TOWARDS AN UNDERSTANDING OF LAND CONSUMPTION IN GERMANY– OUTLINE OF INFLUENTIAL FACTORS AS A BASIS FOR MULTIDIMENSIONAL ANALYSES

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With 2 figures and 1 table
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Summary: Like many other industrialized countries, Germany is affected by the continuing conversion of open space into settlements and transportation infrastructure. Between 2000 and 2010 the rate of conversion was about 12 m² per second. In order to ensure an ecologically-oriented urban and regional development, it is vital to manage land responsibly as a finite resource. Against this background, the topic of sustainable land management is the focus of various fields of spatial research and spatial policy discussion. The current article documents the systematic building of knowledge on factors linked to the expansion of settlements and transportation infrastructure. The selection of so called influential factors presented here is based on a comprehensive literature review as well as expert interviews. The paper aims to support future studies in the selection and verification of variables to be applied to multidimensional analyses of influential factors (e.g. statistical and data mining methods). Such studies are currently still at an early stage both in Germany and other central European nations.

Zusammenfassung: Wie auch viele andere industrialisierte Länder ist Deutschland durch anhaltende Umwidmungen von Freiflächen in Siedlungs- und Verkehrsflächen gekennzeichnet. Im Zeitraum zwischen 2000 und 2010 belief sich dieser Prozess auf durchschnittlich 12 m² je Sekunde. Im Sinne einer ökologischen Stadt- und Regionalentwicklung ist ein verantwortungsvoller Umgang mit der endlichen Ressource Boden unverzichtbar. Vor diesem Hintergrund ist das Thema des nachhaltigen Landmanagements für zahlreiche Forschungsfelder der Raumplanung sowie Diskussionen der Raumordnungspolitik besonders relevant. Der vorliegende Artikel dokumentiert die systematische Wissensaufbereitung von Faktoren, welche mit Entwicklungen der Siedlungs- und Verkehrsfläche in Verbindung gebracht werden. Die Auswahl sogenannter Einflussfaktoren basierte auf einer umfassenden Literaturrecherche sowie auf Experteninterviews. Dieser Artikel verfolgt das Ziel, zukünftige Arbeiten bei der Variablenauswahl und -verifizierung im Rahmen multidimensionaler Analysen von Einflussfaktoren zu unterstützen (z.B. anhand statistischer Methoden sowie Verfahren des Data Minings). Derartige Arbeiten befinden sich zum aktuellen Zeitpunkt sowohl in Deutschland als auch in anderen zentraleuropäischen Staaten noch in einer initialen Phase.

Keywords: Land consumption, sustainable land development, multidimensional analyses, influential factors

1 Introduction

The designation of 2015 as the 'International Year of Soils' (IYS) emphasized "the importance of sustainable soil management as the basis for food systems, fuel and fibre production, ecosystem functions and adaptation to climate change for present and future generations" (cf. FAO 2013). Preconditions for a far-sighted use of soil are the generation of knowledge and consciousness of land use and changes in land cover (cf. Bock et al. 2011; Dosch 2008; Seidl and Schultz 2006; Besecke et al. 2005). In view of the continuing high pace of development of open space into settlements and transport infrastructure (land consumption), the question of how to ensure that such development remains sustainable has been the subject of national (e.g. FONA/REFINA, MORO, ExWoSt) and international research (e.g. Circuse, Lupa, Plurel, Moland, Volante, SUME) as well as spatial development policy discussions for some years (e.g. EU: European Spatial Development Perspective, Soil Thematic Strategy, Soil Framework Directive, Ressource Efficiency Roadmap; Germany: National Sustainability Strategy, German National Strategy on Biological Diversity). This has provoked research into the influential factors of land consumption (cf. Kroll and Haase 2010; Klemme 2009; Hersperger and Bürgi 2009; BMVBS and BBSR 2009; EEA 2006; Heiland et al. 2006; Arlt et al. 2001). One precondition for the acceptance and implementability of reduction policies is a comprehensive inventory of

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influential factors. Currently, the qualitative development of land consumption and urban form is not sufficiently understood (cf. BMVBS and BBR 2007, 5). For this reason more research is needed into the factors' influence on functional and physical types of settlement and transportation area (Christiansen and Loftsgarden 2011, 1; Siedentop und Fina 2010, 79; Distelkamp et al. 2008, 18). Furthermore, influential factors have not been sufficiently considered in a spatially and temporally differentiated manner. Repeated calls have been made for more research into the multi-scale characteristics of land use systems as well as their temporal dynamics and the multi-scale effects of influential factors (BMVBS and BBSR 2009, 16–26; Hersperger and Bürgi 2009, 641; Jörissen and Coenen 2007, 57). The identification and explanation of land use patterns is a crucial task in this context (ESPON 2012; Behnisch and Ultsch 2009; BMVBS and BBSR 2009, 4; Jaeger et al. 2008). Yet currently we lack sufficient knowledge of the interrelationships between influential factors on land consumption (cf. Fina 2013, 35; Christiansen and Loftsgarden 2011, 24; BMVBS and BBR 2007, 121–122).

The growing availability in recent years of georeferenced data sources as well as thematic data has permitted researchers to undertake the quantitative analysis of functional characteristics of land consumption and its influencing factors at high spatial resolutions. However, quantitative multidimensional analyses of influential factors (e.g. approaches based on multivariate statistics, data mining, machine learning or advanced geo-spatial analysis) are still at an early stage of development (Behnisch and Ultsch 2015; Tayyebi 2013; Mennis and Guo 2009; Miller and Han 2009; Wachowitz et al. 2005; Verburg et al. 2004).

The objective of this article is to provide an analytical framework to help quantify the impact of a range of influential factors driving the expansion of settlement and transportation area. To this end the findings of many previous research activities are reported and summarized, and supplemented by data from a survey of experts. The resulting conceptual framework should support future multidimensional studies in Germany and other European countries in the selection and interpretation of variables.

In Section 2 the authors illustrate the relevance of this exploration of influential factors by describing the development of land consumption in Germany between 2000 and 2010 from a municipal perspective, including an indication of spatial and temporal patterns. In Section 3 confirmed and uncertain influential factors of land consumption are presented as a basis for future multidimensional studies on this topic. Finally, Section 4 underlines the importance of understanding how influential factors affect land consumption and highlights the benefit for local planning practices aiming at an ecological urban and regional land development.

2 Spatial and temporal structure of land consumption in Germany

Like many other industrialized countries, Germany has seen an increased consumption of land for settlements and transport infrastructure over recent decades. Simultaneously, the settlement density has decreased while the spatial dispersion of built-up areas has grown (BBSR 2012; Angel 2011; EEA 2006; UBA 2003). This development is not restricted to the immediate suburban environment of large cities; rural areas have also recorded high growth rates of settlement and transportation area in the past, and indeed small cities and municipalities show above-average development ratios in this process (Siedentop and Kausch 2004).

In the following the development of settlement and transportation space for all German municipalities is examined for the decade 2000 to 2010 using data from official land-use surveys according to type of actual use (in German: Amtliche Flächenerhebung nach Art der tatsächlichen Nutzung). In 2010 settlement and transportation area constituted about 13.4% of the national cadastral area, a rise of 1% from 2000. This increase of about 38,000 ha per year corresponds roughly to the area of Cologne (40,517 ha). Thus, settlement and transportation area grew by an average of around 12 m² per second in the decade in question. Against this total increase in settlement and transportation area, it should be pointed out that the annual rate of land consumption decreased in the later years of the decade: While the yearly mean change (median) of settlement and transportation area was 0.79% in the time period 1996 to 2000, its value decreased to 0.55% in the time period 2004 to 2010. The downward trend at the national level reflects the successful implementation of measures to reduce land consumption.

The map on the left of figure 1 illustrates the changing ratio of settlement and transportation area at the municipal level for the period in question. A heterogeneous pattern is clearly indicated, with a few municipalities even showing a decrease in settlement and transportation area. Yet only a mi-

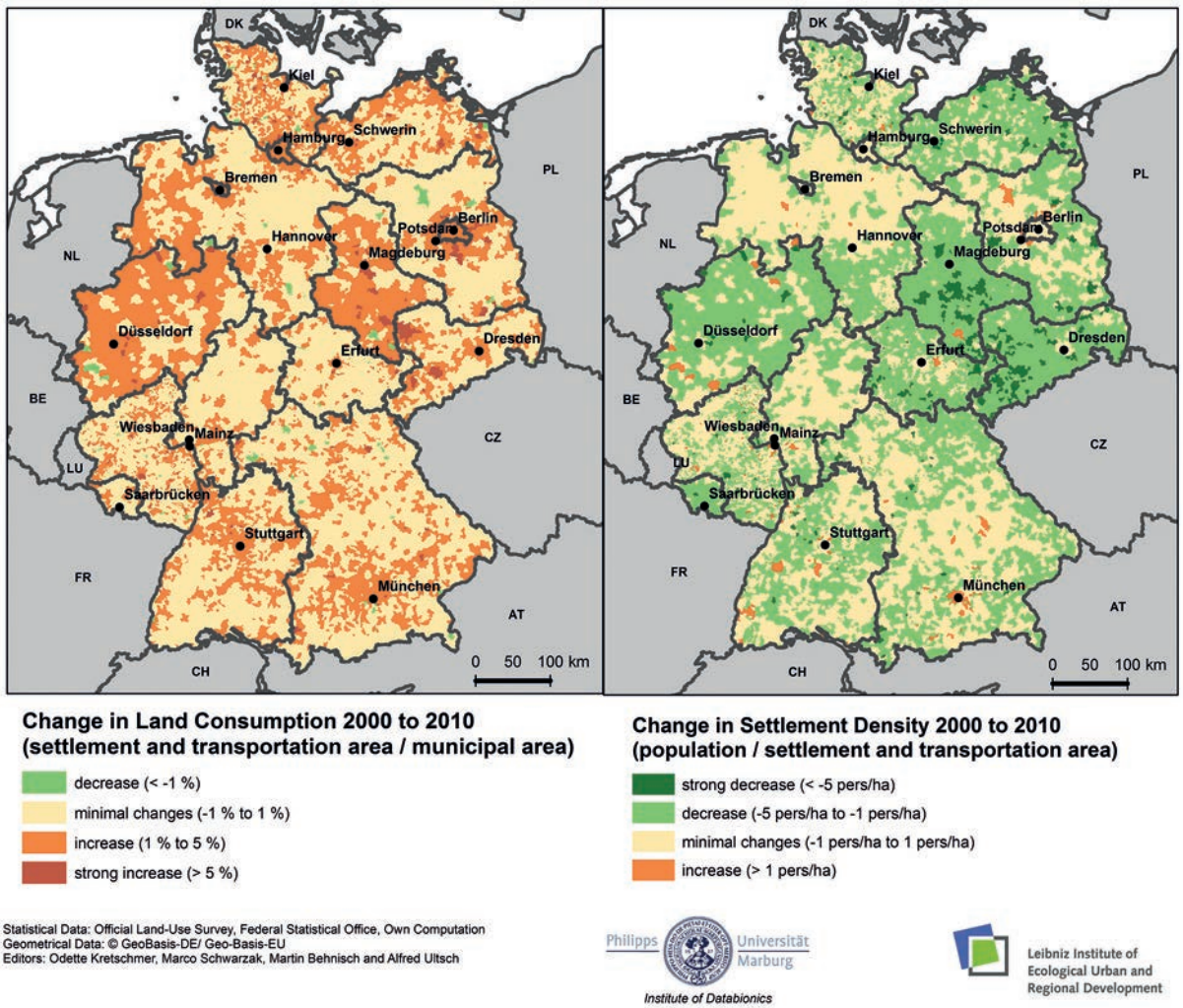

Fig. 1: Spatial and temporal structure of land consumption in Germany over the period 2000 to 2010

nority of such cases actually reflect real-world transformations. Far more often these apparent developments are merely statistical effects that either occur through transferring data into the current ALKIS data model or through administrative reform activities. Yet such effects not only lead to underestimations at the local level of land consumption processes but also to an overestimation of changes in the amount of land used for settlement and transportation purposes (DESTATIS 2013, 6; Fina 2011, 720; Dosch 2008, 41; Dosch and Beckmann 2010).

The map on the right of figure 1 illustrates changes in settlement density for the period 2000 to 2010. The few instances of increased density in this decade are restricted to conurbations. Conversely, strongly decreased settlement densities are seen outside large agglomerations. Here, each inhabitant claims a relatively large area. This development has two major causes: (1) a demographic shift which means that less people use the same amount of settlement and transportation area and (2) growing demand for more area per person (for further analyses c.f. Rienow et al. 2014; Artmann 2013; Mielke and Münter 2010; Kroll and Haase 2010; Nuissl and Rink 2005). Opposing the consumption of land for settlements and transportation infrastructure, there is considerable public pressure to preserve large and interconnected open spaces both to protect biodiversity as well as to provide recreation opportunities. To satisfy these demands as well as to preserve land for power generation as well as for food production, it is necessary to ensure the careful management of land resource by balancing these conflicting demands. In the light of these recent developments, it is increasingly important that we better understand the influential factors driving land consumption.

3 Why is settlement and transportation space still growing?

In order to compile a list of likely influential factors to explain the ongoing expansion of settlement and transportation space, the authors conducted a comprehensive literature review of national and international studies on land consumption (see sub-section 3.2). Thereby the focus relies on research results based on statistical analyses. In addition, a list was drawn up of 'new' variables suggested by experts as potentially relevant but which have not yet been statistically investigated in detail (see sub-section 3.3). The literature review and expert interviews were oriented around a specific conceptual frame, explained below.

3.1 Conceptual frame

(1): Research into the influential factors driving land consumption (see introduction) focuses on either demand-driven or supply-driven factors. Whereas the level of demand for land is largely determined by the activities of private actors, supply varies according to the tax and subsidy policies of public actors (cf. BMVBS and BBSR 2009). In this article all influential factors are assigned to one of these categories ('demand driven' or 'supply driven').

(2): In order to make more generalized statements, all influential factors can be related to a set of dimensions (cf. Christiansen and Loftsgarden 2011, 7; Leontidou et al. 2007, 245; EEA 2010, 23; ESPON 2010, 26; Bürgi et al. 2004, 644–645). Their designation and the attribution of factors to the following six dimensions have been discussed and affirmed by a number of experts (see table 1, final entry).

1. Demographic and social issues
2. Mobility
3. Economy
4. Politics
5. Spatial context
6. Land and real estate market

(3): The demand and supply of land varies according to the particular market, i.e. 'residential use', 'industrial and commercial' purposes or 'transportation'. Hence, investigations on land consumption should distinguish between these three specific subclasses (Müller et al. 2010). Most experts advocate this approach.

(4): The rate of land consumption is variously influenced by the activities of a range of actors. It is important to identify whether an influential factor serves to increase or decrease the level of consumption in order to derive targeted planning strategies towards sustainable urban development.

(5): Influential factors do not act in isolation but interact in complex ways. The particular constellation of factors influencing land consumption can vary significantly between regions and municipalities, and therefore consumption should be investigated in a spatially differentiated manner.

3.2 Statistically proven influential factors of land consumption

Figure 2 presents a mind map of national and international research results based on statistical analyses, largely carried out during the period 2000 to 2010. Here it should be pointed out that the focus of the current investigation is not a comparison of assumptions, raw data and applied methods of these analyses, but rather on the range and depth of the chosen explanatory variables.

The labeling of variables in the mind map refers to the following authors: [1] Tesdorpf 1984; [2] Kroll and Haase 2010; [3] Ma and Xu 2010; [4] Su and DeSalvo 2008; [5] BMVBS and BBSR 2009; [6] Müller et al. 2010; [7] Hoymann 2010; [8] Mann 2009; [9] Hu and Lo 2007; [10] Persky and Kurban; [11] Mann and Zingg 2009; [12] Levia 1998; [13] Batisani and Yarnal 2009. Furthermore, cluster analyses have been carried out for example by Dech and Klein 2009 or Geyler et al. 2008, although findings have not be incorporated in the current work. The influence of the identified factors driving land consumption depend on the characteristics of each cluster. In order to simplify figure 1, such complex interrelations are not represented in the mind map.

A statistical relationship to land consumption could be proven for most influential factors. Our results are structured according to the six dimensions previously introduced. Each factor has been designated as either 'demand driven' (D) or 'supply driven' (S), and is further described by one or more variables. These variables serve to quantify the impact of the influential factor, and are characterized by their effect of increasing (⇑) or reducing (⇓) land consumption. Certain variables for which both a positive and negative dependency have been observed are marked accordingly (⇔). Variables that

could only be proven for specific urban subclasses are labeled 'RA' (significant for residential building area) or 'CA' (significant for commercial area). Non-significant results are also indicated as such ('n.s.'). Variables that relate to transportation infrastructure are not included in the mind map as such statistical analyses (to the authors' knowledge) do not exist.

A total of 23 influential factors emerge, described in detail by 44 variables. It could be shown that 29 of these variables are positively correlated with land consumption. This is particularly true of sociodemographic variables as well as those related to mobility, economic conditions and the real estate market. Such variables largely explain land consumption in terms of demand, and thus only account for part of the growth in settlement and transportation space. Some influential factors on the supply side also serve to boost land consumption. These are, for instance, the availability of public subsidies or construction land. By intelligently managing the supply of land, municipalities can create incentives for households and companies to develop land without raising demand (BMVBS and BBSR 2009).

18 variables were seen to have a dampening effect on land consumption. In some cases these are related to spatial planning instruments (e.g. land policy climate). Other variables serving to reduce land consumption are those related to the spatial context of a region such as the distance to motorways, train stations and roads. In nine cases no significant correlation could be determined (e.g. number of cars, net migration, land consumption in neighboring municipalities).

3.3 Uncertain influential factors of land consumption

The mind map in figure 2 illustrates the comprehensive state of knowledge about the factors and variables statistically correlated with the consumption of land for settlements and transportation infrastructure. The authors then considered the question of whether the compiled variables are suitable to significantly reduce the pace of land consumption in a targeted manner in the coming years. To this end, a group of 13 scientists and practitioners were interviewed to find out whether they regard the presented list of variables as exhaustive; and if not, which further additions they would suggest based on their professional expertise. The interview partners were selected for their specific knowledge of one or more dimensions of influential factors (see sub-section 3.1) based on their long-standing professional background. The interviews, conducted by telephone, lasted for 30 to 45 minutes. The questions as well as the list of influential factors to be discussed were sent to the experts beforehand. Each interview focused on the influencing factors of the dimension most closely aligned to the respective expert's professional background. Furthermore, the experts were asked to give their opinion on the overall structuring and characteristic interrelationships of influential factors as well as their relevance to land consumption independently of any dimension.

The resulting 24 'potential variables' are listed in table 1. In the context of this paper, 'potential variables' describe measures whose correlation with communal settlement and transportation area has not yet been statistically proven. However, the list of variables given here includes measures that have been previously discussed and investigated by means of non-statistical methods. The structure of table 1 is similar to figure 2 in classifying the variables according to the respective influential factors and dimensions. In addition, the experts' hypotheses concerning the direction of the dependency with land consumption (positive or negative) are indicated. 10 of the 17 variables can be assigned to the category 'demand driven' factors. The remaining variables/factors are either 'supply driven' factors or cannot be clearly assigned to one or other of these categories. It should be noted that such factors frequently operate in a political or economic context, and only rarely display a clear positive or negative correlation to land consumption (e.g. tax revenues from the program of municipal financial equalization, available structures of inter-municipal cooperation, public subsidies for urban reconstruction East/West). Research is particularly needed into 'demand driven' influential factors, which are subject to less controversy than 'supply driven' factors (see Tab. 1). Here it is important to emphasize the limited availability of data for some of the variables listed. In these cases much practical and computational effort is required for data collection and processing (e.g. living preferences, population forecasting). In other cases data on variables cannot be gathered due to data protection legislation (e.g. transaction volume of real estates). However, official data is available for many variables. Those variables for which unrestricted datasets exist are indicated in table 1 in bold.

Tab. 1: Experts' statements (all variables indicated in bold are either published as part of Germany's official statistics or otherwise publicly available, ('S' supply side, 'D' demand side, 'RA' residential building area, 'CA' commercial area, ↓ reduces land consumption, ↑ increases land consumption , ↔ can reduce or increase consumption, 'conc.' concerning)

	Influential factor	Variable	Hypothesis [reference]
Demographic & social issues	population number (D)	**population forecast** (↔)	A population forecast will shape political action and thus constitutes an important determinant of land consumption. [5]
	leisure and consumption behavior (D)	number of integrated urban shopping centers (↓)	Shopping centers inside the city center slow the expansion of settlement and transportation space. [11]
	tourism (D)	**number of holiday apartments (↔)**	Tourism infrastructure shows a very heterogeneous spatial dimension, indicating a weak correlation for the pan-German study. [2]
Mobility	commuting balance (D)	**proportion inbound/outbound commuters at the work location (↑ conc. CA, ↔ conc. RA)**	Municipalities with a surplus of inbound commuters will presumably face an increasing demand for land for commercial and traffic infrastructure rather than for housing. [3]
	expansion and attractivity of public transport (D)	**accessibility of local and long-distance train stations (min) (↑)**	Land consumption is expected to be above average in close proximity to train stations with long-distance transport connections. [4]
Economy	municipal financial situation (D/S)	**municipal revenues from land taxes (↓)**	A high land tax dampens the demand for residential- and commercial space. [6] and [11]
		municipal revenues from business taxes (↔ conc. CA)	A high business tax to boost communal tax revenues serves to increase the designation of commercial areas while reducing demand. [6] and [11]
		reaching a municipal debt limit (↓)	Upon reaching the debt limit, no more areas can be designated for settlement and transportation purposes. [7]
		tax revenues from the program of municipal financial equalization (↔)	As the share of municipal revenues coming from the federal authorities is usually unknown, the interaction with land consumption is uncertain. [7]
	state of the financial market (D)	transaction volume of real estates (↑ conc. RA)	Investment driven by the capital market serves to indirectly increase demand for residential land. [6]
		development of the key interest rate (↓)	The higher the rate of interest the more expensive the building loan; this clearly dampens demand for land for housing and commercial development. [8]
		inflation rate (↑ conc. RA)	A high inflation rate is an inducement to supply and acquire land for new residential buildings. [6]
	economic potential of municipalities (D)	average productivity per unit area (↓ conc. RA, ↑ conc. CA)	(1) A high average productivity per unit area reduces the rate of land consumption. [6] (2) A high productivity per unit area boosts economic potential, which can increase the demand for additional commercial sites. [7]

List of experts, subdivided by interview emphases (dimensions): *demographic and social issues:* [1] Dr. Jana Hoymann · Bundesinstitut für Bau-, Stadt- und Raumforschung, Bonn; [2] Dr. Bock · Deutsches Institut für Urbanistik; *mobility*: [3] Sven Altenburg · TU Hamburg-Harburg, [4] Prof. Dr. Stefan Siedentop · ILS, Institut für Landes- und Stadtentwicklungsforschung Dortmund; *economics*: [5] Prof. Dr. Klaus Selle · RWTH Aachen, [6] Prof. Dr. Guido Spars · Bergische Universität Wuppertal,

	Influential factor	Variable	Hypothesis [reference]
Politics	"atomization" of the decision-making authorities on land use (S)	available structures of inter-municipal cooperation between neighboring municipalities (↔)	(1) More intense inter-municipal cooperation lowers communal land consumption. [10] (2) Cooperation between municipalities does not necessarily decrease the rate of land consumption but may in fact increase it. [11]
	public subsidies (S)	public subsidies for urban reconstruction East/West (↔)	(1) The influence of subsidies for urban reconstruction East/West is particularly strong. The effect is more moderate in the residential sector. [11] (2) Subsidies for urban reconstruction and rural development are provided to decrease the consumption of land for housing. [12]
	Regulation of land use by federal and regional planning authorities (S)	share of protected area of the total area, where building development is (1) foreclosed or (2) avoided (↔)	The rate of land consumption largely depends on the category of protection. [9]
Spatial context	accessibility (D/S)	accessibility of regional centers and railway stations on foot and by bike (min). (↔)	In addition to accessibility by motorized vehicles, land consumption is affected by the degree of accessibility on foot or by bike. [3]
Land and real estate market	availability and quality of building sites (S)	**ratio of former military facilities to total area (↑)**	The higher the availability of former military sites, the higher the availability of potential building sites. [9]
		structural condition of vacant buildings (-/↓)	(1) The structural condition of vacant buildings does not influence land consumption, especially if they belong to a sector of the market where demand is low. [13] (2) The better the buildings structural condition, the weaker the demand for additional land. [8]
		ratio of vacant buildings and brown fields to the total area (↓)	A high ratio of vacant buildings and brownfields dampens land consumption. [8]
	availability and prices of building land (D/S)	average price gradient of building land within the region (↔)	(1) If the average price gradient of development land is low, land consumption increases. [5] (2) In theory, a high price of building land can both increase and decrease the rate of land consumption. On the one hand, land is used more efficiently; on the other hand, the designation of new land for construction within the surrounding area will grow if not limited by regional planning. [13]
	living preferences of the population (D)	**living space per household, age-differentiated (↔)**	(1) The demand for more living space per household will influence the rate of land consumption (especially in the case of households of young families and senior citizens). [1] and [8] (2) Living preferences with respect to more spacious housing or single family houses in the suburbs can be realized more cost-effectively in rural locations. While depopulating cities, this leads to a high degree of land consumption in rural areas. [12]
	ratio of owners (D)	**ratio owner-occupied homes/ rental flats (↑)**	Owner-occupiers use living area rather inefficiently. Though senior citizens require less space, they often live alone in their own large homes (remanence effect). [13]
	rental price (D)	average rental price per m² (↓)	An increasing rental price dampens the rate of land consumption. Though the relation is slight, this effect is observed over the long term. [7]

[7] Prof. Dr. Kilian Bizer · Georg August Universität Göttingen, [8] Martin Distelkamp · Gesellschaft für Wirtschaftliche Strukturforschung mbH Osnabrück; *spatial context:* [9] Florian Mayer · Bundesamt für Naturschutz; *politics:* [10] Prof. Dr. Henning Nuissl · Humboldt-Universität zu Berlin, [11] Dr. Uwe Ferber · Projektgruppe Stadt + Entwicklung Leipzig, [12] Dr. Barbara Malburg-Graf · Büro Plan_N Kornwestheim; *land and real estate market***:** [13] Gertrude Penn-Bressel · Umweltbundesamt Dessau-Roßlau

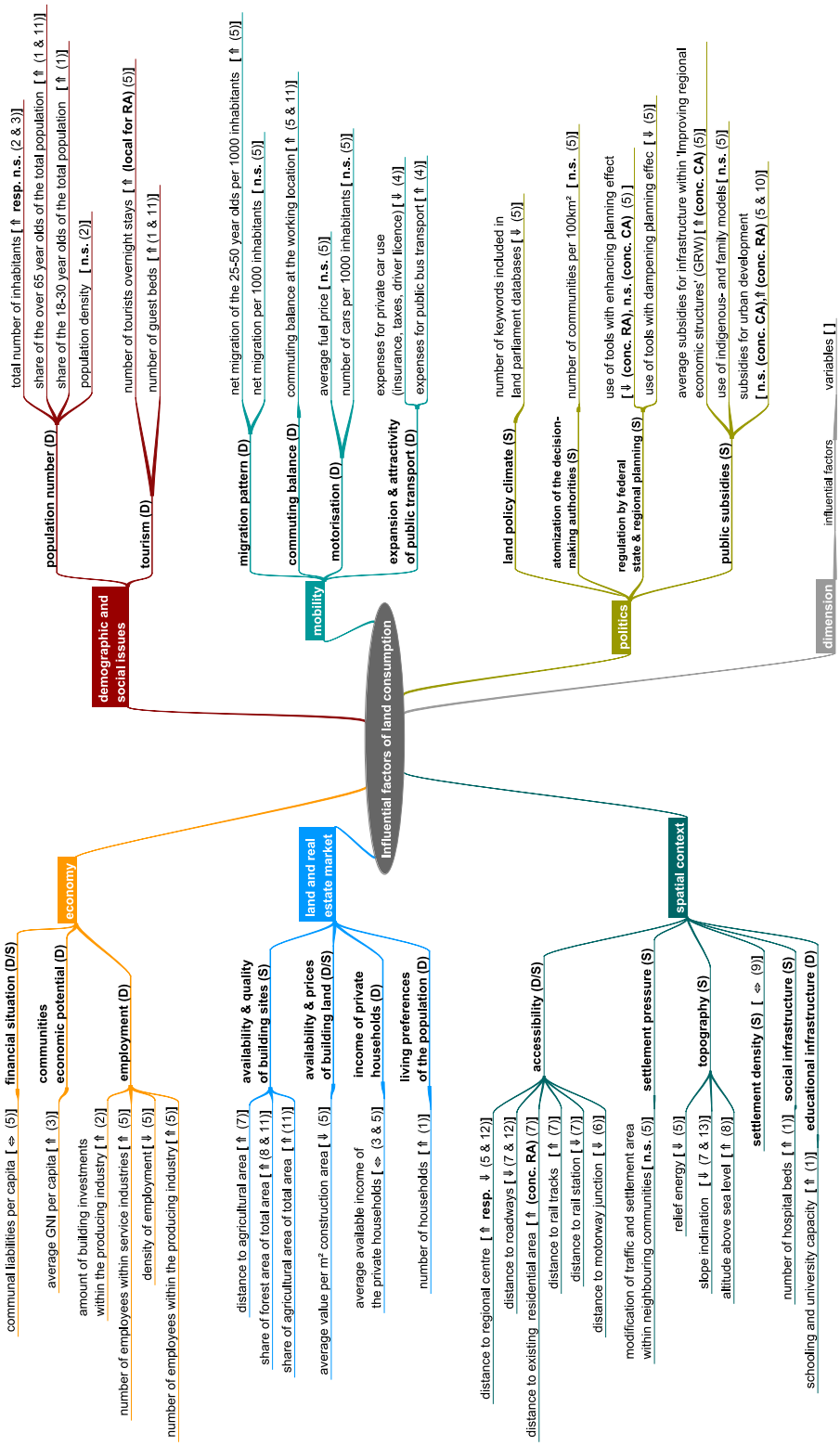

Fig. 2: Statistically confirmed influential factors of land consumption ('S' supply side, 'D' demand side, 'n.s.' not significant, 'RA' residential building area, 'CA' commercial area, ↓ negative dependency, ↑ positive dependency, ↔ can display both positive or negative dependency, conc. concerning). The numbers indicated after each variable corresponding to a particular author or authors (see the beginning of this section)

4 Conclusions: focal points for research and application

Considering the impact of many previous national and international projects and funding initiatives in urban and regional development, it is clear that the challenge to sustainable land consumption lies first and foremost in an adequate analysis of the complex interactions between human/institutional activities and the natural and built environments (cf. EU 2015; BMBF 2015; SNF 2015; RIKS 2015; EU 2013; ESPON 2012; EU 2011; SNF 2011; EU 2010; REFINA 2009; BMVBS and BBSR 2009 etc.). In order to meet this challenge it is essential to isolate and understand those influential factors that are responsible for the increasing scarcity of open space. Two questions therefore framed the current investigation: "Which influential factors can be compiled from a literature review as well as by means of expert interviews?" and "How does land consumption interrelate with theses influential factors?"

As a first step, the problem of rapid land consumption was highlighted by analyses of land use data between the years 2000 and 2010 at the level of Germany's municipalities. This permitted the mapping of recent spatial patterns of land consumption.

Then, to support future multidimensional data analyses, influential factors already identified within the relevant literature were compiled and labeled according to their impact on the extent of settlement and transportation area.

Finally, a second compilation was made of additional influential factors assessed as relevant by an expert group of scientists and practitioners.

The authors consider this article as a vital contribution to future multidimensional data analyses on land consumption in Germany and other European countries. It is hoped that the work will encourage further investigations into a range of influential factors on land consumption such as shrinkage, demographic change, climate change, etc. By examining more closely the spatial patterning of consumption and the various processes involved, it should be possible to develop greater insight into the individual influential factors and indicators of land consumption and their interdependencies.

In conclusion, we outline some fields of application as well as suggesting some approaches to the quantification of influential factors.

Monitoring, Controlling, Reporting: Land use monitoring is still an important task of spatial research to support decision-making processes in spatial planning. Such monitoring can help to anticipate structural changes and to identify likely trends in the demand and supply of land for settlements and transportation infrastructure. In particular, land use monitoring opens up the possibility of detecting trends at an early stage that are undesirable from a spatial and functional perspective. The authors consider the integration of additional influential factors into monitoring instruments as a positive step in refining the design and practicality of planning instruments. To this end, spatial objects with similar structures and process characteristics should be observed and documented in terms of their attribute interrelations and spatial distribution (e.g. at the level of districts and municipalities). Multivariate analyses of high-quality time series of thematic data as well as georeferenced data can enhance our understanding of the interrelations between influential factors and land consumption patterns as well as monitoring these in great detail. Currently such data is rarely available at a useful temporal resolution. Therefore, one major task for future work lies in the preparation as well as description of data series at high temporal resolutions.

Strategies, Management and Cooperation: One focus of international discussion in the political and scientific arenas is the suitability and application of Planning Support Systems (PSS) to simulate and predict land use changes. Further, PSS have the potential to foster public participation in planning processes. These constitute promising tools to deal with challenges in spatial planning or to serve as information platforms for interested members of the general public (Geertman and Stillwell 2004). By taking into account selected influential factors of land consumption, the application of PSS can support the drawing up of planning strategies towards sustainable urban and regional development. This underlines the importance of creating and refining inventories of influential factors to enable local and regional actors as well as political authorities to apply forward-looking concepts and instruments for the reduction of land consumption in their areas of responsibility and in cooperation with one another. Such inventories should permit the identification of relevant actors and their political, economic or private motivations for further land consumption. Furthermore, it is important to determine the specific administrative level most affected by a spatial dependency in order to identify the correct level of action for the implementation of suitable planning strategies (communal, regional and federal state planning). Accordingly, methods need to be developed and applied to realize scalable, multidimensional investigation models

as well as associated instruments and indicators. The challenge of such models is to take account of the spatio-temporal hierarchy of scale (e.g. through multiple representation, up-scaling or down-scaling). This is especially important when aggregating or disaggregating spatial units such as municipalities, districts or states and switching among these units.

Forecasting and Simulation: Alongside the analysis of past influences on land consumption, deeper insight into future potential effects on urban land use is required to derive options for action in land use planning (e.g. financial incentives, planning instruments, policies and laws). As an initial step, the repercussions of land consumption can be described through various parameters (e.g. the degree of sealed surface, the loss of high quality soils) using estimation models (e.g. regression approaches). In a second step, complex scenarios can be created by simulation techniques. For example, a wide range of models (such as cellular automata, neural networks, multi agent systems, etc.) have been applied over the past years to simulate potential changes in land use. One subset of such models helps to simulate the impact of known factors on future land use patterns (as for example in Gonzalez et al. 2015). A second subset supports the identification of influential factors and their effects on land use structures that can lead to some desirable development pattern in land use (e.g. Osman et al. 2015). Some examples of models used in Germany-speaking countries which base their analyses (among other things) on the examination of influential factors on land consumption/urban sprawl are the projects Panta Rhei Regio (Refina 2009), CC-LandStraD (BBSR 2015) and SPROIL (WSL 2013). One example of a tool to generate scenarios of land use change is the spatial model known as Land Use Scanner (cf. Koomen et al. 2011; Hoymann 2010; Hilferink and Rietveld 1999).

In summary, the authors would like to encourage discussion and expansion of the presented compilation of influential factors with the aim of confirming or rejecting hypotheses on the causes of land consumption. So-called multidimensional analyses are increasingly being applied to this issue in order to discover, interpret and present information embedded in large and complex land use datasets. At this point it should be mentioned that the size of spatial units often varies greatly within study areas, both in regard to territorial extent and population. To resolve this problem, grid data can be employed to overcome the effects of scale and to mitigate the influence of the "modifiable areal unit problem" (Maup, Openshaw 1984). In this way the spatial context and the relevant scale for explaining land use structures and changes can be observed more precisely and the detection and explanatory capacity of possible causalities improved. In the authors' opinion, qualitative studies in terms of surveys and interviews should be used to supplement multidimensional approaches in order to quantify the interdependencies of factors as well as describe their complex relations. This can provide a useful contribution to our understanding of the complex system of influential factors on land consumption.

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