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Spatial allocation of future residential land use in the Elbe River Basin

By

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ABSTRACT

Spatial allocation of future residential land use in the Elbe river basin

This paper presents a scenario study of residential land use development in the Elbe river basin. Applying scenarios to a study area with decreasing population but accelerating urban sprawl is challenging. The underlying study shows an approach to empirically determine suitability maps for the application in different scenarios of land use change modelling. In a first step recent urbanisation processes are explained. In a second step these are used in simulations of future land use.

Binomial logistic regression analysis is applied to analyse the location characteristics influencing residential land use change. Estimation results are adapted as weights for the calculation of suitability maps that consist of the location characteristics of residential land use change. Including policy maps into the suitability calculation offers the ability to account for important spatial restrictions and to analyse the impact of spatial planning to the allocation of residential developments. The suitability maps are further applied to the Land Use Scanner model to simulate spatially explicit residential land use developments in the Elbe river basin.

The results show that empirically determined suitability maps in land use change modelling can contribute to the operationalised use of scenario studies in political discussion support. The application of different planning instruments shows considerable differences in their contribution to a sustainable development of residential land use.

Keywords: land use change, residential land, land use modelling, scenario analysis, logistic regression

1. Introduction

Residential land use development is one indicator of measuring sustainable development. One objective of the German strategy for sustainable development is to reduce the current increase in settlement area from approximately 120 ha per day in Germany to 30 ha per day until 2020 (RNE, 2004). This objective is even more important if current developments in the Elbe river basin, covering the eastern and northern part of Germany and large parts of the Czech Republic, are considered. While in the 1990s comprehensive urban sprawl was observed, population decreased in most regions of the Elbe river basin. Moreover, assessments of sustainable development indicators also need to attend to the spatial configuration of residential land use changes (Lambin et al., 2001). Economic as well as ecological processes are influenced by extensive suburbanisation processes. The revealed impacts and costs of suburbanisation and sprawl are reviewed in Gordon and Wong (1985) or Pushkarev (1975). Both, the German and Czech Governments are concerned about these developments and address this issue in their national spatial planning policies. The particular objective of the national planning policy is decentralised concentration of urban developments to ensure adequate living conditions in the whole country (ROG 2004; MMR and ÚÚR, 2006). Germany applies the concept of Christaller's central place theory to guide the development of the settlement structure (ROG, 2004). The Czech government, instead, applies an indicator approach which determines development axes (MMR and ÚÚR, 2006). This leads to the following main research questions: Where do residential areas develop in the future and what are the determinants of location choice? What is the potential impact of decentralised concentration on future patterns of observed settlement structure in contrast to no spatial policy? To analyse these questions a scenario study is conducted.

For the allocation of residential developments land use change models can be applied. Extensive reviews with respect to purpose of the model, scale and theory can be found at Agarwal et al. (2002), Briassoulis (2000) or Verburg et al. (2004b). In this study the Land Use Scanner is applied to allocate future residential developments. The Land Use Scanner is an operational, spatially explicit, GIS-based simulation model that allocates land use / land cover changes on grid-cells with a logit-type approach (Hilferink and Rietveld, 1999; Schotten et al., 2001). Exogenously calculated demand for land is allocated by the algorithm accordingly to location preferences of each specific land use type which is represented by suitability maps. With its ability to simulate all types of land use, both urban and rural, simultaneously and to integrate spatial planning documents which are considered in the spatial allocation process the model is feasible for the present study. Previous applications of the model are, amongst others, the analysis of the development of open space due to pressure induced by residential areas, the impact assessment of land use changes for water management and flood risk or the derivation of land use change scenarios in the framework of the Fifth National Physical Planning Report in the Netherlands (Dekkers and Koomen, 2007; Schotten et al., 2001; Van der Hoeven et al., 2008).

One important aspect of this type of land use change models is the calculation of suitability maps for each land use type. Weighting and combining the different determinants of location choice by expert knowledge is one straightforward way to calculate suitability maps. This approach was applied several times for simulations with the Land Use Scanner (Borsboom-van Beurden et al., 2007; Hilferink and Rietveld, 1999). But the influence of location factors on the spatial allocation is not easily to determine and thus can result in a relatively smooth distribution of suitability values. This can lead to numerical diffusion in the allocation process, a spread effect resulting in a large number of grid-cells receiving a very low amount of land of a certain land use type. To avoid this effect a rather peaked distribution of suitability values is recommended (Borsboom-van Beurden et al., 2002). This results in the consideration of alternative approaches to calculate suitability maps. Amongst approaches reviewed by Verburg et al. (2004b), logistic regression analysis is an often applied approach that offers the opportunity to empirically determine the influence of different location factors for residential development. Approaches can be distinguished into binomial and multinomial models as well as into models explaining existing land use patterns or past land use changes (Aspinall, 2004; Chomitz and Gray, 1996; Dendoncker et al., 2007; Loonen and Koomen, 2008; Pontius Jr and Batchu, 2003; Rietveld and Wagtendonk, 2004; Serneels and Lambin, 2001; Turner et al., 1996; Verburg et al., 2004a; Wear and Bolstad, 1998). Verburg et al. (2004a) and Verburg et al. (2006) apply the results of a binomial logistic regression analysis of past land use changes into the land use change model CLUE-S (Conversion of Land Use and its Effects at Small regional extent) as one aspect of their suitability calculation. By leaving the regression coefficients unchanged in the scenario analysis they assume that the influences of location factors remain constant over time. Applying regression results to scenario studies reveals the question wether structural changes can be expected in different scenarios or not. Pontius Jr and Batchu (2003) also use a binomial logistic regression approach to estimate land cover changes in India and discusses the certainty of the results for predicting land cover changes but without applying the results to a scenario study.

Since this paper carries out a scenario study of residential changes the challenge is to apply and adapt logistic regression results to different scenarios, which are not only differentiated with respect to demand for land but for location preferences of residential developments.

The remainder of this paper introduces to the study area. The estimation of the logistic regression analysis is carried out as well as the adaptation process of these results with respect to scenario storylines. The adapted statistical results are further applied into the Land Use Scanner to calculate the corresponding suitability maps and to simulate future residential developments spatially explicit. Finally the simulation results are discussed with respect to the question whether logistic regression estimations are a suitable basis for adaptation in a scenario study with changing location preferences over time.

2. Residential development in the Elbe River Basin

In the year 2005 12.9% and 10.3% are covered by urban land use in Germany and the Czech Republic, respectively (Eurostat, 2007; STABU, 2006). Socioeconomic development of the 1990s is characterised by a decline of population in many regions, migration to West Germany and to the rural-urban fringe, low birth rates and ageing as well as high unemployment rates due to the break down of the political system of both countries (BBR, 2007). The study area is characterised by a poly-centric settlement structure. Berlin, Hamburg and Prague are the outstanding metropolitan regions and are completed by the Saxon Triangle Metropolitan Region, consisting of Dresden, Leipzig, Halle, Chemnitz (Adam and Göddecke-Stellmann, 2002). While in the metropolitan regions residential areas have a share of more than 30% of the total area all other regions are very rural with a share of residential land of less than 5%. Spatial planning of the socialist regimes was very restrictive and the construction of prefabricated multi family dwellings was preferred (BBR, 2005; 2006). Since the break down of the wall 1990 urban sprawl is mainly accelerating due to the construction of single family houses. An increase of more than 10% in residential areas could be observed (Penn-Bressel, 2003; STABU, 2007). This development was supported by a weak spatial planning policy or the ability of write downs (Coles, 1997; Dosch and Beckmann, 1999; LZB, 2001). Urban sprawl is accelerating most in the surrounding rural municipalities of cities. Single family dwellings account for two third of all new constructions in metropolitan regions of the Elbe river basin and nearly 100% in peripheral regions (BBR, 2006; CRR, 2006). Current observations show a slight increase of population in some cities but without stopping suburbanisation processes in the periphery of the cities. Although municipal planning policy should also contribute to a sustainable development excess supply of residential land can be observed, although population is declining in many municipalities. This leads to three observed processes concerning residential developments: densification and use of brown fields, demolition of the socialist prefabricated multi family dwellings and new developments. The focus of this study will be on the new developments of residential areas because of their potentially negative impact on sustainable development (Gordon and Wong, 1985; Pushkarev, 1975).

3. Data and Methods

3.1. Logistic regression

A logistic regression analysis is carried out to empirically determine weights for the calculation of suitability maps in the Land Use Scanner model. The advantage of this approach in comparison to determine weights by expert knowledge is the assignment of relative values for location factors. Since the focus of this study is on residential land use a binomial logistic regression is applied.

The property of spatial data, especially land cover data, to be spatially dependent was already described in Tobler's cellular geography (Tobler, 1979). This tendency needs to be taken into account if applying statistical models (Anselin, 2002). Therefore the implementation of spatial autoregressive variables is proposed to explain the variation of the independent variable through contiguous or neighbouring units with no other explanatory variables (Anselin, 2002; Loonen and Koomen, 2008; Overmars et al., 2003). This spatial autoregressive model is the first of three different estimations carried out. The second estimation is a model including only other explanatory variables to analyse their predictive power. This seems to be relevant since Loonen and Koomen (2008) stated the only marginally higher explanatory power when combining these variables with the autoregressive ones in a full factor model. This full factor model is thirdly estimated including autoregressive as well as other explanatory variables.

All estimation approaches are applied to residential changes between 1990 and 2000 (Verburg et al., 2004a). A full set of variables is presented in table 1.

The results are validated by applying a ROC-curve (Relative Operating Characteristic) (Pontius and Schneider, 2001). The ROC is a statistic that measures the extent to which grid-cells with larger probability values are concentrated at locations that truly became residential area between 1990 and 2000. The curve shows the proportion of true-positive and false-positive classified grid-cells of a contingency table for a complete range of cut-off values that classify the probability. The ROC statistic measures the area under the curve with values from 0.5 (completely random) and 1 (perfect fit).

Since the database has 2.3 million grid cells and the proportion of residential land in comparison to agricultural areas is very disproportionate a sample was chosen. King and Zeng (2001) and Prentice and Pyke (1979) showed that estimated coefficients are not biased if choice-based sampling is applied where sampling rates for the categories of the dependent variable are unequal. Solely the constant needs to be corrected. Therefore, 50% of all residential areas developed between 1990 and 2000 are randomly sampled and approximately 6000 cases from all cells that did not change. The total sample size is 8500, consisting of 30% new residential land and 70% of cells of no change.

3.2. The land use change model – Land Use Scanner

The allocation of residential land use change is simulated with the Land Use Scanner model. The Land Use Scanner is a GIS-based operational, spatially explicit simulation model that allocates land use / land cover changes on grid-cells. See Hilferink and Rietveld (1999) and Dekkers and Koomen (2007) for a more detailed description. Exogenously calculated regional claim sets and suitability maps for each land use / land cover type are integrated in the model.

A suitability map is generated for each land use type and scenario as a weighted sum of all factors determining location choice to indicate the suitability of each grid-cell for that type.

Regional claim sets representing the demand for land of different land uses types come from sector specific models. For a more detailed description see for example Hoymann (2008). In order to compare the allocation of residential changes due to differences in the suitability maps the demand for residential land is the same in all scenarios within this study.

The Land Use Scanner emphasises two very important characteristics. It integrates urban and non-urban land use types, simultaneously (Hilferink and Rietveld, 1999) and land is not always allocated based on the highest bidding land use type as there are strong public interventions of the spatial planning policy. The Land Use Scanner is able to integrate regional spatial planning documents to account for these restrictions.

Allocation takes place with a doubly constrained logit-model that assigns land uses according to their suitability and the pressure on land induced by the regional claim sets. The constraints ensure that the regional claims are kept and that total amounts of land uses expected per grid-cell are equal to size of the cell (Hilferink and Rietveld, 1999).

3.3. Data and preparation

For the complete study area of the Elbe river basin approximately 2.3 million cells are required to calculate. Regional claims are based on administrative regions. For the Czech part of the study area claims are implemented for Nuts2 regions (Oblastí) and for the German part for spatial planning regions (Raumordnungsregionen).

An extensive database of spatial data is used and is categorised as follows:

- Land cover
- Physical characteristics
- Accessibility
- Nature protection
- Regional spatial planning
- Neighbourhood characteristics

The calculation of suitability maps does not incorporate statistical indicators like population or economic development, because they are considered in the regional claim sets, already.

3.3.1. Land cover

The Corine Land Cover databases of 1990 and 2000 are used for the analysis (UBA, 2004). The dataset of the year 1990 is applied for calibration of the suitability maps in the logistic regression analysis. The year 2000 dataset is used for quasi-validation of the regression analysis and is implemented into the Land Use Scanner. The land cover types are aggregated to 16 classes whereas only residential, arable land and pasture are assumed to change over time. All other land cover types are exogenous and do not change. An analysis of residential land use changes from 1990 to 2000 showed that residential areas developed almost completely on agricultural land.

3.3.2. Physical characteristics

Slope is assumed to be the most important physical characteristic for the allocation of residential areas, since it restricts urbanisation in a considerable part of the study area that is formed by low mountain ranges. It is calculated from the SRTM dataset and scaled to values between zero to one (CIAT, 2004).

Soil or yield maps are not included, since residential developments historically occurred in areas with fertile soils. This resulted in residential developments on fertile soils in the past, already (Siedentop, 2005).

3.3.3. Accessibility

Accessibility measures are calculated as Euclidian distances to existing residential areas, to metropolitan cities, to middle and high order centres. The classification of cities into the hierarchies of the Central Place theory is defined in the regional spatial planning documents of the respective authorities. For the Czech part of the study area the classification was done manually based on the criteria for Central Places. Additionally accessibility to train stations, highway exits, railroads, roads and airports is calculated. Distances to residential areas are based on Corine Land Cover. Distances to infrastructure are calculated from digital terrain models of the German Federal Agency for Cartography and Geodesy and ESRI data sets for the Czech part of the study area.

3.3.4. Nature conservation

Seven types of nature conservation areas are included in the Land Use Scanner. The different types of conservation areas represent varying degrees of restrictions concerning residential developments. While natural parks are least restricted, in nature conservation areas no urban development is allowed. Based on their regulatory framework nature conservation areas are expected to have a lasting effect on choice of location for residential land use (Heiland et al., 2006). The types of conservation areas are grouped in the analysis into strictly protected areas (strcprot), including nature conservation areas and national parks and into areas with potential to be strictly protected (potstrcprot) if the regulatory framework is adjusted, including all other types of nature conservation areas. Within the scenario analysis all types of nature conservation areas are treated as strictly protected but the results will distinguish both types of nature conservation areas to show their potential impact.

3.3.5. Regional spatial planning

Regional spatial planning data sets originate either from state development plans or regional planning documents. The applied instruments aim at preserving land uses, land use functions and landscapes worthy to be protected. Therefore, they are interpreted as restrictions for residential development in the Land Use Scanner. Beyond nature conservation areas there is land reserved for agriculture, mining, forests and nature and landscape in general as well as flood protection areas. These maps are divided into priority areas and reserve areas. While the first excludes land uses with impact on designated priority functions the latter attaches certain importance on the land use in comparison to competing uses. To preserve open space regional green belts and green corridors are defined. All instruments previously mentioned restrict residential development. Development axes along infrastructure and potential residential areas are two instruments attracting the allocation of residential land use. Development axes, defined as infrastructure lines, are not considered in this study separately because they are represented by the distance maps to railroads and roads already. In the Czech part of the study area an indicator approach is applied on municipal level to define development axes for urban developments (MMR and ÚÚR, 2006).

The maps are not used in the logistic regression analysis but in the calculation of the suitability maps to be able to distinguish between the impact of policy and no-policy scenarios. A complete list of all spatial planning datasets included can be found in table 1.

3.3.6. Neighbourhood measures

To account for spatial autocorrelation, autoregressive variables are included in the logistic regression analysis. The suitability values only depend on the land use in the surrounding cells. For these surroundings rings with different radius and width are distinguished. For the first ring, Fc3, the eight immediately surrounding neighbours, for the second ring, Fc5, the sixteen following cells, for the third ring, Fc9, the 56 following cells and so on are used. In total 11 rings are defined with an outer radius of 5000 meter (Fc41). The variables show the ratio of each of the three distinguished land use types within the rings. Figure 1 illustrates this approach.

A radius of 5000 m was applied because residential developments occurred in a certain distance to existing residential areas between 1990 and 2000.

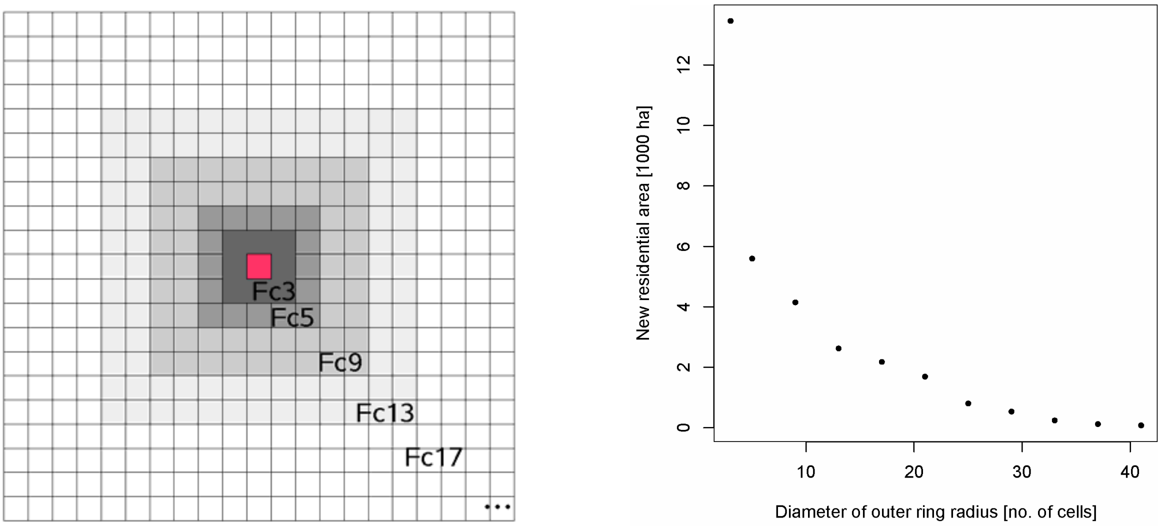

Figure 1: Definition of the autoregressive variables where the numbers represent the outer diameter of the rings in number of cells. Additionally the distribution of new residential cells between 1990 and 2000 amongst the defined rings is presented.

3.4. Scenario description

The study was part of a larger research project concerning the impact of global climate and socioeconomic change on the water cycle in the Elbe river basin (GLOWA-Elbe). Therefore, four scenarios are analysed based on the IPCC SRES story lines (Nakicenovic and Swart, 2000). The story lines A1 and B2 are chosen. They analyse two possible trajectories of regional economic and demographic development and are combined with two orientations of land use policy (0, +) (Hartje et al., 2008). The 0 scenarios represent a weak spatial planning policy while the + scenarios stand for a very restrictive policy.

Assumptions of the scenario $A1^0$ are based on higher growth rates of the economic development and spatial spill over effects from growth clusters, namely the metropolitan regions (Blazejczak et al., 2008). This results in increasing population except in peripheral regions and increasing wealth, which translates into increasing per capita living area, low building densities and thus a continuation of increasing residential land uses in the Elbe river basin. A weak regional spatial planning policy leads to a continuation of urban sprawl.

Based on the same socio-economic development of scenario $A1^0$, the scenario $A1^+$ is characterised by spatial planning policy that consequently implements the objective of sustainable development. Therefore the high demand for residential land is counteracted by higher building densities to reduce resource consumption. The spatial planning documents are strictly followed to realise a concentration of residential development in the sense of the central place theory.

Table 1: List of implemented suitability maps

		Abbreviation/ Classification	Description	Spatial coverage
Used only for simulation	Nature conservation areas	potstrcprot	Biosphere reserve	Elbe river basin
		potstrcprot	Flora-Fauna-Habitat areas	Elbe river basin
		potstrcprot	Landscape conservation area	Elbe river basin
		strcprot	Nature conservation area	Elbe river basin
		potstrcprot	Natural park	Elbe river basin
		strcprot	National park	Elbe river basin
		potstrcprot	Bird protection area	Elbe river basin
	Spatial planning data	Attracting	Potential residential areas	German part only
		Restricting	Regional green belts	German part only
		Restricting	Green corridors	Mecklenburg-Western Pomerania, Thuringia, Admin. Distr. of Leipzig
		Restricting	Priority area for arable land	Mecklenburg-Western Pomerania, Thuringia, Saxony-Anhalt, Saxony
		Restricting	Reserved area for nature and landscape	Mecklenburg-Western Pomerania, Thuringia, Saxony-Anhalt, Saxony
		Restricting	Priority area for nature and landscape	Mecklenburg-Western Pomerania, Thuringia, Saxony-Anhalt, Saxony
		Restricting	Reserved area for mining	Mecklenburg-Western Pomerania, Thuringia, Saxony-Anhalt, Saxony
		Restricting	Priority area for mining	Mecklenburg-Western Pomerania, Thuringia, Saxony-Anhalt, Saxony
		Restricting	Reserved area for flood protection	German part only
		Restricting	Priority area for flood protection	German part only
		Restricting	Reserved area for forest areas	Thuringia, Saxony
		Restricting	Priority area for forest areas	Thuringia, Saxony
		Attracting	National Development Plan	Czech part only
Used for regression analysis and simulation	Distance relations	EUC_FRW	Euclidian distance to freeway exits	Elbe river basin
		EUC_AIRP	Euclidian distance to airports	Elbe river basin
		EUC_STAT	Euclidian distance to stations	Elbe river basin
		EUC_RR	Euclidian distance to railroads	Elbe river basin
		EUC_RD	Euclidian distance to roads	Elbe river basin
		EUC_RES	Euclidian distance to current residential areas	Elbe river basin
		EUC_M	Euclidian distance to metropolitan cities	Elbe river basin
		EUC_MZ	Euclidian distance to middle and high order centres	Elbe river basin
		EUC_RECR	Euclidian distance to recreation areas	Elbe river basin
		SLOPE	Slope	Elbe river basin
	Spatial lag variables	FC3_GG1_00 FC3_GG1_90 FC41_GG9_00 …	Neighbourhood definition with Fc3, Fc5, Fc9, Fc13, Fc17, Fc21, Fc25, Fc29, Fc33, Fc37, Fc41 cells as outer diameter of each ring GG1=residential, GG9=arable land, GG10=pasture, 90=1990 and 00=2000	Elbe river basin

The scenario $B2^0$ assumes lower economic growth rates with a concentration on the metropolitan regions. Population increases solely in these regions, while rural areas suffer from declining population (Blazejczak et al., 2008). This leads to increasing demand of residential areas only in the growth clusters. Simultaneously, the lower level of wealth leads to increasing demand for reuse of vacancies in the cities, which reduces the residential land use demand. A weak regional spatial planning policy leads to a weaker continuation of urban sprawl.

The scenario $B2^+$ is based on the same socio-economic development like the scenario $B2^0$. But the consequently implemented spatial planning policy promotes high building densities and the realisation of the decentralised concentration of residential developments. This leads to residential demand solely in proximity to growth clusters.

3.5. Adaptation of regression results to scenarios

The regression estimation coefficients can directly be implemented as weights for the calculation of suitability values due to the inherent similarity of the logistic regression approach to the allocation algorithm of the Land Use Scanner. As there is a differentiation of location preferences between the four scenarios several adaptations are made. The first exception is the accessibility grid for the middle- and high-order centres. This is used only in the A1 scenarios. The accessibility of metropolitan regions is used in the B2 scenarios, instead. Additionally, the weights were set to higher values to promote the assumed development of the scenario storylines. The rationale is that future development of residential areas will be limited to the metropolitan peripheries in the B2 scenarios. The A1 scenarios are characterised by an increase in mobility, especially in individual transport. Therefore, the accessibility to the central places of lower hierarchies is also considered, in contrast to B2 scenarios.

The second exception is that the inner rings of the neighbourhood measures of residential development get higher values for the residential development of the B2 scenarios to pronounce the restriction of developments to the immediate neighbourhood of existing residential areas. Sprawl should be avoided.

Finally, the third exception is that maps representing spatial policy were not included in the regression analysis. Weights for these policy maps were applied only in the scenarios with stronger spatial policy (+) to reduce urban sprawl and to show their influence on residential development. To allow for the comparison of the different adaptations for the simulation of the scenarios a baseline simulation is added which consists of the unchanged coefficients estimated by the regression analysis. This results in five simulations with the Land Use Scanner.

4. Results

4.1. Location preferences for residential developments

This section presents the results of the binomial logistic regression analysis for residential land use changes between 1990 and 2000 for all three types of the logistic regression model.

An initial version of the regression models revealed two problems. The distance to airports showed a strong correlation of distances to metropolitan areas and higher order central places due to the proximity of the considered airports to their corresponding cities. Therefore, the variable was excluded from the analysis. Furthermore, the neighbourhood measures reveal uncertainty about their influence with increasing distance to a cell. The sign of the coefficients changes between rings of larger distance and they are not significant although residential developments occur in certain distances to existing residential areas. Therefore, all neighbourhood measures with an outer diameter of 17 or more cells are excluded from the regression analysis. Similar problems could be revealed by Loonen and Koomen (2008).

With the reduced set of variables the final regression analyses are calculated. The results are presented in table 2. The corresponding coefficients and goodness of fit measures of these final models do not differ considerably from the initial models. Therefore, it is concluded that the variables excluded form the initial models do not explain residential land use change adequately. In the following paragraphs the results of the final regression estimation are discussed.

The coefficients of the autoregressive model show the expected signs. The probability for residential areas rises if the amount of residential grid-cells in the neighbourhood rises. This effect first increases with increasing distance and than decreases again. This effect is also related to the average size of the clustered areas of residential grid-cells. With an average patch size of 106 ha for residential areas the variable FC9_GG1_90 indicates the radius of a mean residential area. Thus, if the border of a residential area is reached the probability for a cell to be residential area decreases first but increases again. The coefficients thus indicate development of residential areas in the proximity of existing residential areas but not inevitably with direct connection to them. The positive influence of agricultural areas in the residential neighbourhood confirms the development of residential areas on agricultural areas.

The second model, including only other explanatory variables, shows a significant influence on the location choice of residential areas, too. The probability for new residential areas decreases with increasing distance to train stations, roads and freeway exits. The distances to railroads have an opposite influence. While roads can directly be accessed from nearly everywhere railroads can not. To access the railroad network the distance to train stations is a more relevant parameter. An important location factor is the distance to residential areas. With increasing distance the probability of new residential areas decreases. The higher value of the distance to all residential areas in comparison to the distance to central places indicates that residential developments are not restricted to the outskirts of the cities but also occur surrounding the smaller villages. While proximity to middle order and high order central places attracts new residential development, although to a lower degree, this is not the case if considering only metropolitan areas. This indicates the decoupling of residential developments from the economic development and shows the catching up process in suburbanisation. The full factor model shows similar results except for the FC13_GG1_90 variable. The variable gets a negative sign in the full factor model indicating decreasing probability of residential areas if the share of residential land is already high in larger distances.

Table 2: Estimated coefficients of the binomial logit models for residential land use changes between 1990 and 2000. Method is Enter.

	Full model	Autoregressive model	Model with other explanatory variables
Euclidian distance to freeway exits	-2.887***		-2.934***
Euclidian distance to stations	-1.624**		-1.678**
Euclidian distance to railroads	0.703*		0.714*
Euclidian distance to roads	-6.207***		-6.314***
Euclidian distance to current residential areas	-4.790***		-9.216***
Euclidian distance to metropolitan cities	-0.024		0.185
Euclidian distance to middle and high order centres	-0.556*		-0.563**
Euclidian distance to recreation areas	-1.527***		-1.473***
Slope	-6.127***		-10.279***
FC3_GG1_90	1.509***	2.129***	
FC5_GG1_90	3.037***	3.829***	
FC9_GG1_90	0.098	0.390	
FC13_GG1_90	-1.991***	1.153**	
FC3_GG9_90	2.219***	2.281***	
FC5_GG9_90	0.082	0.236	
FC9_GG9_90	0.466	0.711**	
FC13_GG9_90	-2.080***	-1.763	
FC3_GG10_90	0.851**	0.863***	
FC5_GG10_90	1.205**	1.276**	
FC9_GG10_90	-0.924	-0.544	
FC13_GG10_90	-1.255**	-0.697***	
Constant	0.343**	-2.639***	1.535***
ROC-value	0.837	0.786	0.800

* Indicates statistical significance at the 10% level.
** Indicates statistical significance at the 5% level.
*** Indicates statistical significance at the 1% level.

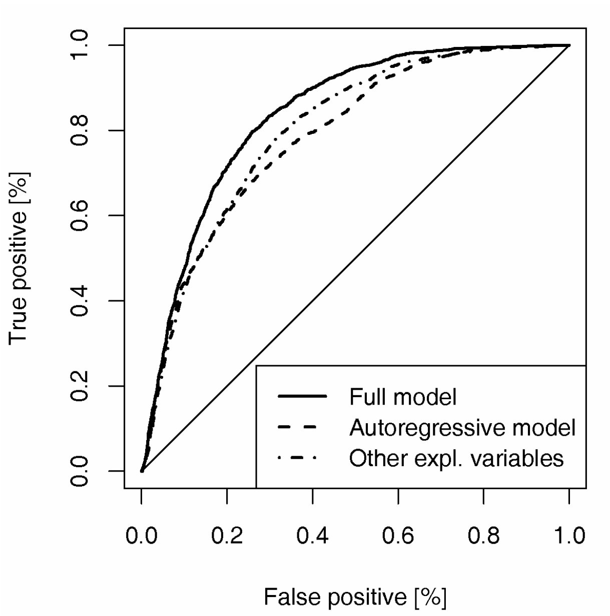

Figure 2: ROC-curve of post 1990 residential developments.

For validation purposes the corresponding ROC-curves for residential development of all three regression models are presented in figure 2 to show the ability of the estimation results to predict location of residential land use changes in the period 1990 to 2000. The area under the ROC-curve is shown in table 2. Both models the autoregressive as well as the model with other explanatory variables, indicate high ROC-values. It can marginally be increased due to the combination of both sets of variables in the full model and has therefore the best predictable power of all three regression models. Thus the estimation approach is suitable to predict locations for future residential land use changes. The full factor model will further be used for the simulation of residential land use change because of its highest ROC-value.

4.2. Simulation of residential development

The estimated regression coefficients of the full binomial logistic model are adapted and implemented into the land use change model and future residential land use changes were simulated for all five scenarios. The suitability values of all scenarios show a more peaked distribution in comparison to a standardised normal distribution and show thus the expected distribution. The effect of numerical diffusion has been reduced. The number of patches and the mean patch size presented in table 3 indicate this development. The number of patches decreases in the B2 scenarios. Although the number of patches in the A1 scenarios increases the patch size increases also considerably. Thus, the residential development shows a concentration of urban cells.

Table 3: Urbanisation indicators

	Current land use	Baseline	$A1^0$	$A1^+$	$B2^0$	$B2^+$
Total residential area [ha]	941812.5	992325	994237.5	994162.5	991787.5	992018.75
Share of residential area within study area [%]	6.4420	6.7902	6.8027	6.8033	6.7881	6.7865
Number of Patches	8859	8831	8947	8946	8783	8769
Mean residential patch size [ha]	106.3114	112.3684	111.1252	111.1293	112.9213	113.1279
Connectivity	0.0013	0.0012	0.0013	0.0014	0.0012	0.0012

The landscape metrics presented in table 3 are further applied to quantify the degree of urbanisation and urban sprawl in the five simulations for the total residential area (Ritsema van Eck and Koomen, 2008). In comparison to the year 2000 the number of patches decreases in the baseline and B2 scenarios and increases in the A1 scenarios. Accompanying with this development the average patch size increases, considerably. This suggests a coalescence of residential areas in the scenarios with decreasing number of patches but cannot be observed as the connectivity index shows. Changes in connectivity in comparison to 2000 are only marginally in all five simulations.

Figure 3 shows the increase in residential land on grid-cells. All five scenarios show hotspots of residential development in and around the metropolitan regions of Hamburg, Berlin and Prague. While in the region of Hamburg the south of the core city show the highest increase in residential areas in Berlin a radial orientation of growth along the important infrastructure lines can be observed. This is a continuation of the current trend. Furthermore the high and middle order central places show significant increases in residential development, especially in the A1 scenarios.

Figure 4 presents the residential development among different size groups of growth within municipalities. Approximately 90% of all municipalities in the A1 scenarios show an increase in residential land of less than 5%. This share decreases to 80% in the B2 scenarios. More than 50ha increase in residential land can be found in 2.5% and 2% of all municipalities in the scenarios A1 and B2, respectively. 70% and 50% of the total newly allocated residential land is allocated in these municipalities with more than 50ha increase. This increase occurs in the already large municipalities of the study area. In all scenarios there is a strong correlation between absolute size of current residential area and growth until 2020. The results show a more concentrated residential development in the A1 scenarios and ongoing dispersed developments in the B2 scenarios.

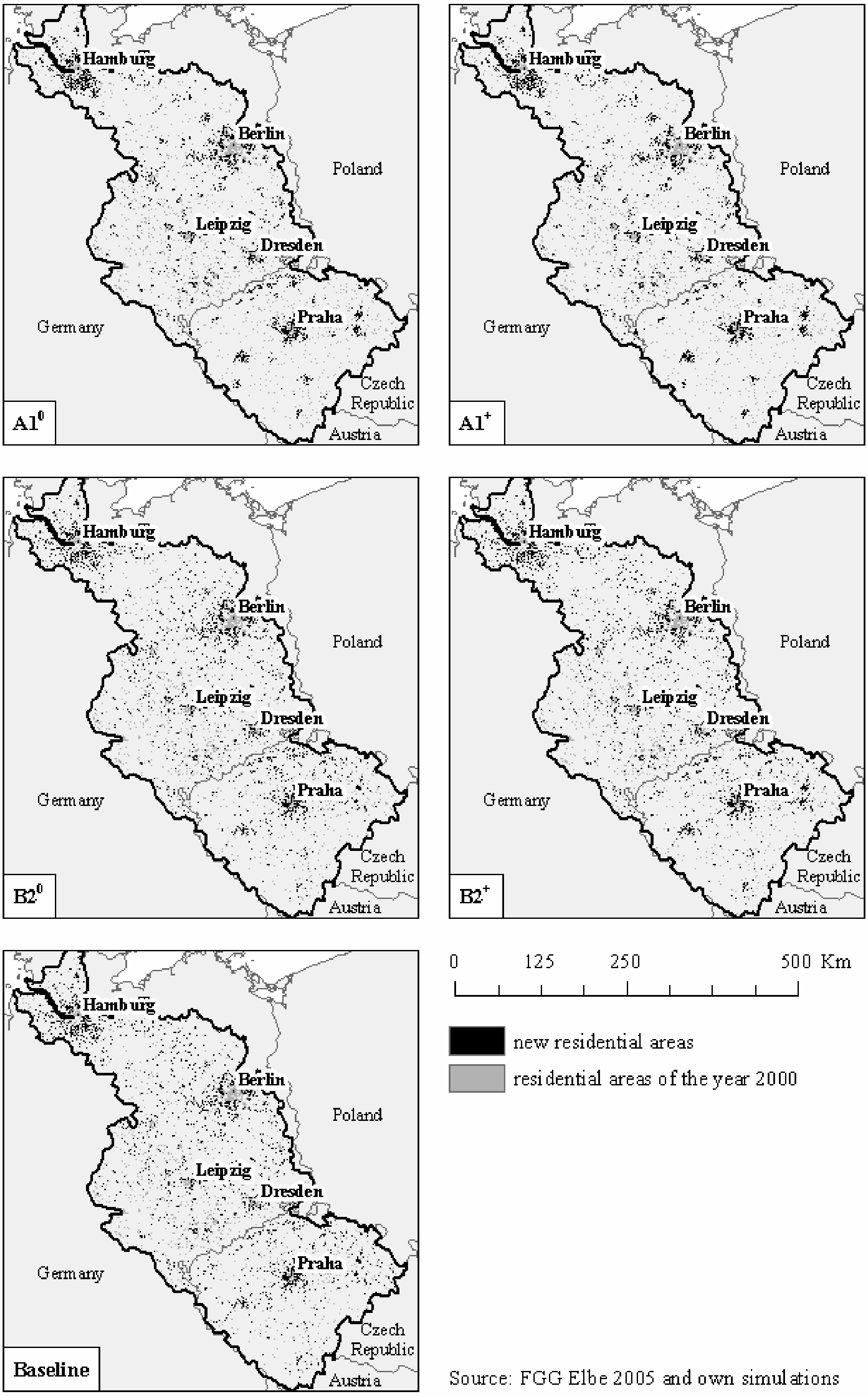

Figure 3: Absolute growth of residential area on grid cells.

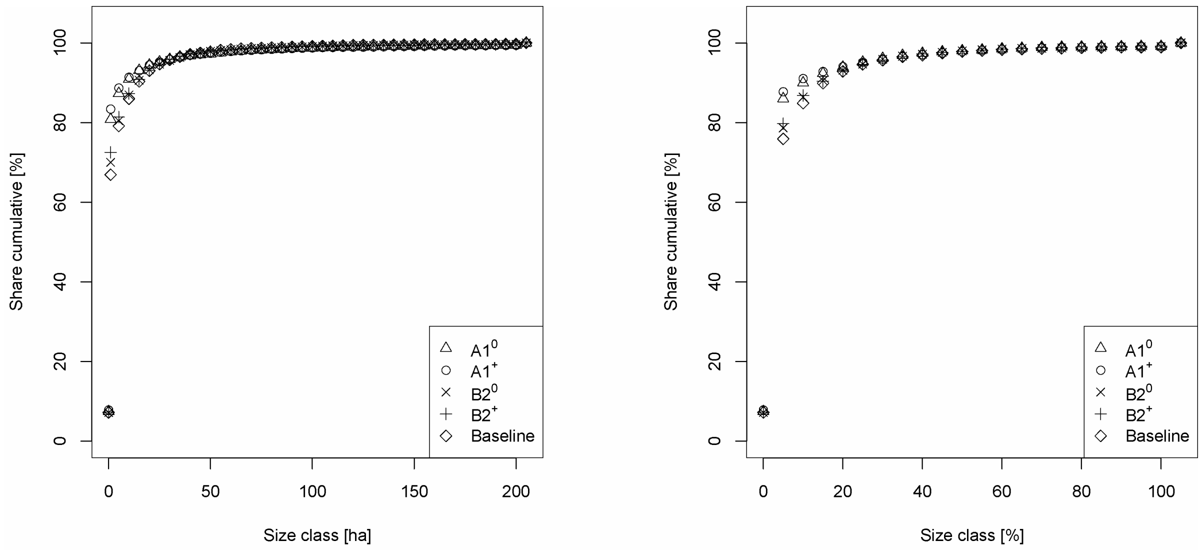

Figure 4: Cumulative share of municipalities in different size groups of growth. (a) absolute growth in ha, (b) relative growth in %

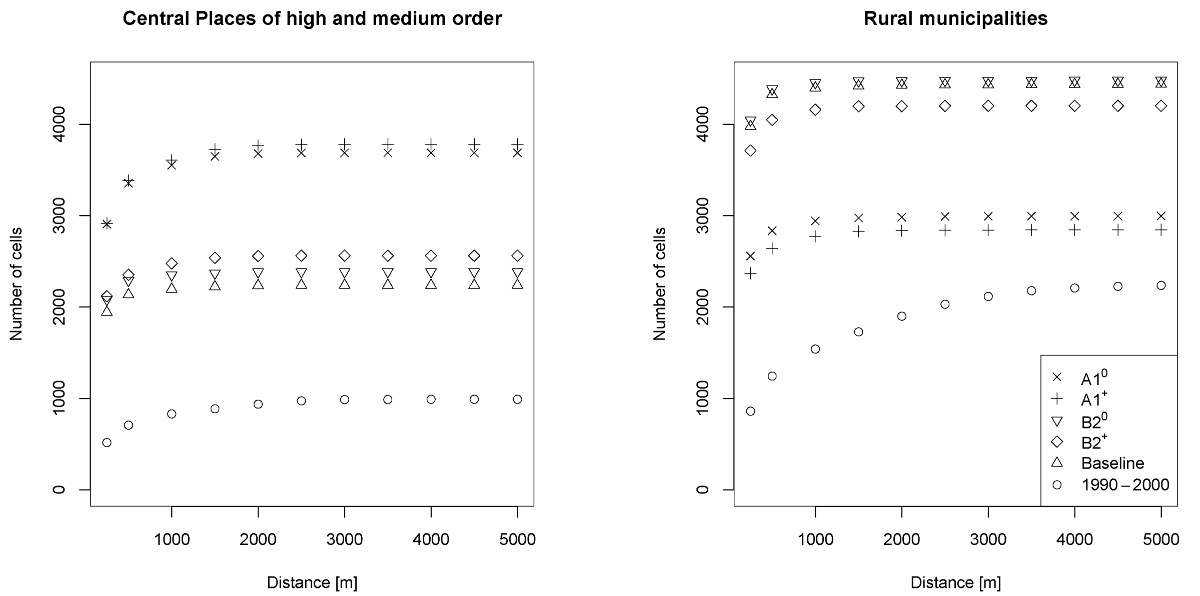

Figure 5: Cumulative distribution of residential development for two types of settlement structure within different distances from current residential areas and scenarios.

This observation is confirmed by figure 5. If the municipalities are classified by their settlement structure as proposed by the BBR, regional differences in the development can be found. For visualisation purposes the 17 types of settlement structure are aggregated to 5 types in this study: metropolitan cities, cities classified as high or middle order central places, very densely populated municipalities, dense and rural municipalities. The figure shows two types of municipalities: high and middle order central places as well as rural municipalities. The high and middle order central places are those with very high increases in the A1 scenarios. In contrast, the B2 scenarios show highest increases in residential land in the rural municipalities. Figure 5 also shows that residential developments occur in a maximum distance from current residential areas of 2000 m in central place municipalities of high and middle order and of 1000m in rural municipalities. This development reflects the results of the logistic regression analysis where neighbourhood measures were only included up to a distance of 1500m. But the figure shows that in the case of the rural municipalities residential areas developed also in a larger distance than 1500m in the past (1990-2000).

Care must be taken with the interpretation of the types of settlement structure since their distribution in the Elbe river basin is not equal. Rural municipalities account for approximately 60% of the total study area and the metropolitan as well as high and middle order centres together for only 11%. While the share of the total newly allocated residential land in metropolitan regions and central place municipalities of middle and high order between 1990 and 2000 was approximately 8%, this share doubles to 17% in the scenarios. The share of all new residential areas in rural municipalities decreases in comparison to the past developments. This development can be observed in all five simulations resulting in a more concentrated development in and around the cities.

Concerning nature protection some interesting developments revealed. Residential development in nature conservation areas is presented in table 4. The scenarios with stronger spatial policy supposed to prevent the (strictly and potentially strict) protected areas from residential development while the 0 scenarios are supposed to protect only the strictly protected nature conservation areas. Table 4 shows that in all scenarios the amount of residential land in nature conservation areas increases. While the increase of residential land in potentially strict protected areas of the + scenarios is below 2%, the 0 scenarios show an increase of more than 5%. This increase is even higher for the strictly protected areas. The increase is even higher in the + scenarios. There are many nature conservation areas, especially in the hinterland of Berlin and Prague. The scenario assumptions attract residential developments to exactly these regions. To prevent residential areas to develop in potentially strict protected areas the impact on the strictly protected nature increases.

Table 4: Amount of cells allocated as residential by at least 33% of the cell in nature conservation and planning areas.

		Current	Baseline	$A1^0$	$A1^+$	$B2^0$	$B2^+$
Nature conservation							
Strictly protected areas	number of cells	346	367	367	376	371	377
	% change		6.07%	6.07%	8.67%	7.23%	8.96%
Protected areas with potential to be strictly protected	number of cells	27037	28732	28524	27385	28734	27455
	% change		6.27%	5.50%	1.29%	6.28%	1.55%
Total in nature conservation area	number of cells	22103	23461	23349	22406	23490	22460
	% change		6.14%	5.64%	1.37%	6.28%	1.62%
Percent change to current residential land in nature conservation areas			6.14%	5.64%	1.37%	6.28%	1.62%
Share of residential areas in nature conservation areas		2.15%	2.29%	2.27%	2.18%	2.29%	2.19%
Spatial planning							
Instruments attracting residential developments	number of cells	3203	3961	4146	4222	3956	4232
	% change		23.67%	29.44%	31.81%	23.51%	32.13%
Instruments restricting residential developments	number of cells	15832	16360	16405	15842	16308	15847
	% change		3.34%	3.62%	0.06%	3.01%	0.09%
Total in planning areas	number of cells	21857	23355	23569	23153	23315	23158
	% change		6.85%	7.83%	5.93%	6.67%	5.95%
Percent change to current residential land in planning areas			6.85%	7.83%	5.93%	6.67%	5.95%
Share of residential areas in planning areas		3.08%	3.29%	3.32%	3.26%	3.28%	3.26%

With regard to the other policy maps the development is as expected. The implementation of the spatial planning instruments has an impact on the allocation of residential areas. This can be seen in the comparison of the scenario results with the baseline simulation. This is the case especially for the priority and reserve areas for different land use functions. Stronger impacts can be observed for those instruments that are applied especially in urban areas like potential residential areas, green belts and green corridors.

5. Discussion

The objective of this paper was first, to analyse the feasibility of using logistic regression coefficients as input in the weighting process for the calculation of suitability maps in a land use change study. The rationale was to reduce the effect of numerical diffusion and to apply adapted weights to a scenario study. The analysis of the potential impact of the application of Christaller's central place theory in comparison to not apply spatial policy at all was the second objective.

The results of this first application of a binomial logistic regression analysis as input in the weighting of suitability maps for a scenario study are promising. Explaining location preferences by logistic regression analysis is a feasible approach but with all shortcomings discussed by Verburg et al, (2004a). The distribution of suitability values is rather peaked and leads to satisfying simulation results with reduced numerical diffusion in all five simulations.

The application of the autoregressive variables reveals a particularity. Although residential changes, and not the pattern of residential areas, were estimated, the autoregressive variables have a limited influence, only, with respect to the distance. This influence depends on the mean patch size of residential areas. The development of residential areas in a certain distance from existing residential areas is hardly covered by the estimation results. This effect was observed by Loonen and Koomen (2008), already.

The most important determinants of residential changes are the distance to current residential areas and the distance to infrastructure for individual traffic. Nevertheless, the logistic regression coefficients revealed some interesting results. The coefficients for the distance to metropolitan regions and central places have low influence on the allocation of residential areas for the calibration period 1990 to 2000. This is plausible since residential developments occurred independently from socioeconomic developments in that time. In the future a different development is expected. Current statistical surveys reveal that some regions in the Elbe river basin gain population back and it emerges that metropolitan regions develop to hotspots of future residential developments. These developments were allowed for in the scenario analysis. Thus the results of the different scenarios may give an insight into the near future of the Elbe river basin.

The combination of a thorough statistical approach with a relatively simple scenario approach is promising. The logistic regression gives an insight into the determinants of location choice in the study area and thus contributes to objectify the determination of the weights for suitability maps. The adaptation of the regression estimation concerns only single variables and not the complete set so that the adaptation remains subjectively but with a deeper understanding of the researcher for past processes. The scenario results also revealed that slight changes in the weights do not result in significant differences of the simulation results. Thus the suitability maps are not very sensitive to slight changes in the weights. To account for the scenario assumptions distinct differences of weights for suitability maps to the baseline scenario are necessary.

One proposition to reduce the subjective component in the scenario analysis could be to find prototype regions whose current development complies with certain scenario storylines and carry out statistical analysis for these regions. The region specific estimation results could be applied to the different scenarios then.

Although only a minority of rural municipalities show high increases in residential area altogether most residential area is still allocated in rural areas. But the distribution is much more concentrated on the municipalities and their hinterland that belong to central places of middle or higher order and metropolitan regions. Therefore, the concept of decentralised concentration results in area wide growth but with focus on the urban regions. The metropolitan areas strengthen their dominant position within residential developments. Since the core cities are not able to grow unlimited, the rural hinterland shows ongoing sprawl. This is the case especially in the B2 scenarios where the demand for land cannot be realised in the direct neighbourhood of the cities. Thus, residential development occurs more spread out in the study area (figure 3). The A1 scenarios in contrast reveal a polarisation of residential developments to the cities and their hinterland.

The application of spatial planning instruments in the weighting process for the calculation of suitability maps was successful. The simulation results confirm the theoretical analysis of Heiland et al. (2006), that nature conservation areas are able to influence the allocation of residential areas. Although attention must be paid because the impact on the remaining landscape outside the different types of nature conservation areas becomes even higher. The scenarios with strong spatial policy reveal the highest impact on the strictly protected areas, due to scarcity of suitable land for residential areas if all nature conservation areas with potential to be strictly protected are strictly protected. Thus this scenario analysis shows the impact of theoretically given recommendations to decision makers. It shows that a recommendation to change regulatory frameworks for nature conservation areas to prevent these areas from residential development can result in increasing pressure on the protected areas. This example shows that land use change models can be a valuable tool to supplement the decision or discussion making process.

The analysis of the development in spatial planning regions shows a high environmental impact also on areas preserved for different land uses than residential land. This study shows a potential contribution of land use change modelling to the discussion support during the development of regional spatial planning documents. Due to the implementation of spatial planning documents into the Land Use Scanner, desirable or undesirable impacts of certain planning instruments on the future pattern of land use and land cover can be pointed out and recommendations could be given to decision makers. This procedure is current practice, for example, in the Netherlands already (Schotten et al., 2001).

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7. References

Adam B, Göddecke-Stellmann J, 2002, "Metropolregionen - Konzepte, Definitionen und Herausforderungen" *Informationen zur Raumentwicklung* 513 - 525

Agarwal C, Green G M, Grove J M, Evans T P, Schweik C M, 2002, "A review and assessment of land-use change models: dynamics of space, time, and human choice", *General Technical Report NE-297* (PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newton Square), http://nrs.fs.fed.us/pubs/gtr/gtr_ne297.pdf

Anselin L, 2002, "Under the hood: Issues in the specification and interpretation of spatial regression models." *Agricultural Economics* **27** 247-267

Aspinall R J, 2004, "Modelling land use change with generalized linear models - a multi-model analysis of change between 1860 and 2000 in Gallatin Walley, Montana." *Journal of Environmental Management* **72** 91--103

Blazejczak J, Gornig M, Schulz E, Schäpel C, 2008, "Szenarien zur Demographie und Ökonomie in der Elbe-Region." *Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II* (Potsdam)

Borsboom-van Beurden, J.A.M., Bakema, A. and Tijbosch, H., 2007, "A land-use modelling system for environmental impact assessment; Recent applications of the LUMOS toolbox", in *Modelling Land-Use Change. Progress and Application* Eds E Koomen, J Stillwell, A Bakema, H J Scholten (Dordrecht) pp 281-296

Briassoulis H, 2000, "Analysis of Land Use Change: Theoretical and Modeling Approaches", Department of Geography, University of the Aegean, Lesvos, Greece, http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm

BBR (Bundesamt für Bauwesen und Raumordnung), 2005 *Raumordnungsbericht 2005.* (Bonn)

BBR (Bundesamt für Bauwesen und Raumordnung), 2006 *Raumordnungsprognose 2020/2050* (Bonn)

BBR (Bundesamt für Bauwesen und Raumordnung), 2007, "INKAR 2006 - Indikatoren, Karten und Graphiken zur Raum- und Stadtentwicklung in Deutschland und in Europa"

CRR (Centre for Regional Development of the Czech Republic), 2006, "Integriertes regionales Informationssystem", http://www.iriscrr.cz/index.php?m=1&l=de

Chomitz K M, Gray D A, 1996, "Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize" *The World Bank Economic Review* **10** 487-512

Coles T, 1997, "Trading places : The evolution of the retail sector in the new German Länder since unification" *Applied Geography* **17** 315-333

Dekkers J E C, Koomen E, 2007, "Land-use simulation for water management. Application of the Land Use Scanner in two large-scale scenario studies", in *Modelling Land-Use Change. Progress and Application* Eds E Koomen, J Stillwell, A Bakema, H J Scholten (Dordrecht) pp 355-373

Dendoncker, N, Bogaert, P, Rounsevell, M, 2007, "Empirically derived probability maps to downscale aggregated land-use data", in *Modelling Land-Use Change. Progress and Application* Eds E Koomen, J Stillwell, A Bakema, H J Scholten (Dordrecht) pp 117-131

Dosch F, Beckmann G, 1999, "Trends und Szenarien der Siedlungsflächenentwicklung bis 2010." in *Perspektiven der künftigen Raum- und Siedlungsentwicklung.* Eds W Strubelt, H-P Gatzweiler, R Kaltenbrunner (Bundesamt für Bauwesen und Raumordnung, Bonn.) pp 827 - 842

Eurostat (Statistical Office of the European Communities), 2007, "Bodennutzung nach Hauptkategorien", http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,45323734&_dad=portal&_schema=PORTAL&screen=welcomeref&open=/env/env_land&language=de&product=EU_MASTER_environment&root=EU_MASTER_environment&scrollto=0

Gordon P, Wong H L, 1985, "The Costs of Urban Sprawl - Some New Evidence" *Environment and Planning A* **17** 661-666

Hartje V, Ansmann T, Blazejczak J, Gömann H, Gornig M, Grossmann M, Hillenbrand T, Hoymann J, Kreins P, Markewitz P, Mutafoglu K, Richmann A, Sartorius C, Schulz E, Vögele S, Walz R, 2008, "Regionalisierung der Szenarioanalyse (der Antriebskräfte und des Nutzungsdruckes) des globalen Wandels für die Wasserwirtschaft." *Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II* (Potsdam)

Heiland S, Reinke M, Siedentop S, Träger T, Knigge M, Meyer-Ohlendorf N, Blobel D, 2006 *Beitrag naturschutzpolitischer Instrumente zur Steuerung der Flächeninanspruchnahme.* (Bonn)

Hilferink M, Rietveld P, 1999, "LAND USE SCANNER: An integrated GIS based model for long term projections of land use in urban and rural areas." *Journal of Geographic Information Systems* **1** 155-177

Hoymann J, 2008, "Szenarien der Siedlungsflächenentwicklung im Elbeeinzugsgebiet", *Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II* (Potsdam)

CIAT (International Centre for Tropical Agriculture), 2004, "SRTM data V3", http://srtm.csi.cgiar.org.

King G, Zeng L, 2001, "Logistic Regression in Rare Events Data" *Political Analysis* **9** 137-163

Lambin E F, Turner B L, Geist H J, Agbola S B, Angelsen A, Bruce J W, Coomes O T, Dirzo R, Fischer G, Folke C, George P S, Homewood K, Imbernon J, Leemans R, Li X, Moran E F, Mortimore M, Ramakrishnan P S, Richards J F, Skanes H, Steffen W, Stone G D, Svedin U, Veldkamp A, Vogel C, Xu J, 2001, "The causes of land-use and land-cover change: moving beyond the myths." *Global Environmental Change* **11** 261 - 269

LZB (Landeszentralbank in Berlin und Brandenburg), 2001, "Stand und Perspektiven des Wohnungsbaus in Brandenburg." in *Jahresbericht* pp 65 - 108

Loonen W, Koomen E, 2008, "Calibration and validation of the Land Use Scanner allocation algorithms." *Rapport* Ed M-e Natuurplanbureau (Bilthoven)

MMR and ÚÚR (Ministry for Regional Development of the Czech Republic, Institute for Spatial Development), 2006, "Spatial Development Policy of the Czech Republic."

Nakicenovic N, Swart R, 2000, "Special Report Emissions Scenarios." Ed Intergovernmental Panel on Climate Change

Overmars K P, de Koning G H J, Veldkamp A, 2003, "Spatial autocorrelation in multi-scale land use models." *Ecological Modelling* **164** 257--270

Penn-Bressel G, 2003, "Reduzierung der Flächeninanspruchnahme durch Siedlung und Verkehr. Materialienband," *Texte 09/03* Ed Umweltbundesamt (Umweltbundesamt, Berlin), http://www.umweltdaten.de/publikationen/fpdf-l/2587.pdf

Pontius Jr R G, Batchu K, 2003, "Using the Relative Operating Characteristic to Quantify Certainty in Prediction of Location of Land Cover Change in India" *Transactions in GIS* **7** 467-484

Pontius R G, Schneider L C, 2001, "Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA" *Agriculture Ecosystems & Environment* **85** 239-248

Prentice R L, Pyke R, 1979, "Logistic disease incidence models and case-control studies" *Biometrika* **66** 403-411

Pushkarev B, 1975, "Costs of Sprawl - Environmental and Economic Costs of Residential Development Patterns at Urban Fringe - Real-Estate-Research-Corporation" *Ecology Law Quarterly* **5** 189-194

RNE, 2004, "Mehr Wert für die Fläche: Das "Ziel-30-ha" für die Nachhaltigkeit in Stadt und Land." Rat für Nachhaltige Entwicklung, http://www.nachhaltigkeitsrat.de/uploads/media/Broschuere_Flaechenempfehlung_01.pdf

ROG (Raumordnungsgesetz) vom 18.August 1997 (BGBl. I S 2081), zuletzt geändert am 24. Juni 2004 (BGBl. I S. 1359), (engl: Regional planning act)

Rietveld P, Wagtendonk A J, 2004, "The location of new residential areas and the preservation of open space: experiences in the Netherlands." *Environment and Planning A* **36** 2047 - 2063

Ritsema van Eck, J, Koomen, E, 2008 "Characterising urban concentration and land-use diversity in simulations of future land use," *Annals of Regional Science* 42 123-140

Schotten C G J, Goetgeluk R, Hilferink M, Rietveld P, Scholten H J, 2001, "Residential construction, land use and the environment. Simulations for the Netherlands using a GIS-based land use model." *Environmental Modeling and Assessment* **6** 133 - 143

Serneels S, Lambin E F, 2001, "Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model" *Agriculture, Ecosystems & Environment* **85** 65-81

Siedentop S, 2005, "Problemdimension der Flächeninanspruchnahme." in *"Flächenverbrauch" und "Bodenbewusstsein" - Nationale Strategie und lokale Umsetzung.* 31.January 1005, A Besecke, R Hänsch, M Pinetzki, Berlin pp 11-22

STABU (Statistisches Bundesamt), 2006, "Zunahme der Siedlungs- und Verkehrsfläche: 114 ha/Tag." (Statistisches Bundesamt), http://www.destatis.de/presse/deutsch/pm2006/p4920112.htm

STABU (Statistisches Bundesamt), 2007, "Siedlungs- und Verkehrsfläche nach Art der tatsächlichen Nutzung. Erläuterungen und Eckzahlen 2006" *Bodenfläche nach Art der tatsächlichen Nutzung* **Fachserie 3 / Reihe 5.1**

Tobler W, 1979, "Cellular Geography." in *Philosophy in Geography.* Eds S Gale, O C. (Reidel, Dordrecht) pp 379-386

Turner M G, Wear D N, Flamm R O, 1996, "Land Ownership and Land-Cover Change in the Southern Appalachian Highlands and the Olympic Peninsula" *Ecological Applications* **6** 1150-1172

UBA (Umweltbundesamt), 2004, "CORINE Land Cover." Eds Umweltbundesamt, DLR-DFD,

Van der Hoeven N, Aerts J, Van der Klis H, Koomen E, 2008 (forthcoming), "An Integrated Discussion Support System for New Dutch Flood Risk Management Strategies." in *Planning Support Systems: Best Practices and New Methods.* Eds S Geertman, J Stillwell (Springer, Berlin)

Verburg P H, Ritsema van Eck J R, de Nijs T C M, Dijst M J, Schot P, 2004a, "Determinants of land-use change patterns in the Netherlands." *Environment and Planning B: Planning and Design* **31** 125 - 150

Verburg P H, Schot P, Dijst M J, Veldkamp A, 2004b, "Land use change modelling: current practice and research priorities." *GeoJournal* **61** 309--324

Verburg P H, Schulp C J E, Witte N, Veldkamp A, 2006, "Downscaling of land use change scenarios to assess the dynamics of European landscapes." *Agriculture, Ecosystems and Environment* **114** 39 - 56

Wear D N, Bolstad P, 1998, "Orginal Article: Land-Use Changes in Southern Appalachian Landscapes: Spatial Analysis and Forecast Evaluation" *Ecosystems* **1** 575-594