Land use change modelling in an urban region with simultaneous population growth and shrinkage including planning and governance feedbacks

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Dagmar Haase a, b

a Helmholtz-Centre for Environmental Research – UFZ, Department of Computational Landscape Ecology
b Humboldt-University Berlin, Institute of Geography
dagmar.haase@ufz.de

Abstract: In the EU-project PLUREL we develop scenarios for future land use development in European urban regions facing population growth or shrinkage. We combine the spatially explicit modelling work with a participatory approach to involve stakeholder knowledge on drivers and policy instruments to steer land use development. Our scenario technique aims at incorporating feedbacks from planning into land use modelling. For modelling land use futures and options of the urban region of Leipzig-Halle, Germany, the MOLAND cellular automata model was used. To integrate stakeholder knowledge into the functionality of MOLAND and, so doing, to develop locally adapted land use storylines was the major purpose of a respective 1-day scenario workshop with local experts and practitioners. First, MOLAND model results stimulated the discussion about both impacts and steering options of future land development. Second, three pre-defined storylines were transferred into maps in a planning game. Participants created future land use patterns, assessed their drivers and impacts and reflected the instruments they would use to steer such a land use development. The resulting maps and the new knowledge about steering instruments were again used to improve the MOLAND model setup for Leipzig-Halle. So doing, we can feed stakeholders’ expert knowledge into the modelling work. Overall, quite positive experiences concerning the potentials of such a transdisciplinary approach have been made.

Keywords: land use change model; urban region; stakeholder feedbacks.

1. INTRODUCTION

1.1 The challenge: Land use pressures in growing and shrinking urban regions

Urbanisation is one of the most complex and dynamic processes of landscape change. Although only about 4% of the world’s land area is urbanised and densely populated (Ramankutty et al., 2006), we claim “the millennium of the cities” since more than half of the currently 6.6 billion world population is living in urban areas (UN, 2007; Kasanko et al., 2006). Projections for the future show that urbanisation – in terms of an increasing share of population living in urban and peri-urban areas – is very likely to continue (Batty et al., 2003; EEA, 2006; Lutz, 2001). The ongoing urbanisation process and megacity region growth (Hall and Pain, 2006) affects migration and population allocation between regions in Europe depending on their access to existing growth poles which often ends up in urban growth and peri-urbanisation. This macro-trend may be explained by the fact that economies are increasingly concentrated in urban centres (Hall and Pain, 2006). Moreover, pre-existing settlement patterns are important constraining factors. In some parts of Europe, most notably in Central and Eastern European countries, the fundamental political and economic changes towards capitalism and the market-oriented system lead to a massive
increase in suburbanization and urban sprawl (Tosics, 2004). All in all, this means an increase of urban land, share of impervious surface and of transport infrastructure. However, also urban shrinkage is increasingly observed in the industrialized world and today, shrinkage represents another major challenge for a sustainable urban development in Central Eastern parts of the post-socialist Europe, the former Rust Belt in the US or Russia (Rieniets, 2009; Kabisch and Haase, 2009; Blanco et al., 2009). Shrinkage is understood primarily as the quantitative process of population decline in an area which might be the result of very different processes such as de-industrialisation or demographic change (Haase et al., 2010). Population decline leads to a decrease in population density and to an oversupply/underuse of urban residential and commercial land, infrastructure and services. In consequence, wide-spread housing vacancies and large brownfields come to pass (Haase et al., 2007). In Leipzig, Germany, where in the 1990ies more than 60,000 flats became vacant and nationally financed large-scale demolition actions took place, the term of land use perforation was created (Lütke-Daldrup, 2001). Perforation describes a scattered land use development in the (former very dense) inner parts of the city.

It comes clear that an accurate assessment of impacts of urban processes has to relate to both urban growth and shrinkage. Modelling tools are suitable to predict urban land use change and to get a better knowledge of the drivers behind one particular development (Haase and Schwarz, 2009). Regardless good progress in numerics and spatial representation there is still a big gap of integrating social science knowledge into urban land use modelling, particularly for the case of shrinkage (Schwarz et al., in press).

1.2 Land use change modelling in urban regions

As urban regions mostly are very densely populated and their land use components highly interlinked (Liu et al., 2007), developing views about their future is both a major concern in landscape research and a complex task. Modelling urban and peri-urban land use relationships helps to understand underlying drivers of land use change, to create future land use scenarios and assess possible environmental impacts (Lambin et al., 2006). A variety of land use change models, particularly for urban landscapes, already exist, ranging from specific case studies to generic tools for a variety of urban regions. These models differ largely in terms of their structure, their representation of both space and human decisions, and their methodological implementation (Haase and Schwarz, 2009). Compared to land use change models for rural landscapes, urban areas are shaped particularly by human activities, societal processes and human-environmental interactions (Couclelis, 1997).

In the EU-Project PLUREL we develop scenarios for future land use development in European urban regions facing population growth or shrinkage (Haase et al., 2009). So doing, we link the spatially explicit modelling with a participatory approach which involves stakeholders and their knowledge about drivers and policy instruments that are used to steer land use development. Our scenario technique aims at incorporating feedbacks from planning into land use modelling (Haase et al., 2009). For modelling land use options for the urban region of Leipzig-Halle, Germany, the MOLAND cellular automata model was applied. In order to adapt the pan-European scenario framework of PLUREL to the regional MOLAND application, stakeholder knowledge was indispensable to develop locally adapted land use future storylines. This was the major purpose of a respective 1-day scenario workshop with stakeholders, experts and practitioners (Haase et al., 2009).

1.3 Aim and structure of the Paper

The aim of this paper is to present a study where (1) a pan-European scenario framework and (2) the functionality of the MOLAND model were linked to (3) stakeholder knowledge in order to develop regionally adapted land use storylines and, respectively, to modify and to improve the MOLAND simulation by stakeholder input and feedback. So doing, in section 1 an introduction into the challenge of land use modelling in urban regions was given. In the second section, the methods are described, with the empirical case study (2.1), the MOLAND model introduction (2.2), the scenario framework (2.3), and the scenario workshop (2.4). The results and the feedback by the stakeholders are discussed in section 3 before the paper comes to some conclusions in section 4.
2. METHODS

2.1 Case study

For the coupled modelling-stakeholder-feedback study we use the test area of the urban region of Leipzig-Halle, Central Germany, which faces simultaneous population growth and decline. At a size of 4,390 km², the region has 1,073,000 inhabitants. On the whole, the region lost inhabitants since the 1970s, this was spurred by the political change in 1990 and subsequent de-industrialisation. The locally divergent population growth and shrinkage patterns have been accompanied by residential, commercial and infrastructure development. While the post-socialist transformation period with heavy urban sprawl has passed, moderate development in the peri-urban continues to the present-day (Couch et al., 2005). At the same time, considerable parts of the inner city faced a population outflow followed by residential vacancy, large urban brownfields and massive under-utilisation of urban infrastructure (Haase et al., 2007).

2.2 MOLAND model

MOLAND is a complex, computer based land use model, based on the Metronamica simulation software by RIKS, NL (http://www.riks.nl/products/Metronamica). MOLAND simulates land use change patterns for (in our case) 100x100m grid cells stratified into maximum 30 land use classes for time slices until 2025. Growth rates (land use pressures) are determined by statistical or expert based regional estimates using targets for the future, e.g. residential land use based on population growth scenarios where additional demands for residential land per capita are based on the new (future) population projections (Barredo et al., 2003; Petrov et al., 2009). Planning and governance strategies are incorporated based on a regional scenario workshop enabling a ‘regionalization’ of the PLUREL pan-European scenarios which are explained in section 2.3. Thus, planning is translated into land use neighbourhood attraction curves and suitability maps that stand for planners’ decision-making. The model outcomes can be used to assess the effectiveness and suitability of the strategies by the planners. At the same time, planners can feed their ideas and responses on the model results back to the modellers to modify the simulation.

2.3 Scenario framework

Scenarios are ‘stories of the future’, providing a tool for the investigation of possible future conditions and trends, risks and opportunities. They can take different forms such as (a) stories or narratives which can be more fictional, or more realistic, (b) models (technical and quantitative, or, more conceptual and qualitative, (c) visual or narrative images or (d) visions (Ravetz and Rounsevell, 2008). The scenario framework for the land use modelling used in the PLUREL project is twofold (Figure 1): (1) Four scenarios of pan-European trends up to the years 2025 and 2050 with relevance for urban regions provide the framework for the investigation of future trends in land use and its related functions, including risks and opportunities for sustainable development. These scenarios are based on the IPCC SRES scenarios (IPCC, 2007) and can be ordered on two main axes which may be called a governance axis and a value axis. Within PLUREL, the four basic IPCC SRES A1, B1, A2 and B2 scenarios have been extended based on the development of ‘shock’ scenarios and dedicated to particularly urban regions (more information see Ravetz and Rounsevell, 2008). The shocks will allow an analysis of changed drivers that potentially are of great significance to urban-rural land use and represent a novel development of regionally-interpreted SRES scenarios: A1 – rapid development in information and communication technology and rapid counter-urbanisation (Hypertech), A2 – self-reliance (extreme water crisis) due to rapid climate change and water crisis, B1 – sustainability (energy price shock) due to extreme energy prices it comes to a localisation of activity, B2 – fragmentation (social exclusion) due to a pandemic disease followed by a polarisation of cities. Four related narrative storylines are used for the modelling on economic, demographic, and environmental and land use changes (Ravetz and Rounsevell, 2008).
<table>
<thead>
<tr>
<th>Planning</th>
<th>No restrictions</th>
<th>Current planning system implemented</th>
<th>Strong planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drivers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth (population, GDP)</td>
<td>Hypertech</td>
<td>Unrestricted growth In-migration, new transport axes, commercial investment, gentrification</td>
<td></td>
</tr>
<tr>
<td>Stable development</td>
<td></td>
<td>BAU Managed growth stable population, weakening of protection zoning</td>
<td></td>
</tr>
<tr>
<td>Shrinkage</td>
<td></td>
<td>Price shock Managed shrinkage Declining population, eco-tourism growth, investment in public transport, urban renewal</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: The scenario framework (BAU = Business-as-usual): PLUREL shock scenarios in bold, regionalised and locally adapted main ideas of the scenario storyline below.

(2) Based on the aforementioned pan-European ‘shock’ scenarios, at the case study level, the storylines were further developed and adapted which is meant by ‘regionalised’. One of the case studies is Leipzig-Halle. In doing so, the population development was adapted in terms of specific in- and outmigration dynamics of specific age groups, localised GDP values were added for each municipality in the region, and transport and peri-urban commercial projects were considered as axial development factors. In addition, the regional planning policy – that is land use planning in form of zoning or regulation but also land preparation plans and financial subventions – was included into the scenarios (which was completely neglected in the pan-European approach due to the scale). So doing, first and foremost flood maps, protection areas and green space networks were incorporated (Petrov et al., 2009). Figure 1 shows the details of the locally adapted scenario storylines which specify the above mentioned assumptions.

2.4 Scenario workshop

The scenario workshop's main objectives were to discuss the MOLAND land use modelling results and maps together with local stakeholders, experts and practitioners. It generally contributes to the dialogue between research and practice on spatial and land use development in the urban region of Leipzig-Halle. The above introduced land use scenarios as well as the MOLAND modelling were presented by scientists in order to stimulate a debate on the implications of future land use development. Policy options for regional planning and governance were discussed. The central element of the workshop, a planning game, was conceptualised to jointly develop future land use patterns for the Leipzig-Halle region under the diverging assumptions (Haase et al., 2009).

The three land use development options for the scenario workshop where developed under consideration of the locally adapted scenario storylines given in Figure 1. Using the same driving forces, the following options were realised by the stakeholders: “Unrestrained growth”, “Managed growth” and “Managed shrinkage”. In practice, according to the scenario, every planning game was supplied with a certain amount of “land use” in the form of coloured paper and a storyline. The stages and the results of the planning game were documented in minutes, photographs and films (Haase et al., 2009). The main idea behind the scenario workshop was to let the practitioners create their own land use maps framed by the land use options. The scientists were interested into the facts where the stakeholders place future housing and transport growth and where they assume land perforation and brownfields will occur and why. In addition, the practitioners listed the instruments they would use to steer the before created land use maps (Haase et al., 2009).
But how do the land use options used at the scenario workshop relate to the above mentioned pan-European and the regionalised scenarios? They can be understood as an extension of both but rather represent qualitative visions how the region might look like in 2025. Both the regionalised storylines for the MOLAND modelling and the land use options of the stakeholder scenario workshop are compatible so that they can be fed back into the pan-European scenarios (Haase et al., 2009).

2.5 Feedbacks

The reactions of the stakeholders on the simulated MOALND maps, their own manual maps created at the scenario workshop and, last not least, the listing of the drivers and instruments that steer the future land use development (which are indirectly also a reaction on the simulated land use maps so far) are defined as the ‘stakeholder feedback’ in this paper. Respectively, they are presented and evaluated in the results’ section.

3. RESULTS

3.1 Model results

Figure 2 shows the results of the spatially explicit MOLAND land use change modelling for the urban region Leipzig-Halle. Overall, an increase of sealed and built surfaces can be found. Whereas in the ‘Business as usual’ (BAU) scenario the area of discontinuous, low density residential land increases most, in the ‘Hypertech’ scenario most of the growth is due to commercial land development.

The ‘Price shock’ scenario shows no further settlement growth but an increase of urban green space instead. As the ‘Hypertech’ scenario assumes a somehow extreme development this goes along with a stronger segregation of the land use and thus the core cities of Leipzig and Halle are faced with no further building activities in their centres, while residential land in the peri-urban area is growing (Figure 3). This inner-urban decline of sealed surface does not occur in the ‘BAU’ scenario where a stronger impact of land use planning is assumed. Most of the built-up and sealed land comes either from agricultural areas, the natural green spaces and floodplains in the cities’ surroundings or the former...
sites of mineral extraction which are more or less continuously declining in both scenarios. In the ‘Hypertech’ scenario, the expansion of the Leipzig-Halle airport leads to a big step of land consumption in 2010. In terms of open land, we find a decrease of up to 25%. Natural green spaces, in particular, decline up to 60%. The most effective wetland protection (196%) we find in the ‘Price shock’ scenario where commercial and transport growth is limited (Figure 3).

![Figure 3: Aggregated relative land use changes (in %) for the time horizon 2025 for the three locally adapted, “regionalised” scenarios BAU, Hypertech and Price shock.](image)

In the scenarios, the trend of population, residential and commercial growth is prescribed and MOLAND “translates” these trends into numbers of residential and commercial or industrial cells. The way the new cells are allocated in the area is calculated endogenously in the model based on the transition potential driven by suitability, accessibility, zoning, neighbourhood cells and random perturbation (Barredo et al., 2003).

### 3.2 Results of the scenario workshop

Table 1 summarises and compares the results of the stakeholder scenario workshop. Concerning land use, commonalities between the three scenarios were as follows: persistence of existent urban centres, new development mainly within the centres, decline of rural areas, partial abandonment of peripheral settlements. Differences were found mainly in the increase of green spaces and water bodies in the ‘managed’ scenarios, more polarisation of residential and economic land uses, social segregation, urban sprawl in the unrestrained growth story; Table 1):

**Unrestrained growth**

Urban sprawl increases within the Leipzig-Halle beltway. However, the cities of Leipzig and Halle remain the most important centres while rural areas face further decline. At the same time, business locations and residential areas undergo a process of differentiation and polarization. Decay and slums on one hand and growth and gated communities on the other coexist in close proximity (Table 1).

**Managed growth**

The regional development is based on the persistence of the existing structures. The recycling of sites opens up further land potential within existing settlements. Overall, there is a concentration of residential and commercial development within urban core areas. A network of green spaces structures the urban region, enhances the cultural characteristics and the ecological functions of the landscape (Table 1).
Managed shrinkage
Business locations and housing estates concentrate in existing urban cores and along spatial axis. The number of administrative centres and infrastructure sites is reduced. Villages and estates on the periphery of the urban cores disintegrate. Green spaces permeate the region, the access to waterways and lakes is improved (Table 1).

Table 1: Converging and diverging arguments during the game between the three scenarios with respect to land use changes, drivers, land use steering instruments and its valuation by the participants

<table>
<thead>
<tr>
<th>Land use changes envisaged</th>
<th>Unrestrained growth</th>
<th>Managed growth</th>
<th>Managed shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>urban sprawl, in particular in corridors between the centres</td>
<td>persistence of overall settlement structure</td>
<td>persistence of centres</td>
</tr>
<tr>
<td></td>
<td>persistence of urban centres</td>
<td>new residential and commercial development within existent centres</td>
<td>new residential and commercial development within existent centres</td>
</tr>
<tr>
<td></td>
<td>rural areas face severe decline</td>
<td>strengthening of green space network</td>
<td>further suburban development only in exceptional cases</td>
</tr>
<tr>
<td></td>
<td>polarisation of business locations and residential areas within the settlement structure</td>
<td></td>
<td>shrinkage of medium-sized settlements, abandonment of peripheral settlements</td>
</tr>
<tr>
<td></td>
<td>rich and poor residential areas in proximity</td>
<td></td>
<td>increase of green spaces and water bodies in and around settlements, well connected to centres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drivers identified</th>
<th>Unrestrained growth</th>
<th>Managed growth</th>
<th>Managed shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>positive net migration</td>
<td>sustainability widely accepted as a guiding principle for public policymaking and planning</td>
<td>out-migration of population and businesses</td>
<td></td>
</tr>
<tr>
<td>intense competition of investors over business locations</td>
<td>cooperation between investors, politicians and citizens</td>
<td>realisation of housing preferences</td>
<td></td>
</tr>
<tr>
<td>quickening of land use cycles due to rise and fall of new technologies</td>
<td>attention to residents’ housing preferences</td>
<td>limited mobility</td>
<td></td>
</tr>
<tr>
<td>privatisation of public property and services</td>
<td></td>
<td>local authorities under financial constraints, decreasing means to influence land use</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instruments to be used</th>
<th>Unrestrained growth</th>
<th>Managed growth</th>
<th>Managed shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>privatisation of public services</td>
<td>federal state, regional and local government reform</td>
<td>regional parliament</td>
<td></td>
</tr>
<tr>
<td>decreasing influence of formal planning and recommendations instead of rules</td>
<td>regional planning for entire region</td>
<td>federal state, regional and local government reform</td>
<td></td>
</tr>
<tr>
<td>urban and regional marketing</td>
<td>transfer of responsibilities in planning from local authorities to regions</td>
<td>influential role of urban region in politics</td>
<td></td>
</tr>
<tr>
<td>joint infrastructure planning</td>
<td>pool of compensation areas</td>
<td>regional planning for whole region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>commitment to the protection of green spaces</td>
<td>joint infrastructure projects</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>continuation of landscape planning</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Feedbacks on drivers and steering instruments by stakeholders

The original assumptions of the MOLAND simulations could be improved by the above listed arguments discussed during the stakeholder process. The following drivers of land use development in the urban region Leipzig-Halle were already incorporated in the model: migration, population growth, GDP and urban regeneration programs. The following drivers were identified by the stakeholders: cooperation between investors, politicians and citizens and concerted actions of urban renewal in form of demolition. But, whereas in case of population and economic growth investor competition and new technologies were highlighted by the stakeholders, in case of population decline the role of normative planning principles, of private and small-scale investors became more important (Table 1). In the case of economic (and population) growth, commercial development relies on positive netmigration to the region because the local population is diminishing. An intensive competition over business locations increases land consumption for roads and sites, fuelled by short term investment incentives. New technologies and media lead to shorter land use cycles. Financially weak, local authorities seek a further privatisation of
land and services, thereby reducing the public and strategic planning options. In case of a more managed growth the spatial development follows the principle of sustainability. Investors, politicians and citizens have recognized that the long term ecological need and cost benefit of reduced land consumption; they seek cooperation and a better incorporation of housing preferences by the residents. Particularly, the stakeholder feedback concerning the “managed shrinkage” option was interesting: Stakeholders highlighted that the shrinkage of the housing sector – that is predominantly demolition – has to be better communicated to service suppliers. In case of further shrinkage economic performance, housing sector and financial transfers are too low to ensure a consistent high level of infrastructure provision in the whole area. The municipal capacities for action are reduced. Within the region there is polarisation. Weak sites cannot be sustained anymore and have to be dismantled (cf. again Table 1). The feedback of the stakeholders here can be regarded as very positive in terms they modified the residential growth and amplify the land abandonment process assumed in the scenarios. Thus, demolition plans were incorporated in the new MOLAND simulations.

4. DISCUSSION AND CONCLUSIONS

Consequently, in a next step, the knowledge/feedback gained in the scenario workshop was incorporated in the MOLAND model to improve the simulation results. This is still work in progress and therefore, in this paper first preliminary results are presented: So, for example, we incorporated residential preferences and demolition plans as suitability and zoning maps into the MOLAND model. Figure 4 proves evidence that we can show inner-urban decline and (empty) brownfield cells – compared to the original ‘Hypertech’ simulation. With respect to the spatial resolution of the model, 100x100 meters, the brownfields in the new simulation represent a realistic picture of a) how demolition already perforated the urban structure in the inner parts of the city and b) where it actually occurs.

Further improvements of the MOLAND model will be done using the information gained at the scenario workshop, first and foremost in terms of a) including new zoning features in the model, b) modifying land use suitability of specific areas, c) modifying land use transition rules according to the expected lowering of peri-urban dynamics compared to the inner-urban.
ACKNOWLEDGMENTS

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REFERENCES


