimes impossible to quantify for modelling.

Special attention has to be given towards protected areas like forest protection or nature conservation areas (Rounsevell et al. 2005; Wilson et al. 2016).

The result of the literature review leads to a table of drivers with the expected influence on a LCC for the Western Bug Catchment (Table 3).

Statistical analysis for the identification of dynamic and spatial drivers of LCC

The spatial drivers were statistically analysed using the weights of evidence method, which was applied to the LCC data from 1989 to 2010. Here, the LCC is analysed within spatial distances[1] of LC categories (Goodacre et al. 1993) to find processes which foster or repel certain changes. Therefore, only the systematic transitions of LCC were analysed, which are identified in step 2, "Retrospective change detection for the Identification of spatial drivers of LCC" section. The gradient of the weights indicates the fostering of the LCC process (positive) or the repelling of the LCC process (negative). Weights close to zero indicate no effect. For this, additional data were included: the slope is retrieved from a digital elevation model (SRTM90-DEM 2000), soil (Wahren et al. 2012), roads/infrastructure (OpenStreetMap 2010), settlements and the stream network (Helm 2012) are considered. A biotic yield layer was calculated which combines the slope, the soil depth, soil texture, annual precipitation rate, and erosion risk (Leser and Klink 1988); Marks et al. (1992); Tavares Wahren et al. (2011)). This was done to present the different nutrient status of the soils in space.

Linear regression was used for the identification of interrelationships between the retrospective LCC and dynamic drivers, such as demography and GDP development, during the same time period. The aim is to find variables (x, drivers) which are able to describe the LCC (y, dependent variable). Several tests were used to assess the goodness

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[1] Therefore, the phrase "up to" is used, e.g. 0 to 200 m is presented as "up to 200 m".

Table 1 Every expert (ascending numbering) is assigned to a scale and working field for the Upper Western Bug River catchment

Societal sector/scale	Water management	Nature conversation	Agriculture and forestry	Spatial planning	Scenario building
Municipal				1	
Rayon*		2	7		
Catchment	3, 4			6	6, 10
Oblast**	3, 4		8, 11, 12		
National			5, 7, 9, 11, 12	6	6, 11

*Rayon = second level of administrative unit, **Oblast = first level of administrative unit

and requirements of the regression, such as the *t* test and the Kolmogorov–Smirnov test (Marsaglia et al. 2003). The goodness of fit is indicated by R^2, and the significance level with the 5% p value. The statistical analysis was performed using the R software (R Core Team 2013).

The data on the potential drivers originated from the Ukrainian census in 2001, as well as actual statistics and recent analyses by the State Statistical Service of Ukraine (HUSuLO 2000). Most of the variables show a temporal change. Either they show the change between 1989 and 2010 or a shorter time period of change from 2000 to 2010, to fit to the change detection time steps of 1989 to 2000 and/or 2000 to 2010. The administrative rayons (the second level of administrative division, like districts) are taken as regression units (sample 9), although the municipal level (sample 27) would be desirable, but no data existed. Therefore, the regression analysis is not representative, and it has only an explorative character and that's why the experts were involved to validate the LCC processes and the statistical findings of the small sample.

The statistical data which describe the LCC were transformed using the z-transformation, which allows the comparison of the variables at different times and scales (Bahrenberg et al. 2010). The LCC was calculated for the rayon units and is represented by a percentage change between the time periods.

Expert judgements for the identification of complementary drivers and for validation of drivers

Expert judgements have been included in the study (sample size, 12 experts). One of their tasks is to *verify* and *validate* the scenario approach at different stages with their knowledge (see Fig. 1). Another task is to *identify* missing drivers and to quantify the future development of drivers of LCC (sample size, 3 experts). The selected experts represent different societal sectors and hierarchical administrative levels relevant to potential drivers (cf. Table 1). Validation and data were gathered through semi-structured interviews. The guiding questions were designed for each LC type, LCC transition rule, and boundary condition. All in all, 12 expert interviews were conducted in February and March 2012.

Step 3: Scenario formulation and projection of drivers

This step refers to the design of plausible, coherent, and consistent scenarios, and ranges from qualitative storylines to quantitative projections of drivers of LCC.

Storylines of regional change

Storylines are a kind of narrative master scenario and are particularly meant to create an overarching logic of alternative scenarios that also include the individual dynamics of the drivers of LCC. According to most global and regional scenario studies (Nakicenovic and Swart 2000; Alcamo 2008; Rothman 2008), the research presented in this paper uses two discriminate axes, one referring to the preferred geographic scale of economic activities, the other to the principal orientation of these activities in relation to the market growth or sustainable development. The resulting four quadrants represent four distinct scenarios (cf. Fig. 3).

In the case of this research, the specification of the quadrants was proposed by the scenario team (researchers, in the case of this project). This proposal was then exposed to experts (semi-structured interview) to revise and enhance them. The storylines refer to regional change in the study region with a focus on societal change.

Projections of dynamic and spatial drivers of future LCC by experts

The qualitative storylines provide the context for projections of the dynamic and partly spatial drivers of LCC identified in step 1. Since there is no possible way to derive quantitative values for the dynamic drivers from the narratives of the storylines, their projection is based on expert judgements. These experts were asked to quantify the qualitative phrases: negative, weak, moderate, or strong development for the *dynamic drivers*. The interview answers concerning the *spatial drivers* are included in the composition of the suitability maps. With this, it is possible to project the drivers and afterwards the LC categories.

Step 4: lcc scenario analysis

All of the previous steps provide the base for the projection of future LCC. The following three sub-steps are required to arrive at these projections.

Suitable areas for future LCC allocation

The retrospective change detection results in transition rules for individual categories of LCC. Since there is a chance that these rules will be altered in the future, the results were validated and, as far as required, enriched by expert knowledge. The latter was gained together with the expert judgements on the drivers. For example, recent politics for regarding the protection of nature, water, or forest may additionally exclude areas from future LCC (to ensure a good water quality). All of the gathered information was combined and operationalised into algorithms, with the help of geo-data, to find suitable areas for LCC of every LC category. Therefore, a multi-criteria approach was used, summing up layers, which resulted in a ranking of the best most suitable areas (high numbers) towards to the low least suitable areas (low numbers or zero) for future LCC.

Assignment of demand rates to LC categories

The *dynamic drivers* were projected via the detected statistical dependencies. For these identified drivers, the experts quantified the future development (step 3, see 2.3.20). Where no statistical dependency was found, the derived rules and processes of the past LCC were used in combination with the storylines, validated and enriched using the background information obtained from the experts and the literature.

Projections of future LC

The previous two sub-steps were finally brought together in changing the most suitable areas, by the amount of the demand rates, into another LC category.

Results and discussion

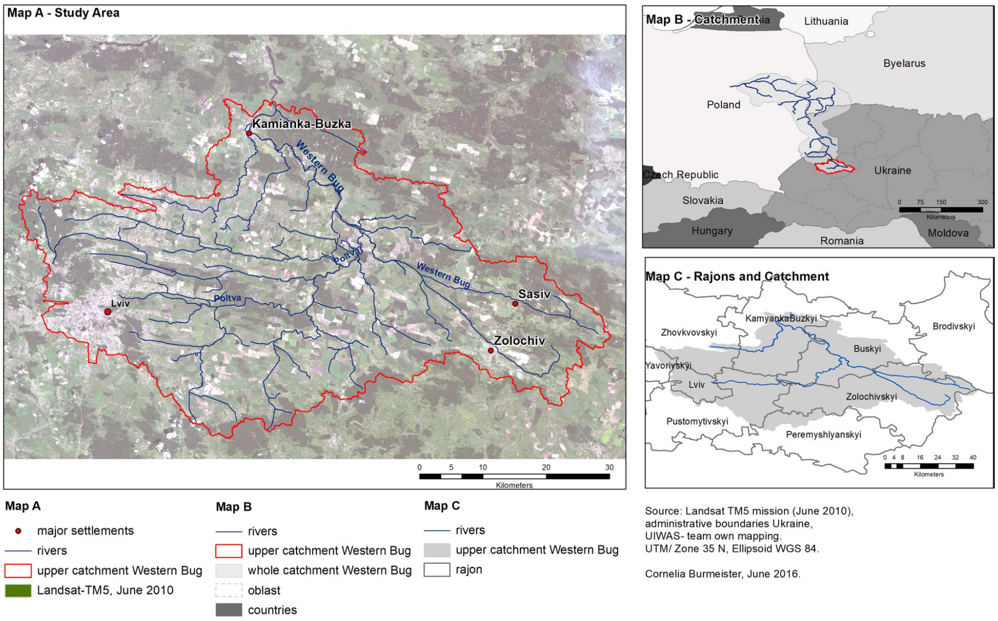
Step 1: Definition of the scenario context

The future LCC up to 2025 was investigated for the upper part of the river catchment of the Western Bug, which is situated in the West of Ukraine (see Fig. 2).

The Western Bug rises in the Podolian Highlands and flows, via Belarus, to Poland to the Narew River, which flows into the Vistula River, which ends in the Baltic Sea. In this study, the upper catchment of the Western Bug was analysed up to the gauge of Dobrotvir. The catchment is characterised by arable land (AL 2010: 44.3%), grassland (GL 2010: 23.5%), broad-leaved and coniferous forest (BLF and CF 2010: 13.9%), and dense settlements (artificial surface (AS), 2010: 13.2%). The regional capital Lviv, in the Western part with around 734,000 inhabitants, has a strong influence on the region in terms of supply, job opportunities, university education, cultural opportunities, etc. The catchment's pollution (microbiological, heavy metals) originates from the main tributary of the Poltva in the upper part of the catchment, which carries the wastewater discharge of the regional capital Lviv. Additionally, diffuse and point sources caused by agriculture and mining activities are identified (Blumensaat et al. 2012; Ertel et al. 2011; Tavares Wahren et al. 2012). The water quality is still poor, and for the Poltva river it is even worse than 20 years ago (Tavares Wahren et al. 2012).

The LCC from the past (1989–2010) shows a high dynamic (LC is understood as the directly detectable biophysical condition of the Earth's surface; LCC is the change of LC in the past from one category into another). The analysed LCC reveals that there are different developments, e.g. for AL. On the one site, there is the subsistence farming around the rural settlements where a circle of private land plots evolved after 1990, after the political breakdown of the communist system took place and Ukraine became a free market economy. The subsistence farming is based on the privatisation of former kolkhozes farms because every kolkhozes member got an equal plot of the AL, but the location was not defined. So, people drew the outlines of their plots close to their homes. On another site, there are large agricultural enterprises which cultivate huge plots with the newest available technology, like GPS-guided tractors. The changes of AL also caused changes in the fertilisation practices, as Tavares Wahren et al. (2012) showed, and with that a changed pollution for the Bug catchment. The livestock and cattle breeding declined after the breakdown in 1990 (political system change), which is also visible in the changes of GL because fewer pastures were needed.

Another important issue is the political and institutional framework in Ukraine, because it has spatial influence, for example, on management practices in river catchments. The political conditions may change abruptly, and that is crucial to keep that in mind for this investigation. Laws and regulatory instruments exist for a variety of protection subjects, such as riparian zones, green spaces, or forests, to protect the environments which have a positive influence on the water quality. Regulations also exist for the agricultural market, e.g. the Land Code. However, these regulations often contradict each other, and it lacks enforcement by state (Riabchuk 2008; Kuzio 2011; Kudelia 2012).



Source: Landsat TM5 mission (June 2010),
administrative boundaries Ukraine,
UIWAS- team own mapping.
UTM/ Zone 35 N, Ellipsoid WGS 84.

Cornelia Burmeister, June 2016.

Fig. 2 Study area of the Upper Western Bug River catchment

Step 2: Identification of spatial and dynamic drivers for lcc

Retrospective change detection for the identification of spatial drivers of LCC

The detailed analysis on *systematic* LCC revealed the following transition rules (transition pathways) (Burmeister and Schanze 2016):

- New AS is mostly developing on GL and not on AL (e.g. in Germany) because AL is quite strictly protected.
- AL is *not* transformed into forest; it is the LC category GL which develops, through succession, into forest.
- Both forest classes, BLF and CF, have decreased since 1989 and an interchange between the classes has been identified. (Because the forest areas are not that big in the study region, this is not a general trend for Ukrainian forests.)
- The high interchange of AL and GL is important due to location and fertility issues.

Change detection between 1989, 2000 and 2010 is seen in Table 2. LC category AS, consisting of urban areas and infrastructure such as roads, increased during the two decades. This is mostly due to the building of new roads or new built-up areas for housing.

Table 2 shows almost no change in the LC category AL, considering the total yearly rates. Only the swap of this category with over 16% shows the high dynamic. The LCC analysis of systematic changes revealed that there is an exchange of GL with AL, and vice versa. This can again be found in the high swap numbers (16 to 17%) of the GL category.

Literature review for the identification of potential dynamic drivers of LCC

First of all, a comprehensive literature review was undertaken which deals with LCC (see "Statistical Analysis for the Identification of dynamic and spatial drivers of LCC" section).

The driver analyses of other studies lead to a first selection of drivers and the a priori hypotheses of dependencies are defined (see Table 3).

Statistical analysis for the identification of spatial and dynamic drivers and expert identification of complementary drivers

The literature review and data availability delivered the drivers for statistical testing (cf. "Statistical analysis for the

Table 2 Results of the LCC between 1989, 2000, and 2010 for the Upper Western Bug River catchment

				1989–2000				2000–2010			
LC	1989 (%)	2000 (%)	2010 (%)	Persistence (%)	Gross gain (%)	Gross loss (%)	Swap (%)	Persistence (%)	Gross gain (%)	Gross loss (%)	Swap (%)
AS	10.7	11.3	13.3	9.2	2.1	1.5	3.0	10.7	2.5	0.6	1.2
AL	47.2	47.2	44.3	39.0	8.2	8.2	16.4	36.0	8.3	11.2	16.6
BLF	15.0	17.0	13.9	13.7	3.4	1.4	2.7	12.5	1.4	4.5	2.7
CF	5.1	4.3	4.8	3.2	1.1	1.9	2.1	3.1	1.7	1.2	2.3
GL	20.6	19.9	23.5	11.5	8.4	9.1	16.8	11.3	12.1	8.6	17.1
WB	0.1	0.3	0.3	0.1	0.2	0.0	0.1	0.2	0.1	0.1	0.2

AS artificial surface, *AL* arable land, *BLF* broad-leaved forest, *CF* coniferous forest, *GL* grassland, *PB* peat bogs, *WB* water bodies

identification of dynamic and spatial drivers of LCC" and Table 3).

Table 4 presents the analysis of the *spatial drivers*, showing the significance of the distance for environmental drivers (hence the usage of the phrase "up to"), Table 5 shows the results of the linear regression (dynamic drivers), and Table 6 presents the drivers that were identified by the experts. Here, the E (= expert) plus a number stands for the person who was interviewed.

The positive (+) dependency between the *LC category AS* and the gross production of agricultural plants reveals that when the settlement and infrastructure areas are growing, the production of food and fodder will grow as well (Table 5). This also fits to the basic hypothesis of the dependency. It can be explained that growing settlements are almost characterised by an increase in the population, which needs more food. The variable is able to explain 0.62 of the variance of the change of AS, which is very good. The founded negative dependency (−) of urban population on the development of AS does not fit the expected gradient and is therefore neglected. One possible explanation could be that the area of AS is not growing when the population increases, because new houses and flats are built as multi-storey houses, also as well as on brownfields (expert 1 and 6, Table 6)—but this is not a probable planning practise. The expert interviews (E, and an additional number for one person) revealed the driving forces for AS as: the economic development (Table 6: E1, E6, and E7), population development, and as well the spatial planning policies (E1 and E6).

Additionally, the impact of the regional capital Lviv was stressed and named by a 30-km zone around Lviv, which represents the suburbanisation belt containing strong development (Table 6). This is also supported by the spatial analysis that a positive development within 8 km of Lviv was found (Table 4, GL − > AS). Moreover, the distance to roads and settlements also has a positive impact on the growth of AS (same table). The negative effect within 50 m of the Western Bug shows its poor suitability for buildings and reflects the protection law for riparian zones.

As was expected before testing, the positive dependency of the population development with AL shows an increase in demand for agricultural area when the population is growing (Table 5). The negative dependency with GL fits as well: for a higher demand of AL, GL is used and is put back into the crop management cycle. The strong significance of this variable shows the importance of explaining the LCC for GL (Table 5, adj. R^2 0.69) and for AL (Table 5, adj. R^2 0.45). This also shows the interdependencies of AL and GL in the Western Bug catchment.

The driver "number of villages" also shows a significant dependency on AL, with a high R^2 of > 0.6. It shows that the villages and their inhabitants actively cultivate fields. This also fits to the evolved subsistence belts around

Table 3 Selection of drivers with expected dependencies (gradient±) for the Upper Western Bug River catchment

Driver	Variables	Expected dependency to a changing LC category	Years	Source[a]	Available*	Driver for*
Economic	GDP	AS (+)		HUSuLO	n	P
	Unemployment rate	AS (−)		HUSuLO	n	P
	Salary	AS (+), AL(AL (+), GL(GL (−), BLF(BLF (−), CF(CF (−)	2002, 2009	HUSuLO	y	P
	Distance to infrastructure (roads)	AS (−), AL(AL (−)		LC 2010, OSM	y	A
	Volume of production and services	AS (+), AL(AL (+), GL(GL (−)	2001, 2009	HUSuLO	y	P
	Agricultural production volume (gross production of agricultural plants and livestock)	AL (+), GL (−), BLF/CF(CF (−)	2000, 2009	HUSuLO	y	P
	Financial results of selected agricultural products: gross production of agricultural plants and livestock, and financial results of the production of crops, winter wheat, of production of milk, of production of beef, of production ofand pork	AL (+), GL(GL (−), BLF/CF(CF (−)	2000, 2009	HUSuLO	y	P
Technology	Productivity	AS (+), AL(AL (−), BLF/CF(CF (−), GL(GL (+)		HUSuLO	n	P
	Number of tractors	AL (+), GL(GL (−)	2000, 2009	HUSuLO	y	P
	Number of harvesters	AL (+), GL(GL (−)	2000, 2009	HUSuLO	y	P
Demographic	Population development	AS (+), AL(AL (+), GL(GL (−)	1989, 2001[c], 2009	HUSuLO	y	P
	Distribution of urban and rural population	AS (+), AL(AL (+), GL(GL (−)	2010	HUSuLO	y	P
	Number of villages	AS (+), AL(AL (+), BLF/CF(CF (−), GL(GL (−)	2010	LC2010	y	A
	Number of urban settlements	AS (+), AL(AL (+),BLF), BLF/CF(CF (−), GL(GL (−)	2010	LC2010	y	A
Environmental	Elevation	AL (−), GL(GL (+), BLF/CF(CF (+)	2012	SRTM90-DEM, 30 m × 30 m	y	A
	Slope (derived from elevation)	AL (−), GL(GL (+), BLF/CF(CF (+)	2012	SRTM90-DEM 30m × 30m	y	A
	Distance to groundwater table	AL (+), GL(GL (−)			n	A
	Soil 1:200,000	AL (+), GL(GL (−), BLF/CF(CF (−)	2012	Wahren et al. (2012)	y	A
	Distance to Lviv	AS (−), AL(AL (−), GL(GL (+), BLF/CF(CF (+)	2010	LC2010	y	A
	Distance to settlements	AS (−), AL(AL (−), GL(GL (+), BLF(BLF (+), CF(CF (+)	2010	LC2010,	y	A
	Distance to stream network	AS (−), AL(AL (−), GL(GL (+), BLF(BLF (+), CF(CF (+)	2013	Helm (2012)	y	A

[a] *HUSuLO* Holovne Upravlinnia Statystyky u Lvivskiy Oblasti (Main Department of Statistics in Lviv Oblast), *LC2010* Land cover from 2010 (own calculations, cf: Burmeister and Schanze (2016), *OSM Open Street Map*, *SRTM90-DEM* Shuttle Radar Topography Mission

**y* yes, *n* no, *c* census data, *P* projection, *A* allocation

Table 4 Results of the analysis of the drivers. Results of the spatial drivers for allocation. Only systematic LCC are considered (cf. 2.2.1 and "Retrospective change detection for the identificati" sections)

Target LC →	To AS	To AL	To BLF		To CF		To GL		
Transition →	GL- > AS	GL- > AL	GL- > BLF	CF- > BLF	BLF- > CF	GL- > CF	AL- > GL	BLF - > GL	CF - > GL
Spatial Drivers ↓									
Distance to Lviv	+ *Up to 8 km*	– Up to 6 km	+ < 6 km	+ Up to 2 km	– Up to 24 km	– Up to 5 km, 10 till up to 26 km	No effect	– 5 Up to 19 km	– Up to 20 km
Distance to settlements	+ *Up to 400 m*	– Up to 100 m	+ > 3.5 km	No effect	No effect	+ > 3.5 Up to 5.5 km	+ 4.7 Up to 5.3 km – 6.6 Up to 6.8 km	– 7 Up to 7.5 km	No effect
Distance to streams	+ > 6.7 Up to 7.2 km	No effect	– > 4.1 Up to 6.7	– < 100 m	No effect	No effect	+ > 6.2 km	No effect	No effect
Distance to Western Bug	– *Up to 50 m*	*Slightly –up to 400 m*	No effect	+ > 1.4 Up to 2.9 km	No effect	No effect	+ < *100 m*	No effect	–
Distance to major roads	Slightly + up to 1 km	+ Up to 50 m							
Distance to roads	+ *Up to 150 m,* *– > 1 km*	Slightly + up to 50 m	– 9.4 Up to 9.7 km	No effect	– > 9.5 – 11.7 km + > 12.6 km	No effect	+ > 9 km	No effect	No effect
Slope	No effect	No effect	+ Steep slopes	No effect	– Steep slopes	No effect	No effect	No effect	No effect
Elevation			<100 and > 200 m +	No effect	200 up to 2300 m -	No effect	+ < 100 and > 200 m	– < 100 m	No effect
Soil[a]	– FHI, HG	– BS, + CCZ	– CZ	– CCZ, CZ, EAR, RPH; + HA	+ BS, CZ, EAR, GRAR	– ChCZ, FHI, GLPH + BS, GRAR, RPH;	+ BS, FHI	+ CCZ, FHI	– BS
Biotic yield	No effect	– *Low fertility*	+ *Low/medium fertility*	+ Medium fertility	– Less fertility	+ *Low/ medium fertility*	+ *Less fertility*	– Low fertility	– *Low/ medium fertility*

Italics highlighted dependencies are expected

BS bare soil, *CZ* chernozem, *CCZ* calcic chernozem, *ChCZ* chronic czernozem, *EAR* endogleyic arenosol, *FHI* fibric histosol, *GLPH* gleyic phaeozem, *GRAR* greyic arenosol, *HA* haplic albeluvisol, *HG* histic gleysol, *RPH* rendzic phaeozem

Categorical variable, no distance measures possible. + means positive dependency; – means negative dependency

the villages, which can be seen on satellite images. Additionally, this process is also confirmed (validated) in the interviews. Another reason for the evolving subsistence belt around the villages is the non-functioning land market (Table 6: E9, E12, Land Code 2001). The spatial drivers "distance to settlements and roads" support this as well (Table 4). The spatial variable "slope" has no effect on the change AL ↔ GL, as it was expected before (again, Table 4). The experts assessed steep slopes (> 12%) for reforestation (Table 6).

The negative dependency of the "production of pork" on AL is hard to explain (see Table 5), because the intuitive thinking would be that an increasing production of pork meat needs more fodder, which is cultivated on AL (Note: AL consists also of pasture grounds). The same logic stands for the financial production of milk with cattle feeding. Here, the sample is too small to identify this as a driver for the AL change in the Western Bug river catchment.

Another significant dependency was detected between the changing salaries and AL, but the basic hypothesis does not fit the founded observed gradient of the dependency (see Table 5). Initially, the dependency was understood as: the salary increases so the need for AL increases, because the people can afford to buy more food and to give up subsistence farming. However, the statistical analysis showed the opposite. A possible interpretation is that a rising salary leads to the usage of less AL because the people can afford to buy *international* products and not only products from the regional market, so that the area of AL shrinks. The adjusted R^2 is rather low with at 0.33, so that this dependency is at least not used for the projection (see Table 5).

Table 5 Results of the analysis of the drivers

	Statistical drivers	Artificial surface	Arable land	Broad-leaved forest	Coniferous forest	Grassland
Economic	Number of harvesters					
	Number of tractors					
	Gross production of agriculture plants	**0.67 | 0.62* + | +**				
	Gross production of livestock					0.48 | 0.38– | +
	Financial results of production of crop					
	Financial results of production of winter wheat	0.8 | 0.76*+ | –				
	Financial results of production of milk		0.47 | 0.37+ | –			
	Financial results of production of beef					
	Financial results of production of pork		0.58 | 0.51*+ | –			
	Volume of production and services					
	Salary		0.4 | 0.33+ | –			0.37 | 0.28.- | +
Demographic	Population		**0.52 | 0.45* + | +**			**0.73 | 0.69**– | –**
	Urban population	**0.53|0.47*+|–**				
	Rural population					
	Number of urban settlements (2010)[a]					
	Number of villages (2010)[a]		**0.65|0.6** +|+**	0.54|0.47*–|+		
	Distance to Lviv[1]			0.86 | 0.84*** + | -	**0.4 | 0.32. + | +**	**0.35 | 0.25.+ | +**

Results of the regression analysis showing goodness of fit (R^2 | adjR^2), the significance value and the expected vs. observed gradient (exp. grad | obs. grad) for the study site Upper Western Bug River catchment

First row in the column shows the R^2 | adjusted R^2; second row opposes the exp. grad | obs. grad

AdjR^2 adjusted R^2, *exp. Grad* expected gradient, *obs. grad* observed gradient; bold fields indicate a congruence of the expected gradient (hypothesis) and observed gradient; fields without bold indicate a non-congruence. Empty fields = no significance value within the threshold ≤ 0.05; [a]variable does not present change

Significant codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "."

The result of the expert interviews reveals as drivers: the protection of the green spaces and the riparian protection zones, which have an influence on AL. Expert 5 named the Haplic Albeluvisol and Czernozem types as the best soils for AL and GL (see Table 6, E5) within the Western Bug catchment.

The LC category *BLF* shows a dependency (Table 5) on the "distance to Lviv" and "number of villages" (static drivers). The expected gradient does not fit the observed gradient. CF also shows a dependency towards the "distance to Lviv". Here, the gradient of the dependency fits the basic hypothesis (Table 5). The spatial analysis (Table 4) showed that within a short "distance to Lviv", a change towards BLF is fostered, whereas for CF it is discouraged. The influence of "distance of settlements" on BLF and CF growth is identified as well, but only at shorter distances (Table 5). The impact of Lviv shown here means that the forest areas are probably well protected around Lviv, e.g. for recreation purposes. This is also stressed in the expert answers for protection of green spaces and forests for BLF/CF. The analysis of the biotic yield layer confirms the hypothesis of giving up low to medium fertility locations in favour of the forest categories (succession).

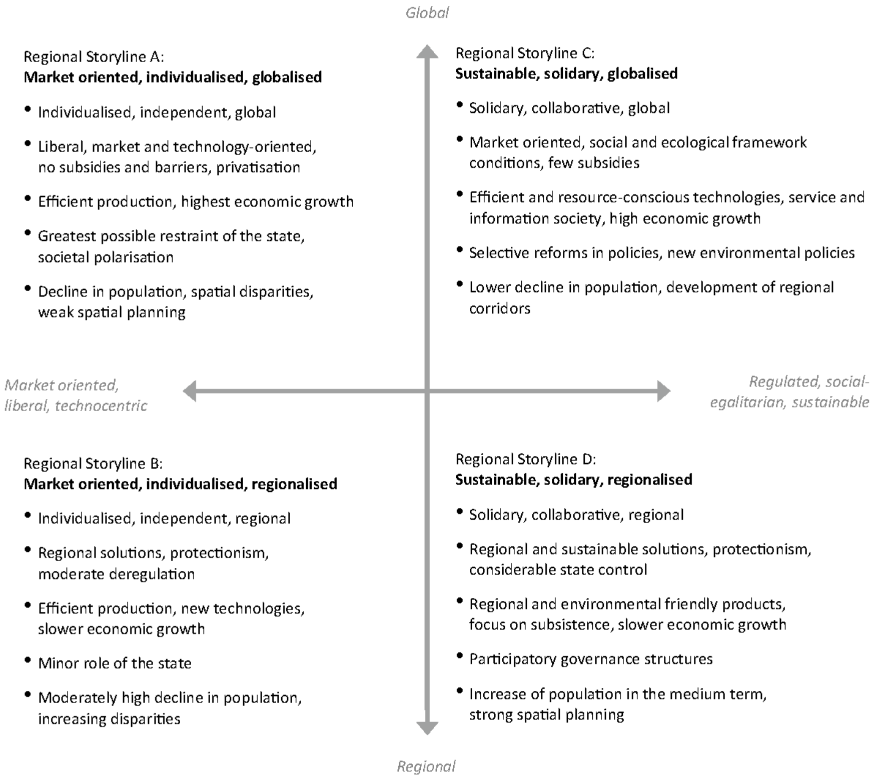
The natural *GL* change shows relations (Table 5) with the population change with a high significance, and with the "distance of Lviv" with a low adj R^2 of 0.25. The dependency between the salary development and the production of livestock does not fit into the basic hypothesises and is therefore disregarded.

The hypothesis that low-fertile AL is changed into GL is confirmed by the spatial analysis of the biotic yield layer (Table 4). Also, within close distances of the Western Bug (< 100 m) the change of AL into GL is supported.

Table 6 Results of the analysis of the drivers. C: identification of drivers by experts for the Upper Western Bug River catchment

Experts' drivers	AS	AL	BLF	CF	GL
Economic development	Jobs, settlement of companies (E1, E6, E7)	Increase in productivity of farmers/intensification of agriculture (E8)			
Population development	E1, E6, E7				
Spatial policies	Land development plans (E1, E6)	Law for land market, Land Code (E9)			
Protection of green spaces and forests with buffer zones	Restrictions E2, E5	Restrictions E2, E5	Restrictions E2, clear cutting corresponds to new planting (E5)	Restrictions E2, clear cutting corresponds to new planting (E5)	Restrictions E2, E5
River and riparian protection zones		25 m, 50 m, 100 m; Water Code (E3)	25 m, 50 m, 100 m; Water Code (E3)	25 m, 50 m, 100 m; Water Code (E3)	25 m, 50 m, 100 m; Water Code (E3)
Slope			Reforestation of areas with steep slopes (E5), > 12% (E7)	Reforestation of areas with steep slopes (E5), > 12% (E7)	>12% (E7)
Soils		Haplic Albeluvisol, Czernozem (E5)	Areas with high soil erosion reforested (E5), sandy soils reforested (E9)	Areas with high soil erosion reforested (E5), sandy soils reforested (E9)	
Impact of regional capital Lviv	For suburban belt 30 km, no regulation for suburbanisation (E1)				

E expert



Regional Storyline A:
Market oriented, individualised, globalised

- Individualised, independent, global
- Liberal, market and technology-oriented, no subsidies and barriers, privatisation
- Efficient production, highest economic growth
- Greatest possible restraint of the state, societal polarisation
- Decline in population, spatial disparities, weak spatial planning

Regional Storyline C:
Sustainable, solidary, globalised

- Solidary, collaborative, global
- Market oriented, social and ecological framework conditions, few subsidies
- Efficient and resource-conscious technologies, service and information society, high economic growth
- Selective reforms in policies, new environmental policies
- Lower decline in population, development of regional corridors

Regional Storyline B:
Market oriented, individualised, regionalised

- Individualised, independent, regional
- Regional solutions, protectionism, moderate deregulation
- Efficient production, new technologies, slower economic growth
- Minor role of the state
- Moderately high decline in population, increasing disparities

Regional Storyline D:
Sustainable, solidary, regionalised

- Solidary, collaborative, regional
- Regional and sustainable solutions, protectionism, considerable state control
- Regional and environmental friendly products, focus on subsistence, slower economic growth
- Participatory governance structures
- Increase of population in the medium term, strong spatial planning

Fig. 3 Storylines for regional change in the study region. *Source* Schanze et al. (2012)

The analyses showed a variety of driving forces for the LCC in the Western Bug River catchment. The same driving forces are confirmed (population development, soil fertilities/biotic yield, slope) through different methods. Other driving forces are not confirmed, e.g. “production of pork or livestock” for GL or the influence of salary. These different results lead to a validated drivers base for projection of LCC.

As for economic variables, the GDP was identified in the literature review process and through the expert interviews. The regression analysis indirectly supports this choice because other economic variables like the “financial results of different agricultural products” show a dependency on AS and AL. It is hard to estimate the development of several “agricultural production volumes” or the “financial results of agricultural products” for the future. Therefore, GDP is chosen as a main driver for expert quantification, because it is more generic and easier to handle. Climate change has not been treated as a driver of LCC in this study. According research could not be realised for the Upper Western Bug River catchment. However, direct climate change impacts on the water balance have been extensively addressed by complementary studies for the region (e.g. Pavlik et al. 2011) and jointly considered with the impacts of LCC (see Schanze et al. 2012).

Step 3: Scenario formulation and projection of drivers

Storylines of regional change

The past development of the Ukraine was and is so uncertain and unsteady that a more general description of the storylines is favoured in this study (cf. Fig. 3). The storylines are further detailed for the future developments with qualitative phrases like negative, weak, moderate, or strong (see Table 7).

Table 7 Drivers under scenarios A to D for the Upper Western Bug River catchment

	Storyline A	Storyline B	Storyline C	Storyline D
Principle characteristics	Market oriented, individualised, globalised	Market oriented, individualised, regionalised	Sustainable, solidarity, globalised	Sustainable, solidarity, regionalised
Economy				
GDP (%/years)	Strong	Strong	Moderate	Weak
Expert 1				
Expert 2	6 to 10%	6 to 10%	3 to 6%	0 to 3%
Expert 3	9 to 12%	9 to 12%	6 to 9%	1%
Average	9.25%	7.5%*	6%	1.25%
Society/demography				
Population development [%/years]	Decrease	Decrease	Stagnant	Stagnant to weak increase
Expert 1	− 1.1 to − 0.5%	− 1.1 to − 0.5%	0%	0 to 0.2%
Expert 2	− 0.2 to − 0.5%	− 0.2 to − 0.5%	− 0.2 to 0%	0%
Expert 3	− 0.5%	− 0.5%	0%	0.2%
Average	− 0.55%	− 0.55%	− 0.1%	+0.1%

*Reduction in the average of the deviation of experts 2 and 3

Projections of dynamic drivers of future LCC by experts

Table 7 shows the quantification of the dynamic drivers identified by the experts.

The assessments of the driver demographic development are very similar between the experts. The numbering of the driver “GDP” delivered a broader range between two experts; the third expert declined to quantify the GDP. The storyline B shows a strong economic growth, but lower than in scenario A. That is why the average quantification of the experts is reduced by the average deviation and leads to 7.5% for scenario B.

Step 4: LCC scenario analysis

The LCC scenario analysis consists of three steps: (1) suitability maps, (2) demand rates for future development, and the (3) projection of LCC.

The calibration and validation of the scenario approach was achieved through the involvement of experts in different stages in the process. Known results such as the transition rules, which were deduced from the systematic LCC, were validated by the experts. Additional information on thresholds and knowledge for the LCC process, as well as the identification of additional drivers and the quantification of the future development, belong to the scenario calibration.

Suitable areas for future LCC allocation

The LCC transition rules (see "Retrospective change detection for the identificati" section on of spatial drivers of LCC") are used as a starting point for the development of future suitability maps. The rules present the systematic changes, but not all observed changes (Burmeister and Schanze 2016). They are enriched with the information of the spatial driving force analysis (see 3.2.3 and Table 4), the experts’ answers (cf. Table 6) and available planning documents. As a result, future suitability maps for each LC category are developed (cf. Table 8).

Assignment of demand rates to LC categories

Artificial surface

The demand for future settlement area is calculated via the relation of GDP as an economic driver and population as a demographic driver towards the settlement area.

Equation 1

$$A_F = \sum_{n=1}^{2} \frac{(E_{F_n} \times F_n \times t)}{2} \tag{1}$$

with n = GDP, population

Equation 2

$$\text{whereat } F_{\text{n}} = \frac{A_{\text{P}}}{E_{\text{Pn}}}, \tag{2}$$

where A_{F} is AS in the future, E_{Fn} the experts’ quantification of the future development of n (GDP or population), F_{n} the factor of n, t the future time horizon, A_{P} the past development of AS, and E_{Pn} the past development of GDP and of the population in 1 year.

Table 8 Derivation of future suitability maps of LCC presenting the transition pathways and rules, data, and resulting map for the Upper Western Bug River catchment

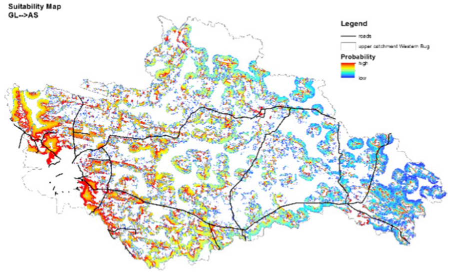
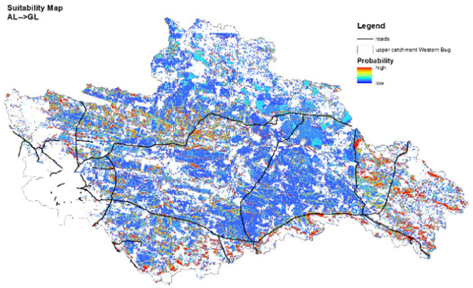
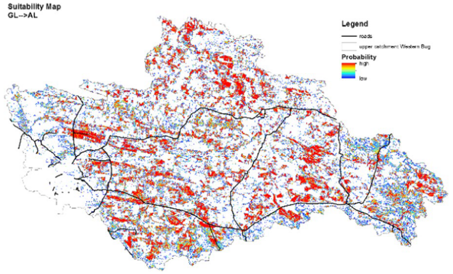
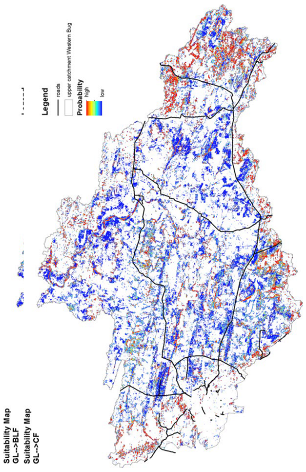
→To Class	From class with transition rule and GIS algorithms	Data	Suitability Map Legend: blue (low) up to red (high) suitability
AS develops on…	GL and not on BLF/CF or AL Within the vicinity of settlements and roads (different functionalities/sizes of cities refer to different buffer distances) Mainly in the suburban region of Lviv, the closer to Lviv the more GL change into AS Not in riparian zones (buffer of distances) Not on fertile soils with GL	LC data, rivers, soils, biotic yield	
GL develops on…	Less fertile AL In areas with declination of > 12% -On flood plains (buffer distances)	LC data, SRTM-DEM, soil data, biotic yield, rivers	
AL develops on…	GL, not on AS Areas with a declination of < 12% Not in flood plains On more fertile soils (Chernozem, Gleysoils)	LC data, SRTM-DEM, soil data, biotic yield, rivers	

Table 8 (continued)

→To Class	From class with transition rule and GIS algorithms	Data	Suitability Map Legend: blue (low) up to red (high) suitability
BLF/CF develops on…	GL, not on AL In areas, with declination of > 12%, and on less fertile soils and sandy soils In the vicinity of existing forests Within forests in clearings Exchange of forest types (from/to BLF and CF) On flood plains For BLF: Higher BLF development if areas are closer to Lviv	LC data, SRTM-DEM, soil data, biotic yield	

Based on change detection and expert interviews

To bring the two developments of future GDP and future population together, a share of each has to be calculated. For that, the former developments of these are put into relation to the LCC. As example for scenario A, in the decade 2000 to 2010, AS increased by 0.19%/years; GDP increased by a mean of 4.7%/years, and population decreased by a mean of − 0.7%/years. These numbers were used to calculate the factor using Eq. 2: F_{GDP} is 0.04 and $F_{\mathrm{population}}$ is 0.27. With that, the future development rate A_F using Eq. 1 for scenario A based on GDP is calculated to be 5.61% (= 9.25%/years × 0.04 × 15 years) and based on population it is calculated to be 2.24% (= − 0.55%/years × − 0.27 × 15 years). The average of both is 3.92%.

Using Eqs. 1 and 2 and the experts' quantification, the future AS resulted in a growth of 3.9% for scenario A, 3.4% for scenario B, 2.0% for scenario C, and 0.2% for scenario D.

Arable land and grassland

The calculation of the demand rates for the LC categories AL and GL is conducted via the calculated regression function with the future demographic development. The driving force demographic change has, with LCC, a positive dependency for AL and a negative dependency for GL. First, the projection of the population for the year 2025 for each scenario was calculated with the mean rates of the expert assessments. Afterwards, the regression formula is used and results in the future rates of AL: A and B are − 2.9%, C is 0.4% and D is 1.9% until the year 2025, and for GL: A and B are 2.3%, for C is − 1.8%, and for scenario D the rate is − 3.7%.

To ensure that the changes are balanced in the end, the LC category GL is used to include all changes. After balancing the demand rates, the rates changed for GL for scenario A by − 0.3% and for B by 0.2%, for C by − 2.4% and for the scenario D by − 5.7%.

Broad-leaved forest, coniferous forest

The analysis of potential drivers for LCC (see subsection 3.2.3) showed a dependency on the static variable "distance to Lviv" (Table 5). This is implemented in the suitability maps. The demand rates are estimated using the drivers of the experts (Table 6) and the literature.

In the storylines, the environmental state for scenario A and B is described with a decline, and the economic growth is strong (cf. Fig. 3). This will also lead to a decline in the amount of forest. It is assumed that the change is similar to the former development (change between 1989 and 2010 of − 1.4%) and will continue with weaker development in the future. A rate of − 1% for both forest categories is assigned to scenario A and B.

The interview with expert no. 5 (Table 6, E5) revealed that there is a law for economically used forest, where the rate of clear cutting should be the same as the amount of afforestation. This assumption is passed to scenario C with 0% change of forest in the future.

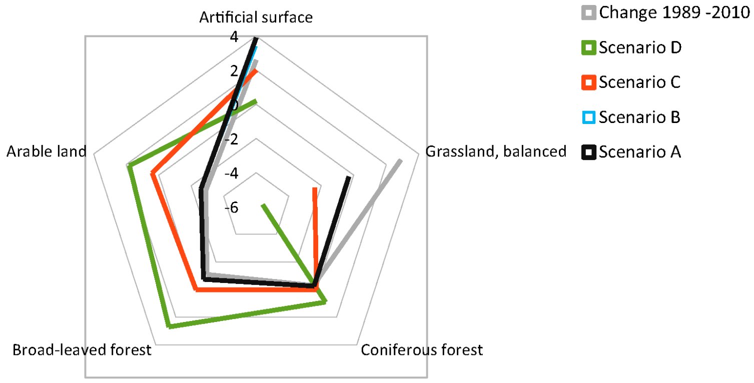
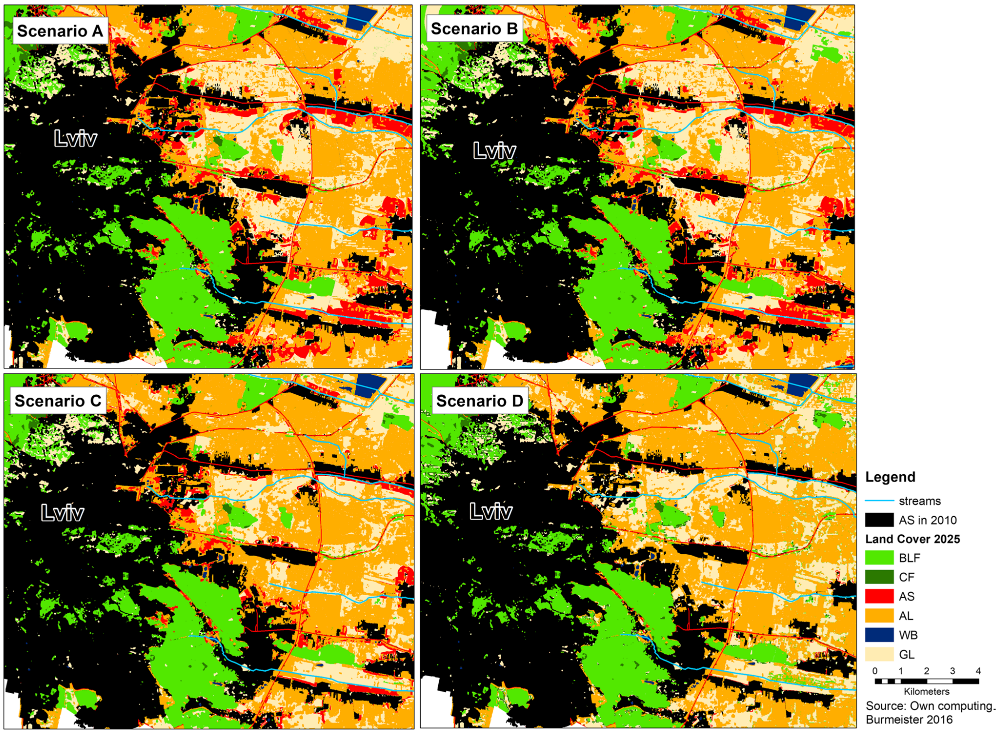


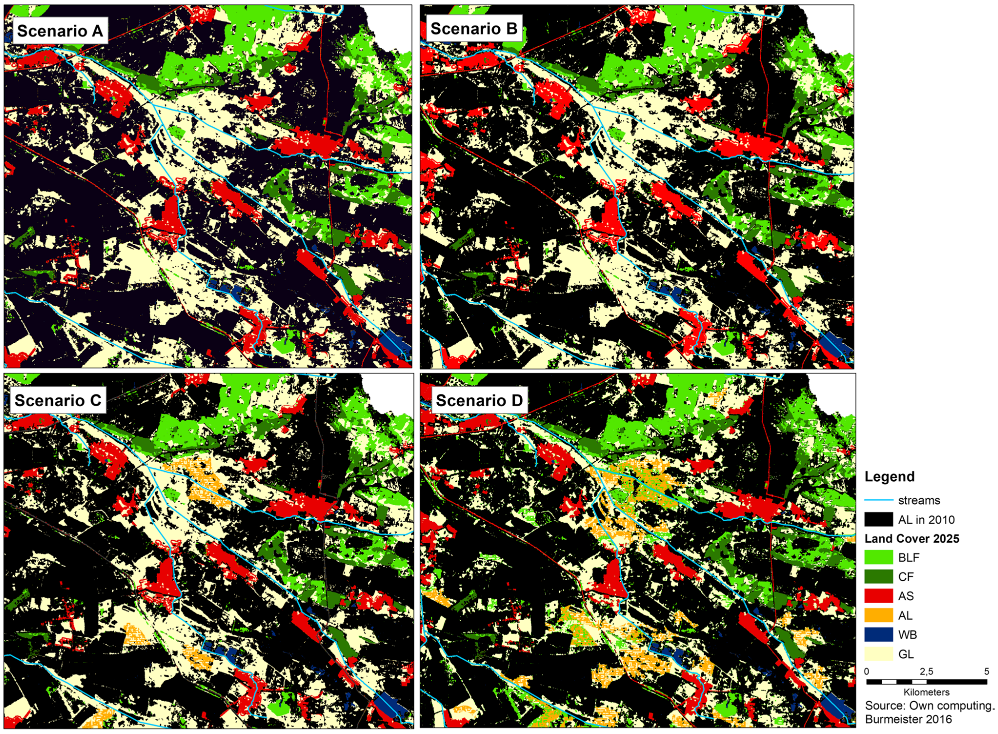
Fig. 4 Demand rates for all LC categories and scenarios A to D between 2010 and 2025 for the Upper Western Bug River catchment

Scenario D is the most sustainable scenario; therefore, a growth of forest is expected. This fits to the answers of the expert no. 5 (Table 6, E5) who estimated an optimal forest cover for the Ukraine. The global forest LCC showed that the amount of forest in Europe was growing between 1990 till and 2000 with at a rate of 0.46% per year, and from 2000 till



Source: Own computing.
Burmeister 2016

Fig. 5 Projections A–D of LCC in 2025 for the Upper Western Bug River catchment, surrounding Lviv. Focus AS



Source: Own computing. Burmeister 2016

Fig. 6 Projections A–D of LCC in 2025 for the south-east Upper Western Bug River catchment—rural areas. Focus AL

to 2010 the annual growth rate was around 0.36% (Lindquist et al. 2012). That is why a rate of 0.24%/years (3.6% until 2025) is set for scenario D (Fig. 4).

Projections of future LC

The demand rates are applied to the suitability maps. The results are shown in Fig. 5 (surroundings of Lviv) and Fig. 6 (rural part in the south-east of the catchment). In Fig. 5, the AS from 2010 is shown in black and new AS (in 2025) is coloured red. Scenarios A and B are the scenarios with the highest growth of AS in comparison with C and D (cf. previous subsection). AS is growing mostly in the fringes of Lviv, e.g. the north-east. It also grows close to roads and other settlements, as determined by the transition rules. In scenario C and D, AL (orange) grows, especially on GL (light colour, see also Fig. 6). In scenario D, the forest categories grow mostly in the north-west and south-east of Lviv (cf. Fig. 6, lower right).

This is also seen in Fig. 6 where AL in 2010 is shown in black, and where the new AL (coloured orange) is accompanied by new BLF/CF patches (light and dark green) which present a multi-structured agricultural area. This can particularly be found in scenario D. AL is mixed with BLF patches, which is sustainable with regard to wind erosion and biodiversity.

Discussion and conclusions

This study shows how quantitative and qualitative methods are combined in an IWRM project to calculate future LCC (cf. Fig. 1). This approach offers one way to answer the first research question: How can the urban and rural LCC of river catchments be consistently projected in the future?

For an IWRM study, it is crucial to consider not only urban, but also rural LCC, because different pollution sources play an important role, as Tavares Wahren et al. (2012) and Blumensaat et al. (2012) have shown.

The sequence and the meshing of the methods helped to overcome the single methodological disadvantages such as mistakes in the classification procedure of the satellite images or change detection, mistakes in the statistical analyses, and a low number of experts. The involvement of regional experts from different hierarchical levels and thematic working fields validated the "desktop research" for the transition rules, the identification of the dynamic and spatial drivers, and LCC processes for Ukraine. This helped to close the knowledge and the data gaps for the study site—the data availability is not that good in the Ukraine. Additionally, catchment borders do not fit to administrative borders as, for example, statistics are only available for rayon level (second level of administrative division, like a district) and Hagemann et al. (2014) have discussed. The different scales of the catchment and administrative units are considered by using the rayon as the unit of investigation. The LCC was calculated for the rayon to fit to the statistics. Nevertheless, there remain scale problems, as seen in Fig. 2, Map C, because the catchment covers only part of the rayons.

The second research question is answered in Sect. 3.2.30: Which spatial and dynamic drivers of LCC can be identified for the Upper Western Bug River catchment? It is answered in Sect. 3.2.30; same drivers are verified by different methods, such as the impact of the regional capital Lviv, the distances of settlements and roads for LCC of AL and GL. The date of the available driver statistics differed. Only population statistics are available for 1989, and the others are only available from the year 2000 or even later. That is why not all changes from 1989 could be explained, but for this gap the expert interviews are used, as well as the analysis of the systematic LCC (cf. Burmeister and Schanze (2016)). Population and economic development are identified as dynamic drivers. Special location features, such as soil, slope, distances to infrastructure, and environmental laws like protection zones, are identified as spatial drivers. The results fit to the findings of other studies (cf. Table 3 and "Statistical Analysis for the Identification of dynamic and spatial Drivers of LCC" section). Baumann et al. (2011) found a dependency between the number of villages and the farmland abandonment. In this study, the number of villages per rayon can explain the change in agricultural land (positive relation) and as well the change in broad-leaved forest (negative relation). So, the findings of Baumann et al. (2011) fit to the here presented results.

The third research question, "What are plausible scenarios with projections of future LCC for this catchment considering both allocation and demand of LC types?" is answered with the application of the whole integrative approach and ultimately results in the end in the projection maps (Figs. 5 and 6).

The expert interviews also determined precise thresholds for e.g. the appropriate suitability of grassland and agricultural land. Additionally, transition rules and assumptions were validated. A general criticism concerning the expert interviews is the low number of involved experts for scenario quantification (three experts for demographic development, two experts for GDP development, and 12 experts are interviewed for the identification and validation of drivers). Nevertheless, the advantages of involving regional experts prevail. Pahl-Wostl (2008) described these advantages of involving stakeholders in scenario building as follows: "it ensures that the different perspectives are considered and, as possible users of the scenarios, it ensures a higher level of understanding and first of all acceptance of scenarios". Additionally, it is common to have a small sample when using qualitative methods—the contents of the expert answers are important. The questionnaires were produced with the knowledge of the results of the systematic LCC, so that the questions were purposeful and selective. As well, a validation of the LCC process and the transition rules was done by the expert interviews. The identified drivers were also known at this stage of the work. This is why the decision to ask only three experts to quantify future development was made. The independent expert answers of the quantification of the phrases, weak, strong, etc., showed the same understanding of the developments for Ukraine because the answers are so similar.

The differentiation between quantitative LCC development and its allocation in space shows good results. The future demand of every LC category is calculated with the identified specific method. The allocation algorithms of future LCC include not only the past trends (transition rules), but also the results of the driver analysis and, very importantly, the opinions of the experts.

For a successful IWRM, stakeholders have to be engaged in the process and have to be informed of the impacts of human actions on the environment, which are crucial for the water quality of a river catchment. These pictures of possible future states, based on reliable assumptions, may help to foster the awareness of these actions and what could be avoided and prevented in the Western Bug River catchment.

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