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Quantifying demand for built-up area

A comparison of approaches and application to regions with stagnating population

Von

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ABSTRACT/ZUSAMMENFASSUNG

Quantifying demand for built-up area - A comparison of approaches and application to regions with stagnating population

Land use changes in urban environments can lead to huge pressures for governments. Accurate projections of future developments of built-up areas are crucial for sustainable development and protecting the natural environment. This paper reviews approaches to project developments of built-up area. A selection of these approaches is applied to Germany and the Czech Republic, and the results are quantitatively compared. The advantages and disadvantages of the different approaches are analysed and discussed. The results reveal a high uncertainty when projecting past changes with the selected approaches. The spatial scale, variable selection, and the spatial structure of the study area have a significant influence on the results. Both study areas are characterised by metropolitan areas and rural populated regions. Achieving high accuracy projections for rural and urban areas remains difficult.

Bestimmung der Siedlungsflächennachfrage – Methodenvergleich und Anwendung für Regionen mit stagnierender Bevölkerung

Landnutzungsänderungen im urbanen Raum üben großen Druck auf Regierungen aus. Möglichste genaue Projektionen der künftigen Entwicklung von Siedlungs- und Verkehrsflächen sind unabdingbar auf dem Weg zu einer nachhaltigen Entwicklung und dem Schutz der natürlichen Ressourcen. Dieser Artikel stellt eine Auswahl an Methoden zusammen, welche zur Projektion künftiger Siedlungsflächennachfrage als geeignet erscheinen und erläutert sie. Diese Methodenauswahl wird daraufhin für einen vergangenen Zeitraum in Deutschland und die Tschechische Republik angewendet und die jeweiligen Ergebnisse der Methoden miteinander verglichen. Die Vor- und Nachteile der Methoden werden untersucht und diskutiert. Die Ergebnisse zeigen, dass Projektionen künftiger Siedlungsflächenentwicklungen nachwievor mit hohen Unsicherheiten versehen sind. Die räumliche Skala, die Raumstruktur und die Variablenauswahl haben großen Einfluss auf die Ergebnisse. Beide Untersuchungsgebiete sind durch einige große Metropolen und sehr ländliche Gebiete charakterisiert. Das Erzielen hoher Genauigkeiten für Projektionen der Zukunft bleibt eine Herausforderung.

Keywords: built-up area; land use demand; land use modelling; land use change; statistical analysis

1. Introduction

The world's population is steadily increasing resulting in accelerating urbanisation. More than 50% of the world's population and more than 75% of the European population now lives in urban areas (UNEP 2002, 2007). Stagnating and decreasing population have been observed in several European countries (Eurostat 2009), but this stagnation does not necessarily result in stagnating or decreasing development of the urban area. Urban areas are still growing. The following Figure 1 gives an impression of the development during the last decade. Urban density is declining in parts of Germany (Siedentop and Kausch 2004), where a contradicting development of socio-economic indicators and urban areas is observed. In the Czech Republic a stabilisation of population and urban area development is observed (CZSO 2009).

Are there approaches for projecting the past development of built-up areas in study areas with a post-socialist history? The objective for future research is to project future developments.

Different approaches were developed to analyse past developments of population and urban areas and to calculate the future demand for urban areas. These approaches, originating from different scientific disciplines, focus on different study areas, datasets, temporal and spatial scales. Selecting the most suitable approach is difficult because an immediate comparison of results is not possible. Therefore, this paper will present a comparative analysis of different approaches to calculate the demand for urban land use. Three constraints are considered. First, the approaches are applied consistently to the same dataset. Second, the approaches are analysed for their appropriateness for considering the diverging development of the population and built-up area. Third, the approaches are applied to two different spatial scales in two different study areas, to determine the transferability of an approach to different study areas.

The remainder of this paper reviews approaches from different disciplines that are concerned with the development of urban areas. Following the review section, the selected and applied approaches are described in detail. The datasets and constraints are described. The results section compares the results of the different approaches, and the applicability of the approaches to regions with demographic change is discussed. Some conclusions and suggestions for future research are given.

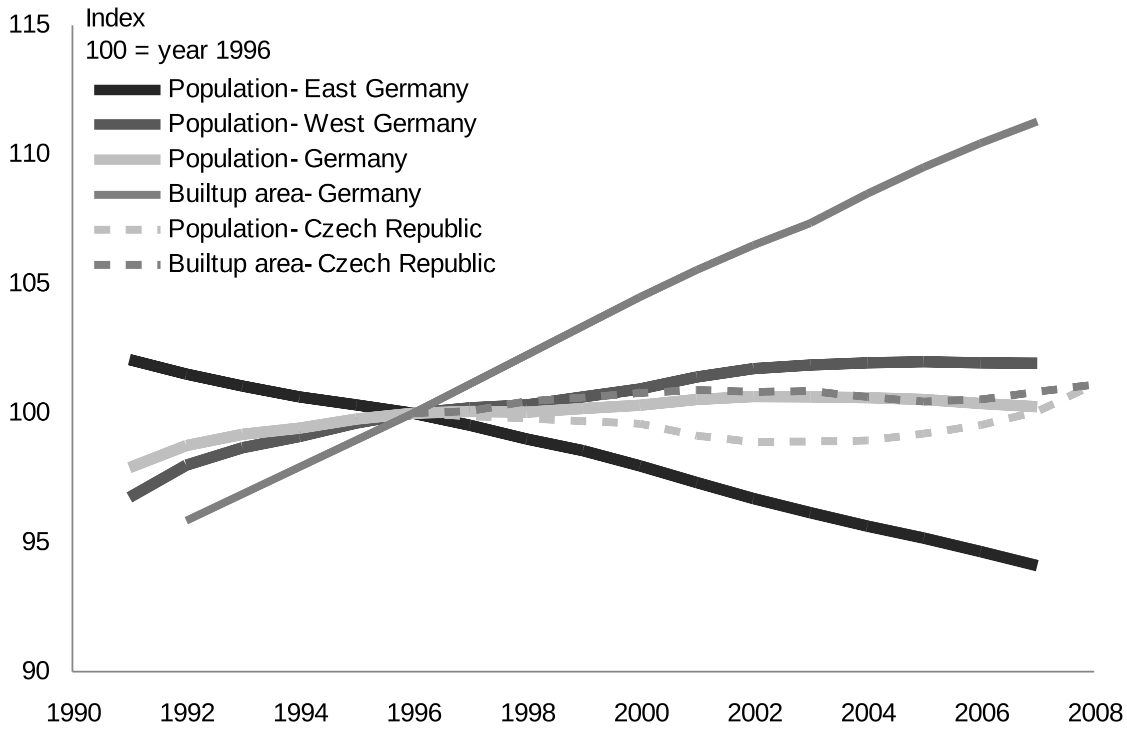

Figure 1: Population development and development of built-up area in Germany and Czech Republic. (Source: STABU 2009, CZSO 2009)

2. Study Area

Germany and the Czech Republic are the countries being studied (Figure 2). These countries are located in central Europe and both have a post-socialist history. The eastern parts of Germany are economically supported by the western parts of the country. This situation is not true in the Czech Republic. Therefore, the dynamic economic development and urban land use changes are lower in the Czech Republic than in Germany (Table 1).

Table 1: Basic indicators of the study area for the year 2004 (Source: STABU 2006, CZSO 2008)

Indicator	Unit	Germany	Czech Republic	Cz share in % of Ge
Population	Mio	80.0	10.0	12.5
Area	Mio ha	35.7	7.9	20.0
Built-up Area	Mio ha	4.5	0.1	3.0
GDP per Capita in current prices	Thousand €	26.8	8.6	34.0

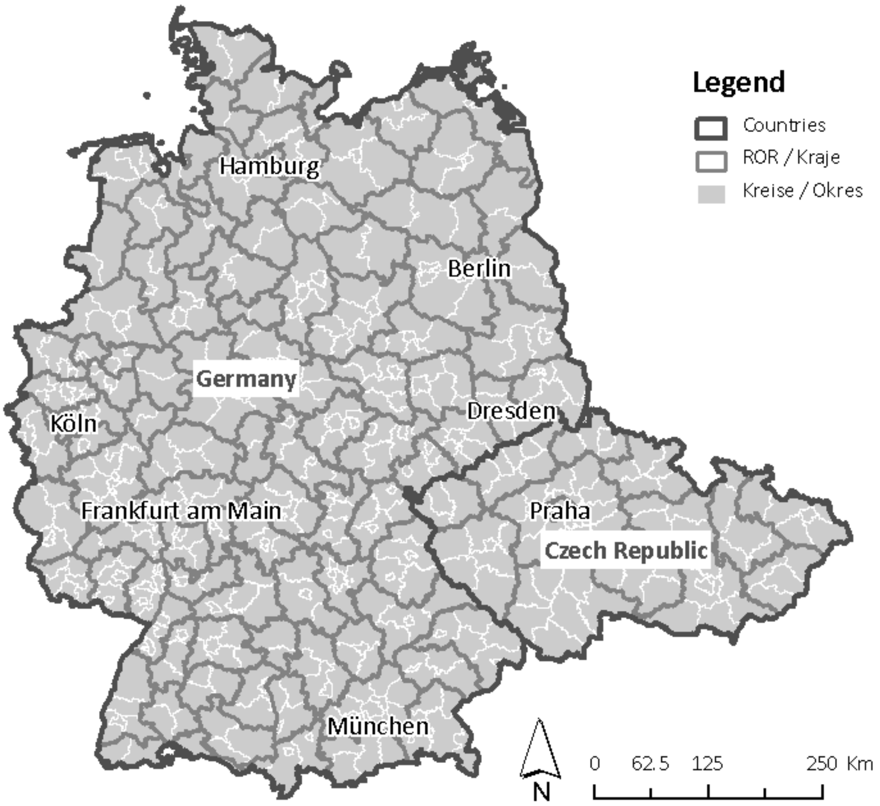

Figure 2: Overview Study Area (Source: BKG 2006, ÚÚR 2005)

Germany is characterised by a polycentric settlement structure (BBR 2005). Large metropolitan areas are surrounded by more rural areas. The population density varies across both Germany and the Czech Republic. Prague, the capital city of the Czech Republic, has an outstanding position as a metropolitan area within the country (CZSO 2006). Beyond the cities the Czech Republic has a dense network of small settlements (Sýkora and Ouredníček 2007). In Germany well educated people migrated from rural or peripheral regions to economically strong metropolitan areas, but in the Czech Republic migration took place in the 1990s and was mainly within metropolitan areas (BBR 2005; Sýkora and Ouredníček 2007). Therefore, diverging demographic development is observed within the countries. Some regions still grow, but other regions have experienced significant decrease in population. The largest decrease in population was greater than 5% and was observed in the rural areas of the eastern parts of Germany. The growing regions are mostly the rural areas around the metropolitan regions such as Berlin, Munich, and Hamburg. A population increase of more than 7% was observed in these areas between 1997 and 2003. This tendency has lessened since the year 2000 in the western part of Germany where the cities regained population (BBR (Bundesamt für Bauwesen und Raumordnung) 2005). The overall population has been declining since 1994 in the Czech Republic and since 2004 in Germany (CZSO 2006; STABU 2008). The built-up area is steadily growing in both countries. Although there has been destruction of multi-family dwellings the total urban development is still positive. The strongest increase in built-up area between 1996 and 2004 (up to 10%) was denoted in the rural areas surrounding the metropolitan areas (Siedentop and Kausch 2004).

In the Czech Republic this increase in urban area can only be observed in the periphery of the cities of Prague and Brno (CRR 2006). Suburbanisation of economic activities has had more impact on the change of urban areas than residential suburbanisation. The trend of residential suburbanisation is currently changing because the government supports the development of family housing with subsidies (Sýkora and Ourednícek 2007).

How can the described development, which is also presented in Figure 1, be explained? Three categories of driving forces can be identified: economy, demography and lifestyle and living. They are briefly summarised here. More detailed analyses can be found for example in Dosch and Beckmann (1999), Arlt et al. (2001), Heitkamp (2002), Penn-Bressel (2003), Stiens (2003), Siedentop and Kausch (2004) BBR (2006) or EEA (2006).

The economic development of a region is an important driving force for urban development. Economically growing regions have migration surpluses which increases the demand for built-up areas. Additionally, the demand for industrial areas and infrastructure increases (Arlt et al. 2001). The relatively low overall dynamic of the socio-economic development in the Czech Republic in comparison to Germany is a result of limited purchasing power (Sýkora and Ourednícek 2007). Demographic changes can include changes in birth rates, death rates and household sizes. The aging of the population leads to an effect called remanence. Older people stay in large houses after their children have grown-up and left the household, causing an increase in the per capita floor area of the elderly. This floor area is therefore not available for young people leading to increased demand for built-up area (BBR 2001). The size of households steadily decreased from 2.27 to 2.13 between 1991 and 2003 in Germany (BBR 2005). The same development is observed in the Czech Republic where the household size was 2.38 in 2001 (Bartonová and Kucera 2005). Living and lifestyle preferences include the demand for specific building types, floor area and a preference for the suburbs or the city centre. Suburbanisation is driven by a preference for single-family dwellings which are easier and cheaper to acquire outside the city (BBR 2005; CZSO 2006). Current trends in Germany show a preference for living in the city centre (BBR 2005).

3. Quantifying the demand for built-up area

Approaches often used to calculate the demand for built-up area include trend extrapolations, statistical analyses by applying regression models and density measures. This classification of approaches is based on an extensive literature review.

3.1 Trend extrapolation

Trend extrapolations use a historical time series to extrapolate indicators to the future or assume constant absolute growth or growth rates (e.g. White et al. 1999, Fritsch et al. 2000, Allen and Lu 2003, Houet and Hubert-Moy 2006). This method is expected to be a valuable approach for the short-term analysis of land use change because it does not require any explanation of causality. Trend extrapolations assume no structural change of the underlying determinants. In mid- or long-term studies, this assumption does not necessarily hold true, because of structural changes in the socioeconomic development of the study area. These structural changes are observed or expected in Germany and the Czech Republic.

3.2 Regression analysis

A statistical analysis of land use demand, explains changes using variables that are assumed to be driving forces of the observed change (e.g. Smits and Annoni 1999, Bogner and Bartl 2001, Seto and Kaufmann 2003, Betzholz et al. 2005, Kuhlman et al. 2005, Reginster and Rounsevell 2006, Verburg et al. 2006). These approaches can be distinguished from those developed in economic disciplines (e.g. Alig and Healy 1987, Geoghegan et al. 1997, Ready and Guignet 2006). Most econometric approaches use logarithmic variables to interpret the resulting coefficients as elasticity, and other disciplines use simple linear regression equations.

Another difference in the various statistical analyses is the applied approach. Either a theory about the underlying driving forces exists and is to be accepted or rejected by a regression analysis or an exploratory approach is chosen. In exploratory approaches an automatic variable selection is used to find the most influencing variables. Much criticism exists for the exploratory approach because the selection algorithms might not be the real driving force and could be a randomly collinear variable.

Population development and gross domestic product (GDP) are the variables that are most often applied to explain the development of built-up areas. Both variables are assumed to have a positive influence on the built-up area. One comprehensive statistical analysis has been undertaken on the regional level for Germany (Siedentop 2007a, b, BBR 2009). He uses a variety of indicators such as population by age group, sector-specific employment measures, commuters and attractiveness to tourists. Most indicators are treated as absolute values at one time step and as absolute change or relative change between two time steps. A regression on all subsets based on an extensive set of variables was conducted to find the most suitable model based on Mallow's Cp statistic (BBR 2009). Tötzer et al. (2007) used population, population density, number of employees and purchasing power parity as explanatory variables and observed that the coefficient for population is negative, indicating an increase in built-up area when population declines. This relationship is not correct. Per capita demand for built-up area was then applied as an additional independent variable to account for the contradicting development of population and built-up area. From a mathematical point of view, the implementation of per capita built-up area is redundant because this variable is calculated from two variables that are already included in the estimate, and one of them was a dependant variable. By using derived variables or ratios the variance of the variable is reduced because the same ratio can result from different absolute values. Smaller variance leads to a better fit in the regression analysis and influences the significance of the original variables, such as population (Hoymann 2010). Therefore, variables containing a ratio need to be handled with care. Only the studies by BBR (2009), Tötzer et al. (2007) and Hoymann (2010) attempted to account for the contradicting development of demography and built-up area.

3.3 Density measures

Density measure approaches apply indicators such as settlement density, population density or housing density to translate socioeconomic indicators into demand for land use. Therefore, projections of the population, number of households or the housing market are required. Because projections of population developments are often available, the underlying assumptions of housing projections are crucial for this approach, which is based on long-term trends in household size, per capita living area, ratio of newly-built single-family dwellings to all residential dwellings, ratio of owner-occupied households to the total number of households or household incomes (Engelen et al. 1995, Brouwer et al. 2002, Heida 2002, BBR 2006).

One option within density measure approaches is to keep current density measures constant (Hammer Siler George Associates 1998a, b, Brouwer et al. 2002, Heida 2002). A modification is to assume or estimate future building densities (BBR 1996, Ströbl et al. 2003, Jackson et al. 2004, de Nijs et al. 2005, Klosterman et al. 2006). Ströbl et al. (2003) used a population-, household- and housing projection to apply building densities to calculate demand, and Jackson et al. (2004) based her work only on a population projection. The demand for built-up area was subsequently calculated using the marginal land use consumption per additional household empirically calculated by Vesterby and Heimlich (1991). The previously mentioned studies assume static or constant density measures, but an alternative is to use dynamic density measures. If dynamic density measures are used an algorithm is applied that increases the density if a critical amount of built-up area is allocated (White and Engelen 2000).

3.4 Density measures

This section briefly discusses the ability of the three classes of approaches to account for the observed demographic change.

Trend extrapolation assumes that a recent development (the trend) will continue in the future. If a national trend is applied to the study areas, no structural changes are visible. Germany had a stagnating population until 2004. A decrease in population cannot be seen in the studied time period from 1996 to 2004. Therefore, a national trend is not implausible. However, a closer look at the regional level reveals large differences between regions with decreasing population over the last several years and regions where population is still growing. Therefore, a region specific trend extrapolation might be used to account for the region-specific developments of the past. The results might imply an even stronger polarisation between regions with increasing and decreasing population. A change in the trend of developments cannot be taken into account in trend extrapolations.

Within regression equations only certain changes that were observed for past developments can be projected into the future. The values of the estimated coefficients of the independent variables are influenced by the development in the regions of a study area. Because cross-sectional data are applied instead of time series data, structural changes over time cannot be reproduced. Regional structural differences can be taken into account by using dummy variables for different settlement structures. Because both growth and decline are currently observed in the study area an appropriate regression model will be able to project future changes that are within the range of the past changes and includes projections for regions that grew in the past but are expected to decline in population in the future.

If the density is determined dynamically, structural changes can be modelled by adapting the density measure with respect to socioeconomic development. For constant density measures, only a deterministic procedure can be used. Density measures need to be specified explicitly, when the approach is not dynamic, and are therefore defined highly subjective by the researcher.

4. Methods and Data

4.1 Density measures

All reviewed approaches have specific modifications or adaptations for a certain study area but are similar in their methodology. Therefore, only one version of all approaches for each of the three identified groups is used. The available database influenced the selection process, because the same database was applied to all approaches. Only approaches that work with the available variables were selected. Availability of explanatory variables is determined by the existence of future projections for the variables. The rationale is to be able to calculate future projections of the built-up area by applying these explanatory variables.

All approaches are applied to historical datasets to evaluate their applicability and to prove their predictability. Every calculation is conducted for two spatial scales in two study areas.

4.1.1 Trend extrapolation

The daily demand of built-up area is applied as an indicator for trend extrapolation. This indicator is also used by the German strategy for sustainable development which surveys several parameters that measure the progress towards sustainable development (Bundesregierung 2002). The two-step procedure was conducted for both study areas and every spatial scale. In the first step the mean daily demand for the built-up area was calculated for every region from 1996 to 2000:

$$d = \frac{(y_t - y_{t-a})}{a * 365} \quad (1)$$

where:

d is the daily demand for built-up area

y_t is the built-up area in a certain year

a is the number of years between two time steps

t is a year (2000 in this case).

In the second step the calculated regional daily demand for built-up area was used to extrapolate the trend 1996 to 2004:

$$y_{t+a} = y_t + d * a * 365 \quad (2)$$

4.1.2 Linear Regression Analysis

A linear regression was applied to explain the built-up area. A set of variables expected to influence the demand for built-up area were used as independent variables. The mathematical formulation for the linear regression analysis is as follows:

$$y = \beta_0 + \sum_{j=1}^{J} \beta_j x_j + \sum_{j=1}^{J} \gamma_j (S_j \, x_j) \quad (3)$$

where y is the amount of built-up area or the change in built-up area between two time steps. β_0 is as constant term. β_j represents the coefficients of the different independent variables x_j. γ_j is the estimated coefficient for the interaction term and S_j represents the interaction variables. The subscript J determines the number of variables. The approach of Ordinary Least Squares is used to estimate the coefficients. The application of a linear regression analysis requires consideration of numerous assumptions that are discussed in (von Auer 1999, Greene 2000).

Variable selection for regression analysis is based on theory about how the processes can be explained. Statistical analysis is applied to accept or reject assumptions. The underlying theory is presented in detail in section 4.3.3.

Multicollinearity is of serious concern if predictions are obtained with observations that are not in the range of the sample. Because the future developments are expected to be within the current range of the sample, multicollinearity is not problematic for the estimation (Moore *et al.* 2009). Multicollinearity is negligible for the estimation if predictions are made but not when collinear variables influence each other. If the sign of the coefficient becomes implausible one of the two variables must to be omitted.

Another assumption made in linear regression analysis is homoscedasticity, the constant variance of residuals. Heteroscedasticity is often observed when variables are skewed and not normally distributed. A transformation of variables avoids heteroscedasticity. For the estimation of built-up area at one time step (in contrast to the estimation of change between two time steps) the variables need to be log-transformed.

In the results section the final model, adjusted R^2, F-value and variance inflation factor are presented. In this application the built-up area for 1996 and the mean annual relative change of the built-up area are estimated between the years 1996 and 2004, for both study areas and multiple spatial scales (two for each study area). Eight regression analyses were used.

4.1.2 Density measures

The density measure approach calculates the ratio between a socioeconomic variable and a specific area. Areas can be the size of the administrative unit or of a certain land use type. In this study we apply the floor area and the population to the current built-up area:

$$s_{t_{pop}} = \frac{p_t}{y_t} \qquad and \qquad s_{t_{floor}} = \frac{f_t}{y_t} \tag{4}$$

where:

s_{tpop} is the population density referring to built-up area

s_{tfloor} is the floor area density referring to built-up area

p_t is the population in a year t

and f_t is the floor area in a year t.

By rearranging equation 4 and applying the socioeconomic indicators of another year, the built-up area of a given year can be calculated:

$$y_{t+a} = \frac{p_{t+a}}{s_{t_{pop}}} \qquad and \qquad y_{t+a} = \frac{f_{t+a}}{s_{t_{floor}}} \tag{5}$$

These calculations underlie the assumption that the density does not change over time. A differentiation of the floor area by different dwelling types and their specific demand for built-up area would be preferable, but there is no information on the share of built-up area covered by specific dwelling types. Information on floor area in different dwelling types and the number of dwelling per dwelling type is available but cannot be used. The statistics of the density measures are provided in Table 2. Every administrative unit on both spatial scales has its own density measure to maintain a regional differentiation. The density measures are calculated for the year 1996 and applied to the floor area and population of 2004 to project the built-up area of 2004.

4.2 Comparison of results

To determine which approach is the most accurate, the results projected for the year 2004 by the three approaches are compared with the observed built-up area in 2004. The absolute and relative deviations of the estimates from the actual built-up area are summarised in box-plots and maps. The advantage of a map is, that regional trends can be identified. The deviations from observed changes between 1996 and 2004 are calculated.

4.3 Data

4.3.1 Data sources

All calculations are based on one consistent dataset for each study area. For Germany, surveys of the German Federal Office for Statistics (STABU 2006) are used. For the Czech Republic, surveys of the Czech Statistical Office (CZSO 2006) are applied. All datasets are cross-sectional. Surveys are available in Germany from 1995 until 2004 and in the Czech

Table 2: Statistics of current density measures for Germany and the Czech Republic (year 2004)

		Floor area (ha/ha)	Population (persons/ha)
Germany - Kreise	Mean	0.077	19.371
	Std	0.037	9.958
	Range	0.188	51.149
Germany - ROR	Mean	0.070	17.506
	Std	0.029	7.808
	Range	0.182	47.713
Czech Republic - Okres	Mean	0.249	75.723
	Std	0.098	34.976
	Range	0.620	198.191
Czech Republic - Kraje	Mean	0.281	86.284
	Std	0.144	46.508
	Range	0.573	184.880

Republic from 1995 until 2008. For this study two time steps in the past are considered: 1996 and 2004.

4.3.2 Spatial scale

All calculations are done on two spatial scales. The rationale is that different driving forces act on different scales. Table 3 and Figure 2 provide overviews of the different scales for both study areas. The approaches are applied solely on regional levels and not on local levels such as municipalities. Because administrative structures change frequently as municipalities are merged or split a consistent cross-sectional dataset could not be created for municipalities in the studied time period. An analysis of a coarse scale of Bundesländer (Federal States) and Oblastí was not possible, because the sample size in these study areas was too small.

4.3.3 Variables

Many variables can influence the demand for built-up area. The list of potential driving forces was assembled by literature review. Table 4 gives an overview of those variables which are discussed in this study. The potential driving forces can be divided into different groups of variables:

- demographic factors
- housing and Live styles
- economy
- spatial planning

An extensive database might be necessary for statistical analysis. Because the purpose is not only to explain the current state of the built-up area and past changes but also to provide an approach for future projections of the development of built-up areas, only those variables can be used for which future projections are available. Therefore, only a few variables can be applied from the extensive database of potentially contributing variables. Sources for projections are the prognosis of spatial development and spatial planning of the BBR (2006) and the population and household prognosis of the CZSO (Bartonová and Kucera 2005, CZSO 2009).

Table 3: Overview of spatial scales.

Spatial Scale	Germany (Number of regions)	Czech Republic (Number of regions)
Fine Regional	Kreise (439)	Okres (77)
Medium Regional	Raumordnungsregionen (ROR) (97)	Kraje (14)

The first selected variable was the population. Population growth results in an increase of built-up areas. However, decreasing population does not necessarily results in decreasing built-up areas. A decrease in population increasing built-up area was observed in both study areas because the size of households is decreasing. The number of households is still increasing, leading to demand for built-up area (Dosch and Beckmann 1999, BBR 2006). Therefore, the mean average household size is also used as a variable in the regression analysis. This variable also represents current lifestyles. More people live without children or remain single, resulting in a lower number of traditional family households. Another variable representing lifestyle is the ratio of single-family dwellings to total residential dwellings. The specific area on the ground used by one apartment in a single-family dwelling is higher than for a multi-family dwelling (BBR 2006). The built-up area is assumed to increase more if the ratio of single-family dwellings to total residential dwellings increases. Building construction can only be accomplished when economic wealth is observed. Economic growth is often correlated to population development because both variables influence each other. People migrate to regions with jobs but jobs also occur where many people live (Gornig and Hornschild 1997, Stiens 2003). The development of industrial and commercial sites is assumed to depend on the economic strength of the region. In the Czech Republic industrial sites consumed most space for built-up areas (Sýkora and Ourednícek 2007). A fourth variable, the area of the administrative unit is also included. This variable is used to account for the maximum possible built-up area that can be realised in one region. If both variables, population and area of an administrative unit, are used population density is represented.

In addition, to these metric variables dummy variables are included in the interaction term of the regression analysis. First, a variable indicating whether a region lies in the eastern or western part of Germany is used to account for the different phases of demographic changes. Regions with a population decline in the studied time period occur almost exclusively in the eastern part of the country. Second, binary dummy variables represent the settlement structure. These variables indicate whether a region belongs to an urbanised or rural area. This variable accounts for different developments in different types of settlement structures. The underlying classification is based on the work of BBR.

Variables that consider spatial planning are not used in this analysis because spatial planning influences the supply of built-up areas. The supply may also influence the demand, but the variable is not consistent for both study areas because of differences in the spatial planning policy.

For the density measures the floor area is needed. The CZSO does not provide total floor area directly, but does provide floor area per newly constructed dwelling and the number of newly constructed dwellings. With the help of the 2001 census-data, which includes the floor area per capita and the population, the floor area could be calculated for the years 1995 to 2000 and 2002 to 2008.

These calculations provide consistent datasets for all years and spatial scales.

Table 4: List of applied variables.

Short Name	Description	Applied Approaches		
		Trend	Regression	Density
SuV	built-up area in hectare	✓	✓	✓
Area	size of the administrative unit		✓	
Bev	population		✓	✓
SuVpc	per capita built-up area in hectare		✓	
BIP	gross domestic product		✓	
AntWhngebEZFH	share of single-family dwellings on all residential buildings		✓	
Whnfl	floor area in hectare			✓
HHGr	household size		✓	
NL (only Germany)	binary dummy variable coded 0 for West Germany and 1 for East Germany		✓	
Kernstadt / urban agglomeration	binary dummy variable indicating a larger cities, reference group: rural areas (Kreise)		✓	
VerstUmland / urban hinterland	binary dummy variable indicating the urban hinterland of the cities, reference group: rural areas (Kreise)		✓	
LndlUmland / rural hinterland	binary dummy variable indicating the rural hinterland of the cities, reference group: rural areas (Kreise)		✓	
Metropole / Metropolitan area	binary dummy variable indicating the larger cities, reference group: rural areas (ROR)		✓	
Verstädtert / urbanised area	binary dummy variable indicating urbanised areas, reference group: rural areas (ROR)		✓	

5. Results

This section presents the results of the calculated demand for built-up area by trend extrapolation, linear regression analysis and density measures.

5.1 Trend extrapolation

For the calculation of the built-up area by trend extrapolation, the mean daily demand for built-up area from 1996 to 2000 was applied to the years from 1996 to 2004. The corre

Table 5: Change in built-up and traffic area based on the trend extrapolation for Germany and the Czech Republic between 1996 and 2004 (Source: STABU 2009, CZSO 2006, own calculations).

	Germany	Czech Republic
Observed mean daily demand in ha 1996-2004	122	0.3
Assumed daily demand in ha (Original demand from 1996 to 2000)	129	0.7
Observed absolute change in ha	356,906	793
Extrapolated absolute change in ha	377,422	2,016
Observed relative change in %	8.5	0.6
Extrapolated relative change in %	9.0	1.6
Deviation of estimated absolute change from observed values in %	5.7	154.2

sponding values for both study areas are presented in Table 5. The national values for the different spatial scales do not differ within either study area.

Figure 3 illustrates these results for regional differentiation. The massive past increase in built-up area in the eastern part of Germany is visible in the left hand portion of Figure 3. Areas with significant changes are underestimated by the trend extrapolation. The regions with the highest deviation from the observed absolute increase of built-up area are coloured light and dark grey in the right part of Figure 3. Areas with small past changes in built-up area are particularly affected by deviations from the observed change in the Czech Republic. This pattern is clear for the Kraje. The pattern for the Okres is more complex.

The built-up area of regions that grew only moderately or slowly was overestimated by trend extrapolation in the studied time period. This overestimation can be observed in both Germany and the Czech Republic.

The regions with the highest underestimation of the trend are rural areas, where the resource land is abundant.

5.2 Linear Regression Analysis

Extensive linear regression analysis revealed eight models that estimate the built-up area for the year 1996 and the change in built-up areas between 1996 and 2004 for both spatial scales of both study areas. The details of the estimated models are presented in Table 6. All models include only a small number of variables because of the multicollinearity analysis and the significance of the specific variables. The estimated coefficients for the year 1996 were then applied to project the built-up area of 2004.

The estimated model for the built-up area of 1996 of the Kreise in Germany is log-linear to avoid heteroscedasticity. This model includes population, GDP and the size of the administrative unit. The ratio of single-family dwellings could not be used because of missing values.

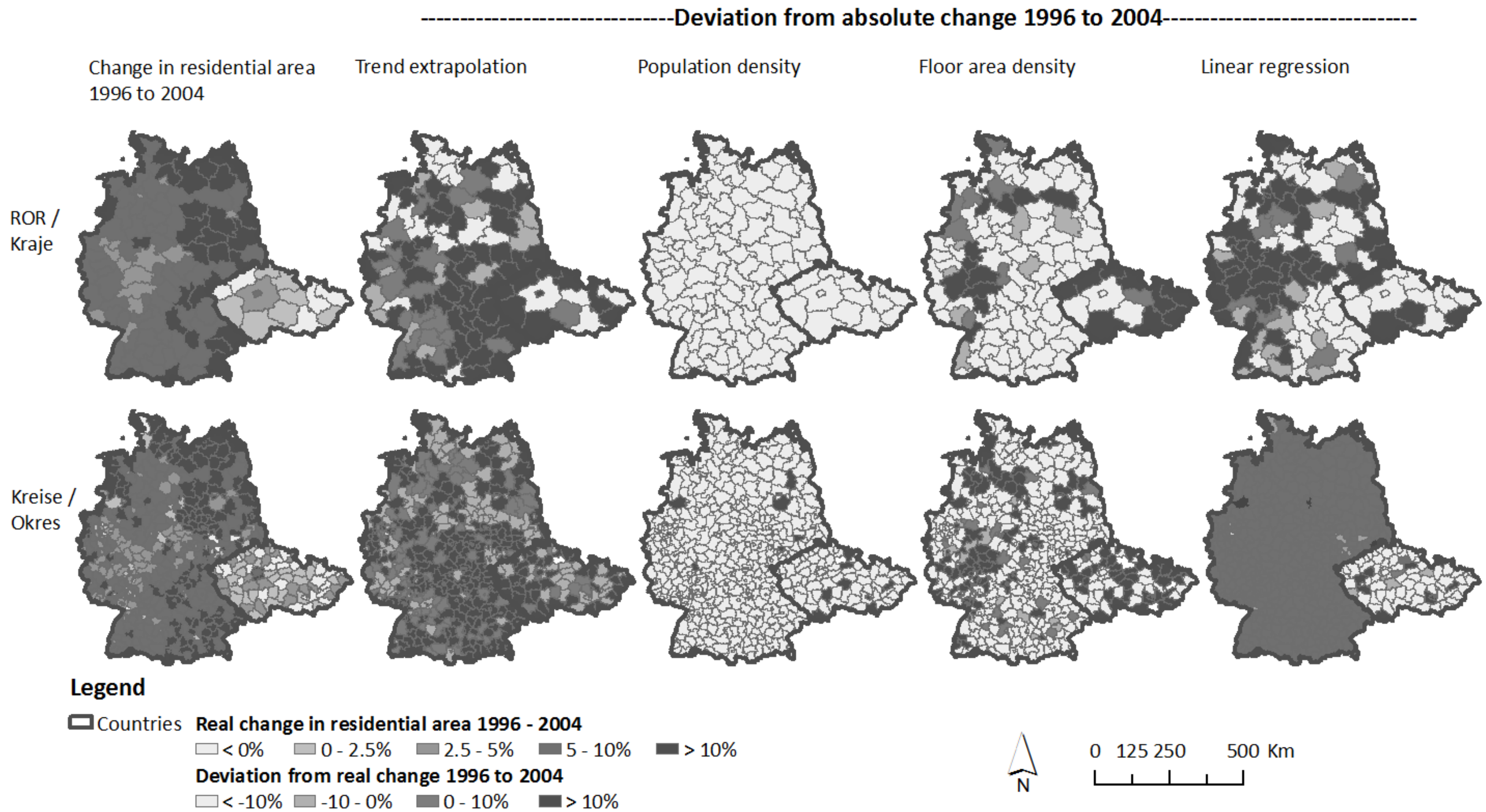

Figure 3: Comparison of original development and projection by the different approaches for the regional differentiation.

Table 6: Regression results.

Response Variable	**logarithmised built-up area 1996: log(SuV_96)**										**mean annual relative change of built-up area**		
Kreise	Eastern Federal States					Western Federal States							
	East Total	Urban agglo-meration	Urban hinterland	Rural hinterland	Rural areas	West Total	Urban agglo-meration	Urban hinterland	Rural hinterland	Rural areas			
(Intercept)	-5.05***	-4.24***	-3.00**	-4.02***	-2.72*	-1.94***	-2.51***	-1.60***	-1.82*	-1.82	(Intercept)	-1.02**	
log(Bev_96)	0.24***	0.17	0.25.	0.19	0.44*	0.60***	0.68***	0.58***	0.63***	0.56*	RelCh_Bev	0.12*	
log(BIP_96)	0.31***	0.52.	0.19	0.32*	0.07	-0.04	-0.08	-0.05	-0.12	-0.04	RelCh_Area	2.23***	
log(Area_96)	0.51***	0.28*	0.45***	0.54***	0.49***	0.41***	0.43***	0.41***	0.47***	0.43***	RelCh_BIP	0.04.	
											RelCh_AntWhngebEZFH	0.53***	
											RelCh_HHGr	-0.89***	
adj. R^2					0.95						adj. R^2	0.33	
F value					277						F value	43.3	
ROR	Metropolitan	Urbanised	Rural									East Total	West Total
(Intercept)	0.03	-3.23***	-0.77								(Intercept)	2.59***	0.86**
log(Bev_96)	0.50***	0.51***	0.25*								RelCh_Bev	-0.16	0.37**
log(Area_96)	0.30***	0.58***	0.65***								RelCh_HHGr	-1.42*	-0.23
log(AntWhngebEZFH_96)	0.40.	1.42***	2.73***										
adj. R^2		0.91									adj. R^2	0.32	
F value		89.51									F value	10.23	
Okres													
(Intercept)	-1.93*										(Intercept)	1.05**	

log(Bev_96)	0.67***	RelCh_Bev	0.57***
log(Area_96)	0.16**	RelCh_AntWhngebEZFH	-0.62*
log(AntWhngebEZFH_96)	0.39***		
adj R^2	0.75	adj. R^2	0.22
F value	79.04	F value	11.76
Kraje			
(Intercept)	-5.89***		
log(Bev_96)	0.71***		
log(Area_96)	0.43**		
log(AntWhngebEZFH_96)	0.31*		
adj. R^2	0.96		
F value	95.09		

All coefficients are as expected. Floor area is not included because it is collinear with population and does not improve the fit of the model. This model differentiates East and West Germany and settlement structure. Although the model has a large adjusted R^2 of 0.95 the projected change in 2004 is underestimated by an average of 848ha in every region, and the mean observed change in Kreise is only 813ha. The error is larger than the observed change. A lower explained variance and better fit of the projected change from 1996 to 2004 shows the estimate of the change of built-up area. The R^2 is only 0.33 but the projected change per region is overestimated by an average of 17ha.

The initial estimate of the built-up area for ROR was based on the results of the analysis of the Kreise. The results revealed that many variables are insignificant and the applied set of variables was adjusted. When estimating a log-linear model for the built-up area in the year 1996, the GDP was insignificant and was therefore omitted from the model. Instead, the ratio of single-family dwellings to total residential dwellings, which is highly significant, was included. With increasing population and increasing ratio of single-family dwellings the built-up area increases. Differentiation of former East and West Germany does not lead to a better estimate but consideration of the settlement structure does. Although the adjusted R^2 is 0.9 this model shows a mean deviation from observed change in 2004 of -3500ha per region. Because the mean observed change is 3700ha the model projects that nearly no change will happen. The model that estimates the change in built-up area differentiates between East and West Germany, and only population and the household size are significant variables. Although the adjusted R^2 is only 0.32 the projected change is overestimated by only 41ha.

The regression analysis for the Czech Republic reveals several difficulties in the statistics. For the spatial level of Okres no economic variables are available. GDP and number of employees are only available for Kraje. Therefore, the estimates for Okres include no economic variables. The second difficulty is the sample size for Kraje. With only 14 regions a regression analysis is difficult to conduct.

For Okres the log-transformed built-up area for the year 1996 was estimated by population, size of the administrative unit and the ratio of single-family dwellings. The explained variance is 75% and the coefficients are significant. However, the estimated built-up area deviates from the observed built-up area by $\pm$500ha per region and the observed change until 2004 is only between $\pm$300ha. The error of the estimate is larger than the observed change. For 2004, a decline in built-up area is projected, and the mean observed change per region is 10ha. If the change in built-up area is estimated (this change is the response variable), the statistical properties of the model are worse, but the mean projected change for one region is 7ha, which is close to the observed change of 10ha.

A regression analysis for the spatial level of Kraje is difficult because only 14 Kraje exist in the Czech Republic. As with previous estimates, the variables for the estimation of the built-up area in 1996 were log-transformed. The GDP is available for Kraje, but was omitted because it is insignificant. The signs of the coefficients of the included variables are all plausible, and the adjusted R^2 is high but a comparison between the observed built-up area and changes and the estimated built-up area and projected change reveal strong deviations. The fitted built-up area per region is in average of 960ha higher than the observed built-up area and the change until 2004 is underestimated by an average of 200ha. Thus, the estimate cannot be used for projection. Attempts to estimate the change of the built-up area between 1996 and 2004 did not produce any results. A summary of the calculations is presented in Table 7. The estimation results of the Kraje are not appropriate and cannot be used for a projection of built-up area in the future. All other regression results show a good approximation of the observed changes in built-up area.

The regional differentiation of the linear regression analysis is presented in Figure 3. The pattern of deviations differs from that of the other two approaches and between the two spatial scales in every study area. For the German Kreise nearly all regions show a deviation from observed change of less than 10%, but the deviations for the German ROR are more extreme. Either overestimates of more than 10% or underestimates of more than 10% area observed. The highest deviations were observed for the linear regression analysis. For the Czech study area most regions were underestimated by more than 10% on both spatial scales.

Table 7: Change in built-up area based on the linear regression analysis for Germany and the Czech Republic between 1996 and 2004 (Source: STABU 2009, CZSO 2006, own calculations).

	Germany	Czech Republic
Observed absolute change in ha	356,906	793
Estimated absolute change in ha (Kreise / Okres)	364,420	552
Estimated absolute change in ha (ROR / Kraje)	360,946	-2843
Observed relative change in %	8.5	0.6
Estimated relative change in % (Kreise / Okres)	8.7	0.4
Estimated relative change in % (ROR / Kraje)	8.6	-2.0
Deviation of estimated absolute change from observed change in % (Kreise / Okres)	2.11	-30.30
Deviation of estimated absolute change from observed change in % (ROR / Kraje)	1.13	-458.57

5.3 Density measures

The calculation of the built-up area for the year 2004 is based on the density measure of the year 1996 and the corresponding socioeconomic indicator of the year 2004. The results for the two different density measures differ strongly from each other. While the calculation based on the population density underestimates the past developments, the calculation based on the floor area density overestimates built-up area in more regions (Table 8). The population density declined between 1996 and 2004. In the same time period, the population stagnated or declined in many regions. The assumed population density of 1996 which is applied in the calculation of built-up areas for 2004, is therefore too high and the estimated total built-up area is too low (Figure 3). This development is pronounced in the rural areas with strong population decline in the eastern parts of Germany and in the peripheral regions

Table 8: Change in built-up area based on the density measures for Germany and the Czech Republic between 1996 and 2004 (Source: STABU 2009, CZSO 2006, own calculations).

	Germany	Czech Republic
Population density		
Observed density 2004 (persons / ha)	18.1	78.3
Assumed density (Original density from 1996)	19.5	79.6
Observed absolute change in ha	356,906	793
Calculated absolute change in ha	-302,833	-1590
Observed relative change in %	8.5	0.6
Calculated relative change in %	-7.2	-1.2
Deviation of estimated absolute change from observed values in %	-184.8	-300.5
Floor area density		
Observed density 2004	0.072	0.258
Assumed density (Original density from 1996)	0.071	0.252
Observed absolute change in ha	356,906	793
Calculated absolute change in ha	115,034	2,986
Observed relative change in %	8.5	0.6
Calculated relative change in %	2.7	2.3
Deviation of estimated absolute change from observed values in %	-32.2	376.5

of the Czech Republic. The smallest deviation from the original development is found around the cities of Berlin, Hamburg, Bonn, Munich and Prague.

In these areas, a significant increase in population was observed. Some of the surrounding regions of these cities also show a higher population density in 2004 in comparison to 1996. These results show that in the past the population decline was accompanied by a decline in population density that lead to significant increases in built-up area.

The estimates based on floor area density, differs from those based on population density. In Germany, an underestimation of the built-up area is observed in the rural areas and the built-up areas of the more densely populated regions are overestimated because of an increase in the floor area density over much of the study area. The strongest tendency for densification of floor area was observed in the hinterland of Berlin. Therefore, the assumed density for the calculation of built-up area is too low (Figure 3). The regions that are overestimated most, when the calculation is based on the floor area density are the same regions with the lowest underestimate or highest overestimate when the calculation is based on population density. This result is coherent because space for built-up area becomes scarce in regions with high population increases. The floor area density increases to save scarce space (or because of high prices for space). The overall development in Germany is underestimated by 32% and extremely overestimated in the Czech Republic. For the Czech Republic, the relative and absolute changes must be considered because development of built-up areas took place in the past on a much lower level than in Germany (Table 8). In some Czech regions, a decline in built-up area was observed in the surveyed development between 1996 and 2004. The projection using the floor area density suggests an area wide increase in the built-up area.

5.4 Comparison of results

A box-whisker plot of all approaches in both study areas and every spatial scale was created (Figure 4). The upper and lower edges of the boxes are determined by the first and third quartiles. The whisker is the 1.5^{th} length of the box. The outliers are represented by circles for mild outliers and stars for extreme outliers. The plots show the relative deviation of projected new built-up area between 1996 and 2004 and the observed change in built-up area during that time. Values close to 1 indicate good predictability, whereas values around 0 and 2 indicate an under- or overestimate of 100%, respectively.

The coarser spatial scale does not show as many outliers as the finer spatial scale in both study areas. Extreme developments in Kreise or Okres that are part of ROR or Kraje are regressed to mean in the coarse spatial scale due to spatial aggregation. The distributions of

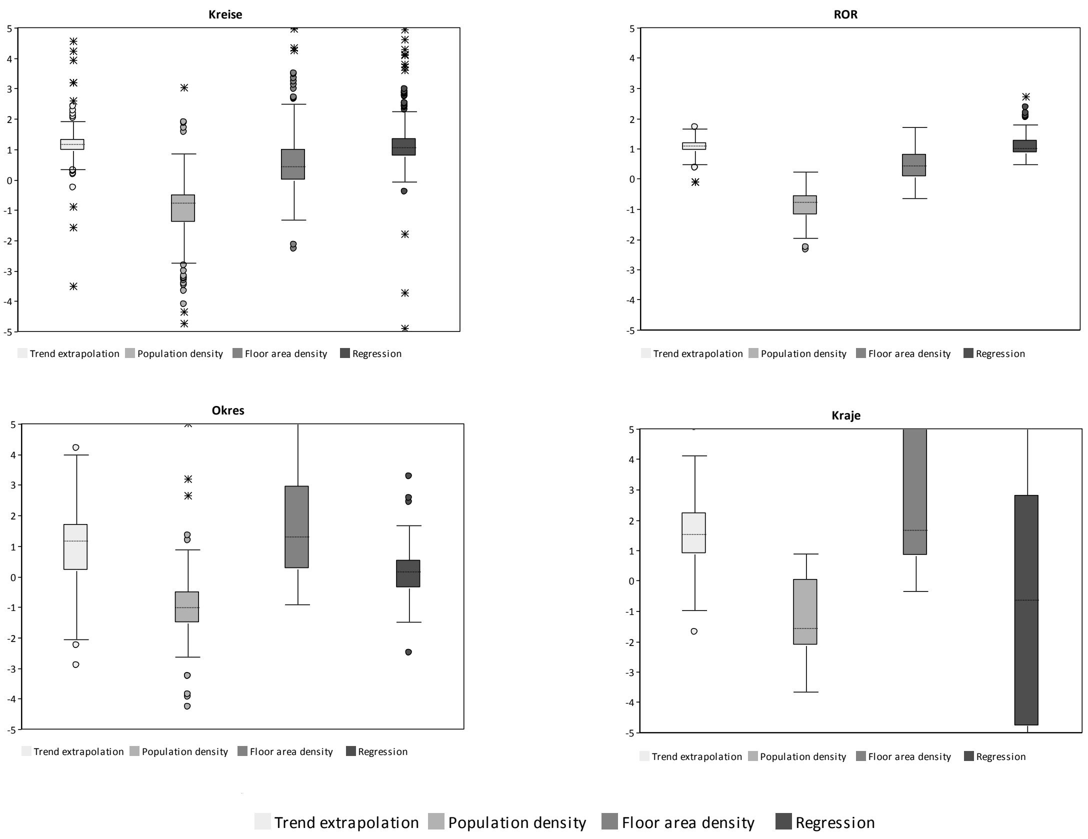

Figure 4: Comparison of distribution of approaches and spatial scales.

the different approaches are narrower on the coarser spatial scale in Germany and on finer spatial scale in the Czech Republic, possibly because the number of regions in the two study areas is different. In Germany the ROR have 97 regions and the Kraje in the Czech Republic have only 14.

In Germany projection by trend extrapolation and regression modelling show the best correspondence to the observed development of built-up area. The density measure approach underestimated the observed development. In the Czech Republic, the projection by trend extrapolation corresponded the best to the observed development. The population density approach and the regression model underestimate the observed development of built-up area. The floor area density approach has a mean around 1, but a wide distribution with large deviations between the estimated and observed change for both spatial scales. The spatial scale of Kraje shows large boxes. The results for small sample sizes are not reliable. The calculations based on population density and the regression models underestimate the observed development and project reductions that were not observed because of the decreasing population density resulting from a regional decline in population. Although the measures of fit for a certain year indicate a good estimate for the linear regression, this approach shows the broadest distribution, indicating a high uncertainty with respect to predictability.

The results must be interpreted with caution, especially in the Czech Republic because the overall development of built-up area was low during the time period under study. Together with a small total built-up area, this small change in development results in huge relative changes even though the absolute changes are quite small.

All results show outliers. Where can the outliers be found and why? For the trend extrapolation the observed development is only moderate overestimated. Outliers that strongly underestimate the real development are rural areas in Saxony-Anhalt, southern Brandenburg, along the coastline and scattered along the river Rhine. The underestimated regions in the eastern part of Germany are characterised by a population decline during the observed time period. This decline is not observed in the underestimated regions along the river Rhine, where an increase in the daily demand for built-up area can be found. Outliers within the calculation by population density can be found in the whole country. The affected regions that were extremely overestimated are those with an increase in population density due to an increase in population. Extreme underestimates were made mostly for the eastern parts of Germany that were affected by a decrease in population density due to declining population. These regions are the rural regions in Saxony, Saxony-Anhalt and Thuringia. The same regions were extremely overestimated in the calculations based on floor area density, which suggest an increase in population and floor area density. Only a few regions are extremely underestimated. Another pattern was observed in the calculations based on linear regression analysis. The observed development of built-up area in most of the larger cities (Kreisfreie Städte) in the south-western part of Germany were extremely underestimated, possibly because of the contrast between rural areas and densely populated cities and diverging population development.

In the Czech Republic another pattern of the outliers can be observed. Extreme underestimates in the calculation by trend extrapolation can be found in those rural Okres that show a significant decline in population and a strong reduction of the daily demand for built-up area. Exceptions are the big cities of Prague, Brno and Plzen. Although the cities lost population in favour of their hinterland, no extreme underestimate was denoted. No significant interrelation with the overall development of these densities over time was found from the calculations based on population density or floor area density, possibly because the floor area and population changes differ strongly from year to year. To analyse the outliers of the regression analysis is not meaningful because the distribution itself is already broad.

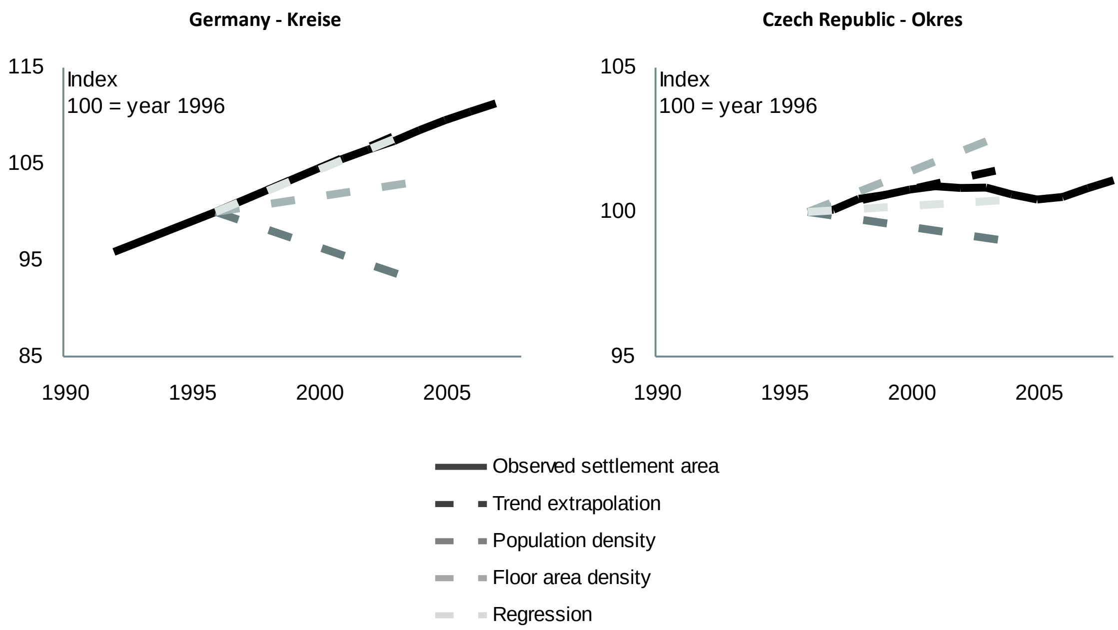

Figure 5: Range of results for projecting the past and projecting the future.

The total development of all approaches is summarised for the Kreise and Okres in Figure 5. For the study areas, the trend extrapolation and regression analysis produced the most accurate results. In Germany, both density measure approaches underestimated the observed development of built-up area, and in the Czech Republic, the underestimation was only observed for the population density approach. The Czech results should be interpreted with care because the range of development is much smaller than in Germany (note the different y-axes in Figure 5).

A spatial qualitative comparison of the different approaches was conducted. Regions with a deviation of more than 10% of the projection from the observed development of built-up area in both directions (under- and overestimation) are marked as are regions with a deviation of 10% or less (a correct estimate) (Figure 6). Many of the regions that are mostly underestimated by the four different approaches are also outliers in the box-plots of Figure 4. No spatial pattern is recognisable. The minority of regions are projected correctly at least once.

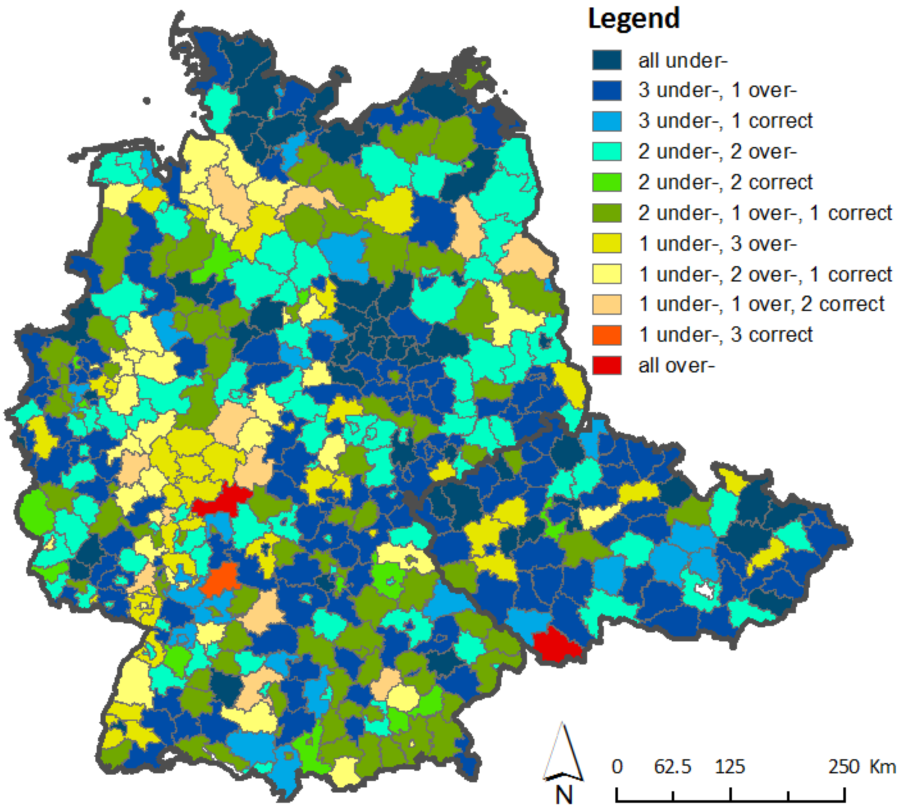

Figure 6: Spatial qualitative comparison of the approaches in Kreise / Okres.

6. Discussion and Outlook

The objective of this study was to analyse different approaches for calculating built-up area, their advantages and disadvantages, and their ability to project future changes are discussed. The results are summarised in Figure 5 to accentuate the range of results for the projection of past changes for Germany and the Czech Republic.

Although a large set of variables was applied, projections of past changes remain highly uncertain. The main influencing factor of these uncertain projections is the heterogeneous population development in both countries. The more an approach relies on the population development, the higher the deviation from the observed development. This effect can be seen in the results of the population density approach.

Although linear regression analysis also relies on the population development, this approach shows good results for the fine spatial scale because additional variables are considered that account for the contradicting development of population and built-up area.

The dynamic of the changes also have a large influence. Regions in which the observed changes are strongly overestimated are not necessarily the regions with the highest relative increase in built-up area between 1996 and 2004. These regions had the highest population growth during the observed time period, resulting in a densification that is not reproduced by the applied approaches. The significant loss of density due to population decline and increase in built-up area in other areas is also not represented, resulting in an underestimation of the changes in built-up area.

Although trend extrapolation does not explain or consider any processes that result in demand for built-up area, this approach is the most accurate over the short time period studied. Similar results were produced with regression analysis. No conclusions can reached for a long-term analysis, but the regression approach is expected to be more reliable for future projections because it is potentially able to account for different socio-economic developments.

Projecting changes using only the population density is not recommended because this approach is not able to reproduce the development of built-up area with declining population. In study areas with relatively stable population densities or population growth, the result might be different, but in the current study, in which both, the population and density declined, the approach produces large mistakes.

A similar conclusion can be reached for the floor area density approach, although the deviation of the results from observed development is not as serious as for the population density because the changes in floor area density are much smaller over time.

Finally, regression analysis did not produce large deviations from observed development. The presented estimate heavily relied on the population development and the availability of forecasts of the applied explanatory variables. Without the constraints for this study, different results are possible, as (BBR 2009) shows.

Another aspect that was studied was the influence of spatial scale on the projection results. The estimated results indicate the better the fit with the observed developments the finer the spatial scale is. For coarse spatial resolutions, local developments are regressed to the mean. This effect could be observed for the regression analysis. Because of the smaller sample size, the variance of the variables does not necessarily decreases, and the fit of the regression analysis does not improve.

Although the literature presents a wide variety of approaches for calculating the demand for built-up area, recent socioeconomic developments must be taken into greater account, than was done in the past. The recognition of the contradicting development of socioeconomic indicators and land use changes is a challenge for the land use change modelling community. The study showed that projections of land use change can show completely different results depending on the input data.

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