GIS-based Backcasting
A Method for Parameterisation of Sustainable Spatial Planning and Resource Management

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1 ABSTRACT

Backcasting, if used as a decision support and planning method, starts from a desired future state or vision and simulates backwards until present time. During the model run, which goes backwards in time, development paths are created. They expose which steps have to be taken in future to reach the desired state. Besides, milestone scenarios are created as outputs that represent interim goals.

The paper at hand proposes an automated, GIS-based backcasting model, since backcasting so far has only been applied in workshops or as theoretical framework. Until now no spatially explicit backcasting model has been set up. The proposed backcasting model first creates a future scenario utilizing an Agent Based Model approach. Afterwards the model simulates backwards implemented as a Cellular Automaton. This is realized in a Python script and linked to the Open Source GIS software Quantum GIS.

The general model is applied to a case study in Salzburg, Austria. The topic concerns sustainable spatial planning. The results of the model run show in time steps a successful backcasting of land-use classes from a future state back until present time.

2 STAGE OF THE RESEARCH

The preliminary title of my PhD work is 'A GIS-based Backcasting: An innovative method for parameterisation of sustainable spatial planning and resource management'. I started my PhD in February 2011 and I am now in the final year. In September 2011 I joined the Doctoral College GIScience at the University of Salzburg which provides a professional and excellent network of students and faculty for potential collaborations and knowledge exchange.

The initially defined research questions of my PhD work are:

1. Can backcasting exercises be reasonably translated into models?
   a. Which options could be used?
2. Are Geosimulation tools applicable to a backwards working approach like backcasting?
   b. Can Cellular Automata and/or Agent Based Models be used?

I meanwhile published one PhD-relevant article in the ISI-referenced journal Futures. Its title is similar to my PhD topic, namely 'GIS-based Backcasting: An innovative method for parameterisation of sustainable spatial planning and resource management' and was published online in November 2011. This paper covers the first ideas and a theoretical framework of the backcasting model. Since then I was working on the implementation of the backcasting model itself, which is now in the final stage.

Currently I am working on my second PhD relevant article which is supposed to be submitted in July to the journal 'Environmental modelling & software'. It presents the implementation of the model and development steps towards the spatially explicit model.

3 OUTLINE OF OBJECTIVES

The main objective of my PhD is to develop a spatially explicit backcasting model. To explore the principle of backcasting, which is not necessarily immediately understood correctly by non-experts, I may start with the often better known principle of forecasting. In a forecasting exercise an analyst usually takes a present situation and applies forecasting methods as for instance trend extrapolations or time series to explore how a future

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situation may look like or what the directions of future trends are. It is a conditional method saying 'If policy A is adopted, state B will happen.' Forecasting is for instance applied in meteorology or economics (c.f. Murphy & Winkler, 1974; Clements & Hendry, 1998; Clements et al., 2004). Contrarily, a general backcasting model starts from a future vision, resp. a desired future state decoupled from currently given structures. From this future state the backcasting model simulates backwards a development until the present state is reached (see Fig. 1).

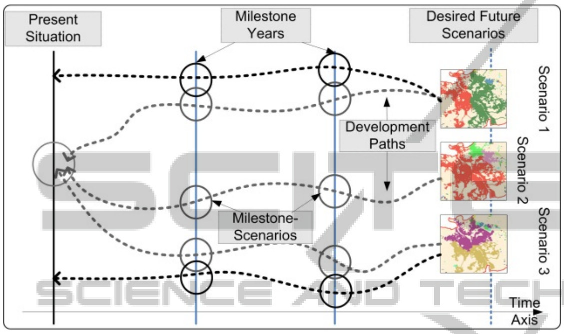

Figure 1: Backcasting principle.

The simulation is based on rules and creates milestone scenarios as interim goals. Next to the interim goals the simulation identifies trajectories. They serve as development paths or guidelines and express which steps have to be taken in order to get from the present to the desired future state.

Backcasting is not a conditional method, as it is forecasting, but it tells the modeller what needs to be done and what needs to be achieved during the next years in order to reach the (desired) future state.

The proposed backcasting model first creates a future scenario. This part of the model utilizes an Agent Based Model. The second part of the model simulates backwards starting from the future state. This part is implemented with a Python script and linked to the Open Source GIS software *Quantum GIS*.

The model is applied to a case study of sustainable land-use planning in Salzburg, Austria. The model shall support to reach a vision in land-use planning in an appropriate time horizon. Thus the results of the model run show in 10 years' time steps a successful back-casting of land-use classes from a desired future state back until present time.

4 RESEARCH PROBLEM

Although the basic ideas of backcasting are relatively old, general backcasting is until now usually applied in non-spatial and non-explicit context. Today, backcasting is often applied to back-cast scenarios for whole cities or regions, for instance, and often performed in workshops. The unique characteristic of the presented backcasting approach is its spatial explicity and automation: The simulations in the proposed model are based on polygonal equi-areal raster cells covering a selected pilot region. So far no tangible method exists for the application of the backcasting concept with spatial reference and to my best knowledge also no model-based, spatially explicit backcasting analysis has been implemented yet.

An automated, GIS-based backcasting model will reveal new perspectives and opportunities applicable to research topics like spatial planning, safety, construction, and health care. The basic research results of this study will provide new possibilities for the integration of decision support systems into the workflow processes of spatial planning specialists and decision makers.

The backcasting model will be applied in a pilot region located in Salzburg, Austria. The model shall help to counteract negative consequences of urban development in this region by proposing a desired future vision and related development paths how to reach this future state.

This research forms a bridge between spatial planning concepts and Geographic Information Science and adds a new dimension to GIS. At the same time it contributes to the provision of innovative solutions.

5 STATE OF THE ART

The origin of the Backcasting concept goes back to the 1970s, when it was introduced by Amory Lovins as a planning method for electricity supply and demand. At that time he referred to it as 'backwards-looking-analysis'. Since then, this method has been regularly used in energy studies, often being referred to as 'energy analysis of the final consumption' (Dreborg, 1996; Quist, 2000). According to Dreborg (1996), general backcasting can be applied if:

- Complex problems are dominating
- Problems include a major trend
- External factors greatly influence the problems
- The time span for implementing changes is

long enough

Following the first implementation of backcasting it took some time before it was realised that the backcasting approach can be used in a much wider range of applications. Sustainability became an important field of application: In Sweden it has been applied to various topics of sustainability research, like transportation systems and air transport. Further studies have been conducted on the sustainability of water, mobility, or households (Carlsson-Kanyama et al., 2008; Miola, 2008, Banister et al. 2000 cited in Quist 2007). In Oxford, backcasting has been applied e.g. within the VIBAT project. There it was implemented to lower transport carbon emissions (Hickman et al., 2009). A Backcasting analysis aiming at an efficient energy system with regard to the development of a sustainable spatial organisation in Austria was proposed by Wächter et al. (2012). Grêt-Regamey and Brunner proposed a new approach in 2011, namely to split the backcasting methodology into inverse modelling (Grêt-Regamey & Brunner, 2011) for explicit quantitative problems on the one hand and a qualitative, strategic backcasting analysis for complex problems in spatial planning on the other hand. The latest research in this field dealt with the implementation of a backcasting analysis with Agent Based Models (ABMs). This was proposed by Van Berkel and Verburg (2012) and was applied to design policies for multifunctional landscapes to simulate landscape changes.

6 METHODOLOGY

The proposed steps in my PhD towards a spatially explicit and model-based backcasting approach include (1) interviews with experts in the field of spatial and urban planning. They have been selected based on responsibilities for planning issues in the pilot region. (2) Visions derived from the experts' views. (3) Extensive analysis of the current state including the land-use pattern and influencing physio-geographical parameters, the population distribution, and the future population development in the pilot region. After having characterized the pilot region (4) normative future scenarios are created. In backcasting, future scenarios are often visionary and decoupled from given structures or circumstances, assuming that there are no constraints for development. In the proposed approach the developed future scenario represents a randomly generated possible future pattern of land-use classes in the pilot region. The development of the future scenario is only influenced by exogenous parameters which have been identified before to influence land-use in the pilot region. The future scenario serves as starting point for the next step (5), the backwards modelling. This is performed by repeatedly applying pre-defined rule-sets describing the backwards development. The backwards modelling simulates changes of equi-areal polygonal cells. Each of these cells changes its state individually, resp. explicitly from one time step to the next. These time steps are represented by milestone scenarios that are created as outputs during the whole backwards run, representing interim goals. Further outputs of the backwards modelling are development paths or trajectories, revealing which changes have to take place to reach the future scenario. Finally the backwards modelling results in a modelled present land-use pattern. This is compared with the actual present land-use pattern in the pilot region which should equal each other.

Based on a profound literature review two principle modelling techniques have been identified to be potentially suitable for the backcasting approach. On the one hand these are Agent Based Models (ABMs) which in general simulate actions of autonomous agents, and display the behaviour and dependencies between those agents and to other agents. The aim of an ABM is usually not to reach equilibrium, but to find out how a system will adapt to changed conditions (Macal et al., 2010). On the other hand these are Cellular Automata (CA). CA are considered to be simple mathematical models used for modelling discrete dynamic systems. These models evolve due to a repeated application of simple, deterministic rules (Wolfram, 1982). The strength of those models is the simplicity of their implemented transition rules which provide more flexible system behaviour than other models. CA can be applied to simulate the transition, for instance from non-urban to urban landscape, of a system like cells in a grid space depending on the neighbourhood: Land-use changes at a certain cell can thus depend on a previous land-use at this location, on multi-criteria factors, or on the land use of its neighbouring cells. These approaches allow a numerical analysis of non-numerical geographic systems. (Kim & Batty, 2011)

Based on an internal evaluation of strengths and weaknesses of both approaches and discussions with other experts, ABMs were chosen to be used for the setup of the backcasting model. Nevertheless, the ABM does not simulate individual agents moving over a rasterized pilot area, but it simulates the changes of equi-areal polygon cells covering the whole pilot area. It can be said that the ABM is utilized as a CA.

The proposed model is applied to a selected pilot region in Austria and is divided into two parts: The first part creates future scenarios and is implemented in ESRI's Agent Analyst. This is an Agent Based Modelling (ABM) extension for ArcGIS and builds on Not Quite Python (NQPy) language. NQPy satisfies nearly all requirements of GIS users, who can also export the models and can add more sophisticated functions.

Due to performance criteria the backwards running process, consequently the second part, which starts from a given future scenario, was implemented as a Python script that is linked to the open-source GIS software Quantum GIS (QGIS).

7 OUTCOME

The first results of the backcasting model present a randomly generated future land-use scenario for 2050. This is input to a backwards running model starting from 2050 and ending in 2006, as the final stage. The ABM-based generated random future scenario for 2050 is shown in Fig. 2.

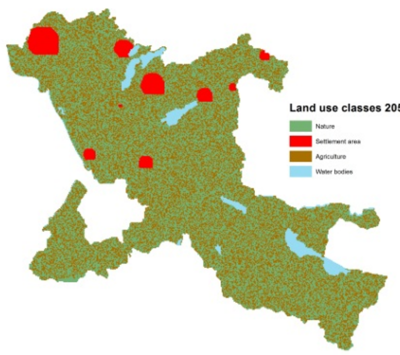

Figure 2: Randomly generated future scenario of 2050.

This random future land-use pattern consists of the four dominant land-use classes in the pilot region: nature, settlement areas, agricultural land, and water bodies. These data were extracted from Corine Landcover data of 2006. The land-use class of nature includes for instance forest areas, pastures, grasslands, and other vegetated areas. Agricultural areas include cultivated areas and arable land, and settlement areas comprise urban areas, industrial units, road and rail network, and other artificial facilities (related to leisure, sports, etc.). All simulated milestone scenarios, as well as the final output, are made up of these four land-use classes.

To give an impression, two selected milestone scenarios for the years 2040 and 2020 are presented in Fig. 3a and b.

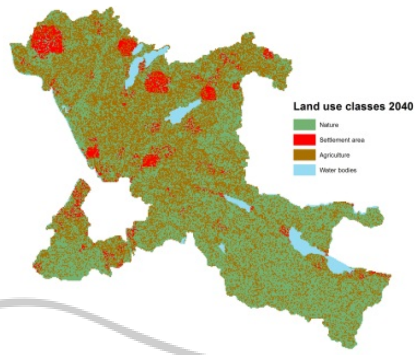

Figure 3a: Milestone scenario of 2040.

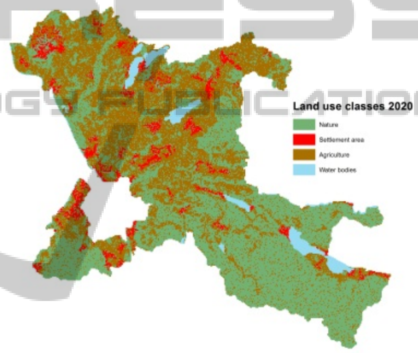

Figure 3b: Milestone scenario of 2020.

Finally, the output of the backwards running model, which is similar to the land-use pattern of the current time (here it is 2006), is presented in Fig. 4.

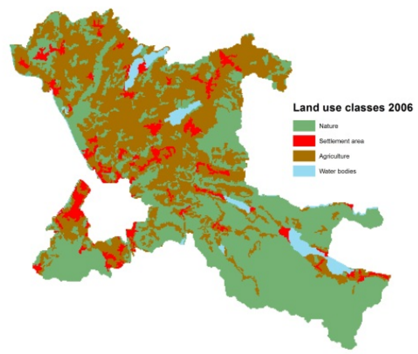

Figure 4: Final model output: the modelled land-use pattern of 2006.

This modelled land-use pattern is similar to the Corine Landcover data of 2006, which represents the initial land-use pattern which was also input for the model. This will always be the final output since the backwards running model converges in any case towards a fixed land-use pattern (in this case it is the land-use pattern of 2006).

8 DISCUSSION

The aforementioned research questions that are also addressed in my PhD and can be answered through the presented outputs are:

1. Can backcasting exercises be reasonably translated into models?
   a. Which options could be used?
2. Are Geosimulation tools applicable to a backwards working approach like backcasting?
   c. Can Cellular Automata and/or Agent Based Models be used?

With the gained results of the model, presented in Fig. 2 to 4, it is possible to answer all research questions: Yes, backcasting exercises can be reasonably translated into models and yes, Geosimulation tools are applicable to a backwards working approach like backcasting. For the generation of a random future scenario of 2050 an Agent Based Model extension (Agent Analyst) for ArcGIS is used. Cellular Automata (CA) models might be used more often but it is made clear that the ABM extension was not used in a sense of studying independently acting agents. This forecasting exercise resulted in a scenario considering pre-defined rule-sets for the development of future land-use patterns. The backwards modelling is implemented as a Python script linked to QGIS. This was preferred against the Agent Analyst due to performance criteria and the free availability of Python and QGIS. Both model approaches, in Agent Analyst and Python/QGIS, act like CA meaning that the equi-areal cells covering the pilot area change their states according to implemented rules. This statement also answers question two, if Geosimulation tools are applicable to a backwards working approach. Yes they are, which has been proven by the herewith presented approach of implementing backcasting with ABM resp. a CA realized via Python.

9 OUTLOOK

Next developments will include the integration of a baseline scenario for validation of the model. The baseline scenario is created with Metronamica, land-use simulation software, developed by RIKS at the VU Amsterdam. *"Metronamica is a unique generic forecasting tool for planners to simulate and assess the integrated effects of their planning measures on urban and regional development. As an integrated spatial decision support system, Metronamica models socio-economic and physical planning aspects. It incorporates a mature land use change model that helps to make these aspects spatially explicit"* (Metronamica Website, 2014).

Furthermore a whole pool of future scenarios will be created each having a different emphasis representing for instance maximum compactness, maximum Quality of Life or maximum autarky. The rules for these scenarios are currently set-up.

An on-going update of the backcasting rule-set includes the integration of neighbourhood influences on settlement development and population development in the pilot region. Preferred areas are then not only influenced by physio-geographic parameters but also by the surrounding environment.

Besides, the road network of the pilot region will be included through an explicit raster input.

Since the two parts of the model, the creation of a future scenario on the one hand, and the backwards modelling on the other hand are for now implemented in different software environments, it is planned to implement both in the same environment. Thus, the creation of future scenarios is transferred to Python scripting as well.

Finally, a sensitivity analysis with respect to the initial condition, which is obtained by the backcasting model, is conducted in order to see whether the same results can be achieved.

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