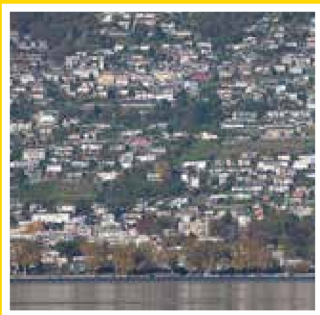
EEA Report | No 11/2016

Urban sprawl in Europe

Joint EEA-FOEN report

ISSN 1977-8449



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

European Environment Agency

EEA Report | No 11/2016

Urban sprawl in Europe

Joint EEA-FOEN report

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

European Environment Agency

Cover design: EEA
Cover photo: © Niklaus Wächter, Switzerland (Altdorf, canton Uri, Switzerland, 2008)
Left photo: © Sina Wild/WSL, Switzerland (Muralto/Minusio, canton Ticino, Switzerland, 2013)
Right photo: © Sina Wild/WSL, Switzerland (Verbier, canton Valais, Switzerland, 2013)
Layout: Pia Schmidt

More information on the European Union is available on the Internet (http://europa.eu).

Luxembourg: Publications Office of the European Union, 2016

ISBN 978-92-9213-738-0
ISSN 1977-8449
doi:10.2800/143470

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Swiss Federal Office for the
Environment (FOEN)
3003 Bern
Switzerland

Tel.: +41 58 462 9311
Web: www.bafu.admin.ch
Enquiries: info@bafu.admin.ch

Contents

Annexes 1 to 5 can be found at: http://www.eea.europa.eu/publications/urban-sprawl-in-europe

Acknowledgements

This report is a result of the continued collaboration between the Swiss Federal Office for the Environment (FOEN) and the European Environment Agency (EEA), with main funding provided by FOEN. It is a sequel to the previous joint EEA–FOEN report, *Landscape fragmentation in Europe* (EEA and FOEN, 2011a). For the present report, a recently described method of urban sprawl analysis has been applied to 32 European countries. This method was developed in Switzerland, which is used as a prominent case study in this report, and Canada.

This report was coordinated by Felix Kienast (the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)) and Jochen A. G. Jaeger (Concordia University, Montreal, Canada) and prepared by Ernest I. Hennig (Concordia University, Montreal, Canada), Tomas Soukup (GISAT, a member of the EEA's European Topic Centre on Urban, Land and Soil Systems), Erika Orlitová (GISAT), Christian Schwick (Die Geographen schwick+spichtig and WSL) and Jochen A. G. Jaeger.

Guidance, support and review were provided by Marie Cugny-Seguin (Project Manager at the EEA), and further assistance and feedback were given by other EEA staff, namely Tobias Langanke, Gorm Dige, Markus Erhard, Geertrui Louwagie, Andrus Meiner and Ronan Uhel.

Valuable support and helpful comments were provided by Nicolas Perritaz (Project Manager at FOEN) and other FOEN staff, namely Jean-Michel Gardaz, Tom Klingl, Gilles Rudaz and Matthias Stremlow.

The authors would like to express their gratitude to Nuška Brot (Statistical Office of the Republic of Slovenia, Ljubljana, Slovenia), Janko Kraševac (Croatian Bureau of Statistics, Zagreb, Croatia), Sami Lahtinen (Statistics Finland, Helsinki, Finland), Karen Tina Larsen (Statistics Denmark, Copenhagen, Denmark), Hervé Rennié (Eurostat, Labour Force Survey, Luxembourg), Álvaro Silva (Instituto Nacional de Estatistica INE, Lisbon, Portugal), David Tesar (Federal Statistical Office, Neuchatel, Switzerland), Marjan van Herwijnen (European Observation Network for Territorial Development and Cohesion (ESPON), Kirchberg, Luxembourg) and Åsne Vigran (Statistics Norway, Oslo, Norway) for the data they provided about commuting and the information they provided about the harmonisation of employment statistics. The authors are also very grateful to the following people (in alphabetical order), who provided detailed comments, valuable advice or technical support: Lewis Dijkstra (European Commission, Directorate-General (DG) for Regional and Urban Policy), Andreas Faludi (Delft University, the Netherlands), Jaume Fons-Esteve (European Topic Centre (ETC) on Spatial Information and Analysis (SIA), Barcelona, Spain), Mirko Gregor (space4environment, Luxembourg), Miroslav Kopecky (GISAT, Prague, Czech Republic), David Ludlow (University of the West of England, Bristol, United Kingdom), Zachary Patterson (Concordia University, Montreal), Hermann Peifer (Eionet and EEA, Copenhagen, Denmark), Christoph Schöder (European Topic Centre on Spatial Information and Analysis (ETC-SIA), Barcelona, Spain), Dominic Stead (Delft University, the Netherlands) and Craig Townsend (Concordia University, Montreal).

The EEA and FOEN wish to thank all participants of the workshops, held in Bern in June 2014 and in Copenhagen in April 2015, for their helpful comments, in particular (in addition to the people already mentioned above) Ece Aksoy (ETC, University of Malaga, Spain), Gorja Bartsch (Eurostat), Martin Behnisch (Leibniz Institute of Ecological Urban and Regional Development, Germany), Herbert Bühl (Winzeler+Bühl, Switzerland), Matthias Bürgi (WSL), Rob Donkers (DG Environment), Piotr Fogel (Institute of Spatial Management and Housing, Poland), Christian Fertner (University of Copenhagen, Copenhagen, Denmark), Anna Hersperger (WSL), Marco Kellenberger (Swiss Federal Office for Spatial Development, Bern, Switzerland), Josiane Masson (DG Environment), Yves Maurer (Swiss Federal Office for Spatial Development, Bern, Switzerland), Rudolf Muggli (Ad!vocate, Switzerland), Zorica Nedovic-Budic (University College Dublin, Dublin, Ireland), Antti Rehunen (Finnish Environment Institute (SYKE), Helsinki, Finland), Sophie Rudolf (WSL), Tobias Schulz (WSL), Marco Schwarzak (Leibniz Institute of Ecological Urban and

Regional Development, Germany), Irmi Seidl (WSL), Gilbert Thélin (regional planning expert, Switzerland; formerly at FOEN), Iván Tosics (Metropolitan Research Institute (MRI), Hungary), Nuria Valcárel Sanz (Instituto Geográfico Nacional, Spain), Anton van Hoorn (PBL Netherlands Environmental Assessment Agency, the Netherlands), Barbara Weilenmann (WSL) and Laurent Zecha (Swiss Federal Statistical Office).

Contact addresses of the authors

Dr Ernest I. Hennig and Professor Jochen A. G. Jaeger, Concordia University, Department of Geography, Planning and Environment, 1455 de Maisonneuve Blvd West, Suite 1255, Montréal, Québec H3G 1M8, Canada. ernest.hennig@interia.eu, jochen.jaeger@concordia.ca

Tomáš Soukup and Erika Orlitová, GISAT s.r.o., Milady Horákové 57, 170 00 Praha 7, Czech Republic. tomas.soukup@gisat.cz, erika.orlitova@gisat.cz

Christian Schwick, Die Geographen schwick+spichtig, Turbinenstrasse 60, 8005 Zurich, Switzerland. schwick@bluewin.ch

Professor Felix Kienast, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland. felix.kienast@wsl.ch

Acronyms

ABS	Alternative Bank of Switzerland
$A_{\text{built-up}}$	Size of built-up area in the reporting unit
$A_{\text{reporting unit}}$	Size (area) of the reporting unit
ATKIS	*Amtliches Topographisch–Kartographisches Informationssystem* (official topographic–cartographic information system of Germany)
BDM	Biodiversity Monitoring Switzerland
Bridge	Sustainable urban planning decision support accounting for urban metabolism
CBC	Cross-boundary connections
CBD	Convention on Biological Diversity
CBI	City Biodiversity Index
CDU	Christian Democratic Union
Ciesin	Center for International Earth Science Information Network
CLC	Corine Land Cover
COP-9	Ninth meeting of the Conference of the Parties
Cordis	Community Research and Development Information Service
Corine	Coordination of Information on the Environment
CSI	Core set of indicators
DG	Directorate-General
DIS	Dispersion of built-up areas
7EAP	Seventh Environment Action Programme
EC	European Commission
EEA	European Environment Agency
EFTA	European Free Trade Association
EIA	Environmental impact assessment
Eionet	European Environment Information and Observation Network
EMBv5_100m	EuroBoundaryMap version 5
ESDP	European Spatial Development Perspective
ESPON	European Observation Network for Territorial Development and Cohesion
ETC	European Topic Centre
EU	European Union
EU-28 + 4	All 28 Member States of the European Union and the countries that are members of the European Free Trade Association (i.e. Iceland, Liechtenstein, Norway and Switzerland)

Eurostat	A Directorate-General of the European Commission that provides statistical information to the institutions of the European Union
FAO	Food and Agriculture Organization of the United Nations
FOEN	Swiss Federal Office for the Environment
FUA	Functional urban area (formerly known as a larger urban zone (LUZ))
GDP	Gross domestic product
*GDP*c	Gross domestic product per capita
Geostat	Project launched by Eurostat in cooperation with the European Forum for GeoStatistics (EFGS) to promote grid-based statistics
GIO land	GMES (now Copernicus) initial operations for the land monitoring service
GIS	Geographic information system
GMES	Global Monitoring for Environment and Security
GPW	Gridded Population of the World
GRUMP	Global Rural–Urban Mapping Project
HP	Horizon of perception
HRL	Pan-European High Resolution Layer
HRL IMD	Pan-European High Resolution Layer of Imperviousness Degree
JPI Urban Europe	Joint programming initiative urban Europe
LABES	*Landschaftsbeobachtung Schweiz* (Swiss landscape observation system)
LASSO	Least absolute shrinkage and selection operator
LAU	Local administrative unit
LCF	Linear correction factor
LEAC	Land and Ecosystem Accounting
LUP	Land uptake per person, that is per inhabitant or job
LUP_p	Land uptake per person based on population data only (not job data), that is per inhabitant only
LUZ	Larger urban zone (now known as a functional urban area (FUA))
NDVI	Normalized Difference Vegetation Index
$N_{inh + jobs}$	number of inhabitants and jobs in the built-up area of the reporting unit
NPP	Net primary productivity
NRPI	Natural Resource Protection Indicator
NRW	North Rhine-Westphalia
NUTS	Nomenclature of Territorial Units for Statistics
NUTS-0	NUTS country level
NUTS-2	NUTS level of regions/provinces/states/prefectures, with a population of between 800 000 and 3 000 000
OECD	Organisation for Economic Co-operation and Development
Pashmina	Paradigm shifts modelling and innovative approaches
PBA	Percentage of built-up area

Peblds	Pan-European Biological and Landscape Diversity Strategy
Plurel	Peri-urban land use relationships — strategies and sustainability assessment tools for urban–rural linkages
PPS	Purchasing power standard
PSR	Pressure–state–response
Scatter	Sprawling cities and transport: from evaluation to recommendations
SDI	Spatial data infrastructure
SEA	Strategic environmental assessment
SEM	Structural equation models
SIA	Spatial Information and Analysis
SNBS	*Standard Nachhaltiges Bauen Schweiz* (standard for sustainable construction in Switzerland)
SOER	'State of the environment' report
SP	Speed
SPC	Sprawl per capita
SPD	Social Democratic Party
TERM	Transport and Environment Reporting Mechanism
UD	Utilisation density of built-up areas
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFPA	United Nations Population Fund (formerly the United Nations Fund for Population Activities)
UP	Urban permeation (i.e. the permeation of a landscape by built-up areas)
UPU	Urban permeation units
URBS Pandens	Urban sprawl: European patterns, environmental degradation and sustainable development
USM tool	Urban Sprawl Metrics tool (for the ArcGIS-toolbox)
Vector25	National land-use/land-cover data set for Switzerland
VIF_j	Variance inflation factors
$w_1(DIS)$	Weighting function for dispersion of built-up areas
$w_2(LUP)$	Weighting function for land uptake per person
WGI	Worldwide Governance Indicators
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
WUP	Weighted urban proliferation
WUP_p	Weighted urban proliferation based on population data only (not job data), that is, per inhabitant only

Country and territory codes

AL	Albania	LI	Liechtenstein
AT	Austria	LT	Lithuania
BA	Bosnia and Herzegovina	LU	Luxembourg
BE	Belgium	LV	Latvia
BG	Bulgaria	MC	Monaco
CH	Switzerland	ME	Montenegro
CY	Cyprus	MKD	the former Yugoslav Republic of Macedonia
CZ	Czech Republic	MT	Malta
DE	Germany	NL	Netherlands
DK	Denmark	NO	Norway
EE	Estonia	PL	Poland
EL	Greece	PT	Portugal
ES	Spain	RO	Romania
FI	Finland	RS	Serbia
FR	France	SE	Sweden
HR	Croatia	SI	Slovenia
HU	Hungary	SK	Slovakia
IE	Ireland	SM	San Marino
IS	Iceland	TR	Turkey
IT	Italy	UK	United Kingdom
KS	Kosovo (under UNSCR 1244/99)	VA	Holy See/Vatican City

Foreword

Europe is highly urbanised and there are indications that this trend will continue. This will lead to an increase in the demand for housing as well as more transport and infrastructure. Urban sprawl has developed over the past decades, contributing significantly to how cities have expanded, and is projected to continue.

Observations and studies show that urban sprawl affects the essential environmental, economic and social functions performed by soils and landscapes, whose importance is often undervalued. Connection with natural cycles and services, including those important for climate change mitigation and adaptation, are curtailed. As such, urban sprawl can be viewed as a typical example of an impact with a cumulative effect, just as viewed in landscape fragmentation. The changes usually occur in a gradual manner over long periods and are not perceived as dramatic. For this reason, urban sprawl is generally underestimated by policymakers. Urban sprawl evolves because of individual and unrelated actions upon the environment such as those taken by citizens, urban planning, economic decisions, the land market, mobility, accessibility, and changes in lifestyle such as a preference for detached housing.

As said, urban sprawl is not a new problem. In 2006, the European Environment Agency (EEA) report *Urban sprawl in Europe — The ignored challenge* bemoaned the scattered expansion of urban areas into the part of Europe's countryside existing on their edge — the 'urban fringe'. Between 2000 and 2006 around 1 000 km² of this land were covered every year by artificial surfaces.

This new EEA/Swiss Federal Office for the Environment (FOEN) report 'Urban sprawl in Europe' not only provides a welcome update to this topic but offers a refined approach for monitoring urban sprawl and a statistical analysis of drivers. There has also been a marked improvement in the quality of available data about built-up areas which makes a European-wide assessment now more accurate.

This report applies a recent method of urban sprawl analysis that was developed in and for Switzerland by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and Concordia University, Canada. These new urban sprawl metrics, developed under the Swiss national research programme 'Sustainable Development of the Built Environment', take into account the spatial arrangement of built-up areas and their utilization. The current report presents, for the first time, the extent of urban sprawl for 32 countries. The analysis is based on the pan-European high resolution layer which maps the degree of imperviousness and is produced as an EU Copernicus land monitoring service every three years.

This report demonstrates that it is now possible to monitor urban sprawl with new indicators. This will allow trends in urban sprawl to be detected more accurately.

The results from this report show that there is an urgent need for action. The current levels of urban sprawl in many parts of Europe are already worrying and may well increase with expected urban development. The methods used in this report can be applied for urban sprawl analysis in urban and regional planning and for performance review. The use of land is nearly always a trade-off between various social, economic and environmental needs that can be tackled through integrated urban and spatial planning. Solutions, such as densification and brownfield recycling, exist to use land in a more sparing way, when addressing urban sprawl challenges in regional and transportation planning. We believe that this report provides timely information for decision and policymakers involved in urban and spatial planning at the local, regional, national and European level.

Such an approach is in keeping with the European Union's 7th Environment Action Programme 'Living well, within the limits of our planet'. This considers land as a resource which needs to be managed in order to respect resource constraints and planetary boundaries. This is similar to the outcome from the United Nations Conference on Sustainable Development, Rio+20, which referred to a 'land degradation neutral world' and recognised the significance of good land management and promoted integrated urban and spatial planning.

We hope that this report, which results from a continued and fruitful collaboration between the EEA and FOEN, will contribute to increase policy awareness on urban sprawl and that the potential threats to maintaining a healthy environment and well-being become more widely understood and fully addressed.

Marc Chardonnens,

Director
Swiss Federal Office for the Environment (FOEN)

Hans Bruyninckx,

Executive Director
European Environment Agency

Executive summary

Urban sprawl is associated with a number of ecological, economic and social effects. Some of these relate to people's desires, for example, to live in single-family homes with gardens. However, urban sprawl has detrimental and long-lasting effects. For example, urban sprawl contributes significantly to the loss of fertile farmland, to soil sealing and to the loss of ecological soil functions. The increase in built-up areas reduces the size of wildlife habitats and increases landscape fragmentation and the spread of invasive species. Urban sprawl leads to higher greenhouse gas emissions, higher infrastructure costs for transport, water and electrical power, the loss of open landscapes, and the degradation of various ecosystem services. Despite various efforts to address this problem, urban sprawl has increased rapidly in Europe in recent decades. Thus, urban sprawl presents a major challenge with regard to sustainable land use, as the International Year of Soils 2015 highlighted.

Sprawl is a result not only of population growth but also of lifestyles that take up more space. Accordingly, urban sprawl has increased even in regions with a declining human population. Many more urban development and transport infrastructure projects are planned for the future, in particular in the European Union (EU) Member States which joined after 2004. Consequently, further increases in urban sprawl in the future will be significant. Therefore, consistent data on the degree of urban sprawl are needed, particularly data that are suitable for the comparison of regions across Europe. This report investigates the degree of urban sprawl in 32 countries in Europe by considering two points in time (2006 and 2009) at three levels. The three levels include the country level, the NUTS-2 region level (based on the Nomenclature of Territorial Units for Statistics (NUTS)) and the 1-km^2 cell level (based on the Land and Ecosystem Accounting (LEAC) grid). The comparison of two points in time allowed an assessment of temporal changes in urban sprawl.

Box ES.1 Short descriptions of the most important variables used in this report

WUP — **Weighted urban proliferation** (*WUP*) is the metric used to quantify urban sprawl. It is the product of the dispersion (*DIS*), a weighting of *DIS*, the percentage of built-up area (*PBA*) and a weighting of the land uptake per person (*LUP*), that is land uptake per inhabitant or workplace. It is measured in urban permeation units (UPU) per square metre of landscape (UPU/m^2). The meanings of the ranges of low and high *WUP* values are explained in Table 2.1 (Section 2.2).

PBA — The **percentage of built-up area** (*PBA*) is the ratio of the size of the built-up areas to the size of the total area of the reporting unit and is given as a percentage.

DIS — The **dispersion** (*DIS*) quantifies the spatial distribution of built-up areas, expressed as UPU per m^2 of built-up area (UPU/m^2). The further dispersed the built-up areas, the larger the value of *DIS*. Therefore, more compact built-up areas have lower values of *DIS* than less compact built-up areas.

UP — **Urban permeation** (*UP*) is a measure of the permeation of a landscape by built-up areas. It accounts for the *DIS* and the *PBA* in the reporting unit. It is measured in UPU per m^2 of landscape.

UD — The metric of **utilisation density** (*UD*) measures the number of people working or living ($N_{Inh + Jobs}$) in a built-up area (per km^2). Built-up areas with more workplaces and/or inhabitants are considered more intensively used, and hence less sprawled, than areas with a lower density of workplaces and/or inhabitants.

LUP — Instead of using the *UD*, the reciprocal can also be used, that is the area of **land used per inhabitant or workplace** (*LUP*). High *LUP* values indicate that more space is used per inhabitant or workplace than in areas of low *LUP* values.

This report applies the method of 'weighted urban proliferation' (*WUP*), which quantifies the degree of urban sprawl for any given landscape through a combination of three components: (1) the size of the built-up areas; (2) the spatial configuration (dispersion) of the built-up areas in the landscape; and (3) the uptake of built-up area per inhabitant or job. The report provides, for the first time, an assessment of urban sprawl in all EU and European Free Trade Association (EFTA) countries using the *WUP* method. The urban sprawl values obtained cover a large range, from low values for large parts of Scandinavia (< 1 UPU/m^2) to high (> 4 UPU/m^2) and very high values for large parts of western and central Europe (> 6 UPU/m^2). The two largest clusters of high-sprawl values in Europe are located in (1) north-eastern France, Belgium, the Netherlands and part of western Germany; and (2) in the United Kingdom between London and the Midlands. The analysis of sprawl at the 1-km^2-grid level shows that sprawl is most pronounced in wide rings around city centres, along large transport corridors, and along many coastlines (particularly in the Mediterranean countries). The lowest levels of sprawl are mainly associated with mountain ranges or remote areas. The level of sprawl, as measured by *WUP*, increased in all European countries between 2006 and 2009. The overall *WUP* value for Europe (all 32 countries combined) increased from 1.56 urban permeation units (UPU)/m^2 in 2006 to 1.64 UPU/m^2 in 2009, that is by 5 % in 3 years or by 1.7 % per year. In most countries, the increase was higher than 1 % per year, and in many countries *WUP* increased by more than 2 % per year. This was also the case for most NUTS-2 regions. Future studies using additional time-points will allow more detailed temporal comparisons. Base data for 2012 will be available in 2016 and these could be analysed in a follow-up project.

Driving forces and predictive models of urban sprawl

The level of urban sprawl is largely a function of socio-economic and demographic drivers, and the geophysical context. Current levels of urban sprawl need to be interpreted within the context of regional socio-economic and geophysical conditions. Therefore, the second part of this study investigated the potential factors that may contribute to an increase or decrease in the degree of urban sprawl, and determined their relative importance. The report applied a set of statistical models to determine which of these factors drive the process of urban sprawl in Europe. We analysed the statistical relationships between urban sprawl and a range of explanatory variables (14 variables at the country level and 12 at the NUTS-2 level). We also applied these relationships to predict the expected sprawl values for all regions in our study area and compared actual values with predicted values.

Most of our hypotheses about the likely driving forces of urban sprawl were confirmed by the statistical analyses. The relevant variables identified as affecting urban sprawl are population density, road density, railway density, household size, governmental effectiveness, the number of cars per 1 000 inhabitants and two environmental factors (i.e. net primary production and relief energy). This result was consistent for both of the years (2006 and 2009) considered in the analysis. The results indicate that economic development has, largely, not been decoupled from increases in urban sprawl. A high amount of variation in the level of urban sprawl, as measured by *WUP*, was explained by the predictor variables: 72–80 % at the country level and 80–81 % at the NUTS-2 level. The variation explained for the three components of *WUP* ranged between 67 % and 94 % at the NUTS-2 level. Efforts to control urban sprawl should take these driving forces into account.

Relevance for monitoring and policymaking

The results provided by this study are intended to contribute to more sustainable political decision-making and planning throughout Europe. In the last 15 years (2000–2015), several projects and programmes at the European level have proposed a suite of concepts and measures to address urban sprawl and promote more sustainable land use. The most recent (2014), and perhaps most important, of these is the Seventh Environment Action Programme (7EAP), which calls for indicators of resource efficiency to be established in order to guide public and private decision-makers. Although the urgent challenge presented by urban sprawl has been recognised, there is still no monitoring in place for European urban sprawl. This report aims to help close this gap.

The results confirm the conclusion of earlier reports (e.g. EEA, 2006a; EEA, 2006b) namely that there is an increasingly urgent need for action. Large discrepancies between the predicted and observed levels of urban sprawl provide a basis for identifying areas for prioritising management action. Our data also provide a basis for scenarios regarding the future development of urban sprawl in Europe. There is an increasing need and interest in including indicators of urban sprawl in systems for monitoring sustainable development, the state of the environment, biodiversity and landscape quality. The results presented in this report are intended for this purpose and can be updated on a regular basis in order to detect trends in urban sprawl. This report also demonstrates the usefulness of the *WUP* method as a tool for urban and regional planning and for performance review based on benchmarks, targets and limits.

This study provides a comparable measurement of urban sprawl for most of the European continent using a consistent data set across Europe. The results will support managers and policymakers with the allocation of resources for the better protection of agricultural soils and landscape quality, and more sustainable political decision-making related to land use. The report also identifies the most immediate priorities and future research needs.

1 The increasing concern about urban sprawl in Europe

Although the importance of the problem of urban sprawl has been recognised at the European level for more than 15 years, there are still no systems in place for monitoring urban sprawl at the European level. This study determined the level of urban sprawl, in 2006 and 2009, in 32 European countries, namely all 28 members of the European Union (EU) and four members of the European Free Trade Association (EFTA), namely Iceland, Liechtenstein, Norway and Switzerland; these 32 countries are collectively referred to as the EU-28 + 4. Urban sprawl has increased in all 32 countries examined. The results provide a basis for monitoring urban sprawl in Europe. To better understand the relationships between urban sprawl and the socio-economic and geophysical factors that may act as potential driving forces, this report also includes a statistical analysis of these variables. The most relevant variables are the population density of the region, the road density, the railway density, household size, governmental effectiveness and the number of cars per inhabitant, along with two environmental variables (i.e. net primary production and relief energy). This allows for a comparative assessment of sprawl that takes the relevant socio-economic and geophysical conditions of the regions into account.

The first chapter provides an overview of the causes and consequences of urban sprawl, and summarises the main results of this report. The second chapter explains the methods used for measuring urban sprawl and for the statistical analysis of likely predictors of urban sprawl. The results regarding urban sprawl in Europe are presented in the third chapter. The final chapter discusses the implications and policy relevance of the results.

1.1 The need to monitor and control urban sprawl

Growing urban sprawl (dispersed urban development) is a serious concern worldwide for a number of environmental and socio-economic reasons. It presents a major challenge with regard to making land use more sustainable, and this was highlighted by the International Year of Soils 2015. Since 2008, half of the planet's population has been living in cities and agglomerations, and this proportion is increasing at a rapid pace (UN, 2006; UNFPA, 2007). The global human population is likely to continue to increase rapidly, which will lead to a continued population shift from rural to urban areas and to significant additional land uptake for urban expansion (Montgomery, 2008; Gerland et al., 2014; UN, 2014). The need for both increased food production and more urban development will lead to competition for land, that is, there will be competing demand for areas suitable for agriculture and areas suitable for urban development. For example, the Food and Agriculture Organization of the United Nations (FAO) expects an increase of 43 % in global food demand by 2030 (FAO, 2011). While this competition for fertile land is most pronounced in continents with the largest population increases, namely Africa and Asia (Chen, 2007; UN, 2014; Lambin et al., 2001), it is also apparent in many other parts of the world in which a significant amount of land has already been consumed by urban sprawl as a result of large numbers of built-up areas, a high land uptake per person and a high dispersion of built-up areas (Eigenbrod et al., 2011).

The increasing urban sprawl in Europe is causing land-use conflicts and is posing a major threat to sustainable land use. Nearly 73 % of the European population lives in cities, and this proportion is projected to reach 82 % by 2050 (UN, 2012). While there are several regions (e.g. eastern Germany) in which the human population is not growing, the expansion of built-up areas has continued in most regions of Europe, even in regions in which the population has declined (Haase et al., 2013; Rienow et al., 2014). From 2000 to 2006, Europe lost 1 120 km^2 per year of natural and semi-natural areas (of which, on average, almost 50 % was arable or cultivated land) to urban or other artificial land development (EEA, 2011b). There is a high probability (> 75 %) that large areas (totalling approximately 77 500 km^2) of the European continent will be or have been converted to urban areas between 2000 and 2030 (Seto et al., 2012). For example, in Switzerland and Baden-Württemberg, Germany, at least as much land was taken up for settlement and transport in the 50 years between 1950 and 2000 as had been taken up for these purposes in the 10 000 years before 1950 (Jaeger, 2002; Schwick et al., 2012); and the rates of land uptake have been similar in many other parts of Europe.

The expected future continuation of urban sprawl in Europe and its associated threats demand action in order to control the spread of built-up areas. Although primarily a local or regional responsibility, this need is also more and more reflected at the European policy level (e.g. the 2011 *Roadmap to a resource efficient Europe* (EC, 2011a), as part of the Europe 2020 Strategy and the Seventh Environment Action Programme (7EAP), as described below). Therefore, there is an urgent need to assess the extent of urban sprawl in Europe in a consistent and comparable way, and to provide relevant evidence that can aid the development of European policy with regard to built-up areas.

On a global level, world leaders at Rio+20 (the United Nations Conference on Sustainable Development) argued that urgent action is needed to halt land degradation, given the increasing pressure on land from agriculture, forestry, pasture, energy production and urbanisation. They agreed to strive to achieve **zero net land degradation** (UNCCD, 2012). However, few instruments have been implemented that have effectively curtailed urban sprawl in Europe so far. The previous report by the European Environment Agency (EEA, 2006b) on the topic of urban sprawl in Europe had already concluded that action is urgently needed, and proposed that European guidelines should be elaborated in order to coordinate and monitor urban planning in Europe (Box 1.1). The knowledge and awareness of the issues associated with urban sprawl has increased substantially in many European countries in the last 10 years. Accordingly, there is heightened concern about the rapid pace of the increase in urban sprawl, which is anticipated to continue relentlessly if more effective measures are not taken.

Box 1.1 Why carry out a new study on urban sprawl in Europe?

In 2006, the EEA published its first report on urban sprawl: *Urban sprawl in Europe — The ignored challenge* (2006b). Since then, several other studies (Couch et al., 2007; Siedentop and Fina, 2012) have addressed urban sprawl in Europe. For example, Kasanko et al. (2006) provide an overview of the urban sprawl that has taken place in several European cities since the 1950s. The EEA (2006b) report used a combination of six indicators to measure urban sprawl for the purpose of environmental monitoring, i.e. (1) the increase of built-up areas (1950s–1990s); (2) the proportion of residential areas that are densely populated (1990s); (3) the proportion of new residential areas that have a low population density (mid-1950s onwards); (4) residential density (1990s); (5) changes in the growth rates of the population and of built-up areas (1950s–1990s); and (6) the available built-up area per person (1990s). Sprawl, between 1990 and 2000, was quantified as urban land development as a percentage of the total area (EEA 2006a; 2006b). However, this approach is insufficient because the spatial arrangement (dispersion or compactness) of built-up areas was not taken into account. The quality of the data, regarding built-up areas, available from GMES (now known as Copernicus) services has improved substantially since the publication of these studies. These data make a European-wide assessment now feasible.

The economic crisis of 2006 affected the political and economic situation of most countries (EC, 2009). The economic crisis also provides an interesting opportunity to investigate the resulting political, social and economic changes since 2006, and their effects on urban sprawl.

Urban sprawl can be observed at various scales, in large cities as well as in villages in rural areas (e.g. shopping malls and industrial areas). An analysis based on larger cities or metropolitan areas alone (as was performed in the previous EEA report (EEA, 2006b) may generalise these insights prematurely without taking into account the effects of sprawl in rural areas and sprawl on larger scales (e.g. Pichler-Milanovic et al., 2007).

In addition, cities and regions can differ considerably, even in the same country, in terms of their economic, social and environmental conditions. By using a sample size as large as possible, a more reliable analysis of the processes that could explain the variation in urban sprawl, and hence help identify the driving forces, can be undertaken. This is now possible because consistent data are available across Europe at a high resolution from the European Copernicus programme.

For all of the abovementioned reasons, an update is urgently needed — 10 years after the previous report — and it is timely given that 2015 was declared the International Year of Soils. We have also extended the analyses of the previous report by providing a statistical analysis of the potential drivers of urban sprawl, and a new approach for monitoring urban sprawl. Novel metrics of urban sprawl, developed within the Swiss National Research Programme 'Sustainable development of the built environment', were applied for this report; these metrics take into account the spatial configuration of urban sprawl. This new set of quantitative measures has been used in various monitoring and planning activities in Switzerland. This novel method (weighted urban proliferation (*WUP*)) was not yet available 10 years ago. An increase in knowledge related to urban sprawl will aid the implementation of mechanisms to better control the spatial arrangement and utilisation intensity of built-up areas.

In the last 15 years, several projects and programmes at the European level have already proposed a suite of concepts and measures aimed at addressing urban sprawl and promoting more sustainable land use. The most recent, and perhaps most important, of these is the **7EAP**. It calls for indicators of resource efficiency to be established in order to guide public and private decision-makers. It entered into force in January 2014. Priority objective 8 is geared towards the sustainability of cities and states that soil protection and sustainable use of land need further action at EU and national levels: the aim is to 'ensure that by 2020, a majority of cities in the Union are implementing policies for sustainable urban planning and design, including innovative approaches for urban public transport and mobility, sustainable buildings, energy efficiency and urban biodiversity conservation' (EC 2013b). Other important projects and programmes have proposed the following in relation to urban sprawl.

- The **Roadmap to a resource efficient Europe** (EC, 2011a) outlines how Europe's economy could be transformed into a sustainable one by 2050. It proposes ways of increasing resource productivity and of decoupling economic growth from resource use and its environmental impacts. It is part of the Resource Efficiency Flagship of the Europe 2020 Strategy. The Europe 2020 Strategy is the EU's growth strategy for the next decade and aims to establish a smart, sustainable and inclusive economy with high levels of employment, productivity and social cohesion.

- The current **EU Cohesion Policy**, for 2014–2020, includes increased resource efficiency as an important objective and has an expanded urban dimension in order to tackle environmental challenges in cities.

- The **Territorial Agenda 2020** is the action-oriented policy framework of the ministers responsible for spatial planning and territorial development, aimed at supporting territorial cohesion in Europe. It aims to provide strategic orientations for territorial development, and to foster the better integration of the territorial dimension within different policies across all governance levels. It was adopted in 2011. One of its six priorities refers to managing and connecting the ecological, landscape-related and cultural values of the regions, and joint risk management is considered an essential condition for long-term sustainable development. Accordingly, territorially relevant policies should support compact and sustainable cities with controlled urban sprawl, and promote environmentally friendly transport (Böhme et al., 2011).

- The **European Spatial Development Perspective (ESDP) — Towards balanced and sustainable development of the territory of the European Union** (EC, 1999) presented 60 policy options, including Policy Option 12: 'Support for effective methods for reducing uncontrolled urban expansion; reduction of excessive settlement pressure, particularly in coastal regions' (p. 23). It recommended the institutionalisation of a 'European Spatial Planning Observatory Network' for the exchange of information among the spatial research institutes of the Member States, and it proposed a 'Europeanisation of state, regional, and urban planning' to overcome any insular ways that local and regional governments and administrative agencies look at their territory and 'to take into consideration European aspects and interdependencies right from the outset' (p. 45).

- The **European Landscape Convention** is dedicated to the protection, management and planning of all landscapes in Europe (adopted in 2000, entered into force in 2004) (Council of Europe, 2000). It covers natural, rural, urban and peri-urban areas; it concerns landscapes that might be considered outstanding, as well as more ordinary and degraded landscapes. The parties of the convention agreed to identify and evaluate landscapes, analyse their characteristics, and the forces and pressures transforming them, note any changes to the landscapes and engage in defining landscape-quality objectives (including objectives related to urban sprawl), after public consultation. The parties promote training programmes in landscape appraisal, policy, protection, management and planning.

- The **Leipzig Charter on Sustainable European Cities** (EC, 2007) is a document of the EU Member States. The Member States' ministers responsible for urban development agreed upon common principles and strategies for urban development policy (EC, 2007). The Charter views a compact settlement structure as an important basis for efficient and sustainable use of resources: 'This can be achieved by spatial and urban planning, which prevents urban sprawl by strong control of land supply and of speculative development. The strategy of mixing housing, employment, education, supply, and recreational use in urban neighbourhoods has proved to be especially sustainable.'

- The **Declaration of Toledo** (Informal Ministerial Meeting on Housing and Urban Development, 2010) supports the suitability of urban recycling and compact city planning as strategies to minimise land consumption, prevent unnecessary conversion of greenfields and natural areas to urban land, and to limit urban sprawl. It promotes the recycling of land (by means of urban regeneration, or the redevelopment or reuse of abandoned, derelict or unused areas, etc.) as a key strategy for reducing land consumption and combating urban sprawl.

- The research project **Sprawling cities and transport: from evaluation to recommendations** (Scatter) proposed a multisectoral integrated strategy based on six case studies from six European countries (Gayda et al., 2005). It includes four main policy measures to counteract the negative consequences of urban sprawl: (1) Fiscal measures to control land use by putting a tax on suburban residential developments and on offices in areas poorly served by public transport; (2) road pricing through a congestion tax; (3) transport pricing measures to lower public transport fares in city centres; and (4) measures to control housing prices.

- The EU Seventh Framework Programme (FP7) research project **Paradigm shifts modelling and innovative approaches** (Pashmina) studied potential future paradigm shifts in the relationships between transport, energy, the environment and land use. It applied advanced simulation models to develop three scenarios for 2050, including different spatial planning strategies (http://www.pashmina-project.eu). The three scenarios differ greatly in the resulting spatial distribution of urban areas, transport demand, energy consumption and impacts on climate change. The outcomes show that urban sprawl could be counteracted by adjusting planning strategies, which would then lead to more sustainable land-use patterns and a shift in the transport of people from individual to public transport modes (Fuglsang et al., 2013).

- Many other research projects refer directly or indirectly to urban sprawl, such as the 'Peri-urban land use relationships — strategies and sustainability assessment tools for urban–rural linkages' (Plurel ([1]); Piorr et al., 2011) project, the 'Joint Programming Initiative Urban Europe' (JPI Urban Europe ([2])) project, the 'Sustainable urban planning decision support accounting for urban metabolism' (Bridge) project (Gonzáles et al., 2013) and the 'Urban sprawl: European patterns, environmental degradation and sustainable development' (URBS Pandens) project (Nuissl and Rink, 2005).

Some effects of urban sprawl are related to biodiversity and landscape diversity, and are reflected in the **Pan-European Biological and Landscape Diversity Strategy** (PEBLDS; http://www.strategyguide.org), the **European Biodiversity Strategy** ([3]) (EC, 2011b) and the **Habitats Directive** (92/43/EEC, 1992). The **European Green Infrastructure Strategy** stresses that green infrastructure is a vital accompaniment to the Natura 2000 network because it enhances the coherence and resilience of the network (EC, 2013a). It also points out that 'green infrastructure can play a particularly important role in cities, where it can deliver services like clean air, temperature control, and mitigation of the local 'heat island effect', recreation areas, flood protection, rainwater retention and flood prevention, maintenance of groundwater levels, restoring or halting the loss of biodiversity, alleviation of extreme weather and its effects, improving the health of citizens, and enhancing the quality of life in general, including by providing accessible and affordable areas for physical activity' (European Parliament, 2013).

European data sets, such as the **Urban Atlas** and **Urban Audit,** and the European **Community Research and Development Information Service** (Cordis), serve these activities by providing data and other relevant information. The Urban Atlas is part of the Copernicus (previously known as Global Monitoring for Environment and Security (GMES)) land monitoring services (EEA, 2010). It provides comparable, high-resolution land-use maps for 305 large urban zones and their surrounding areas (with more than 100 000 inhabitants) for the reference year 2006. It was created to fill a gap in the knowledge regarding land use in European cities. Cordis is the primary public repository and portal for the European Commission to disseminate information on all EU-funded research projects and their results (http://cordis.europa.eu/home_en.html).

1.2 Urban sprawl and its effects

The increase in urban sprawl has serious environmental, economic and social consequences; it affects natural resources and ecosystem services, and leads to higher costs for provisioning services, such as public transport, and lower social cohesion. Before investigating the relationships between urban sprawl and its various drivers and effects, it is helpful to first clarify the notion of 'urban sprawl'.

([1]) http://www.plurel.net/ accessed 2 March 2016.
([2]) http://jpi-urbaneurope.eu/ accessed 2 March 2016.
([3]) COM(2011) 244 final: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN accessed 2 March 2016.

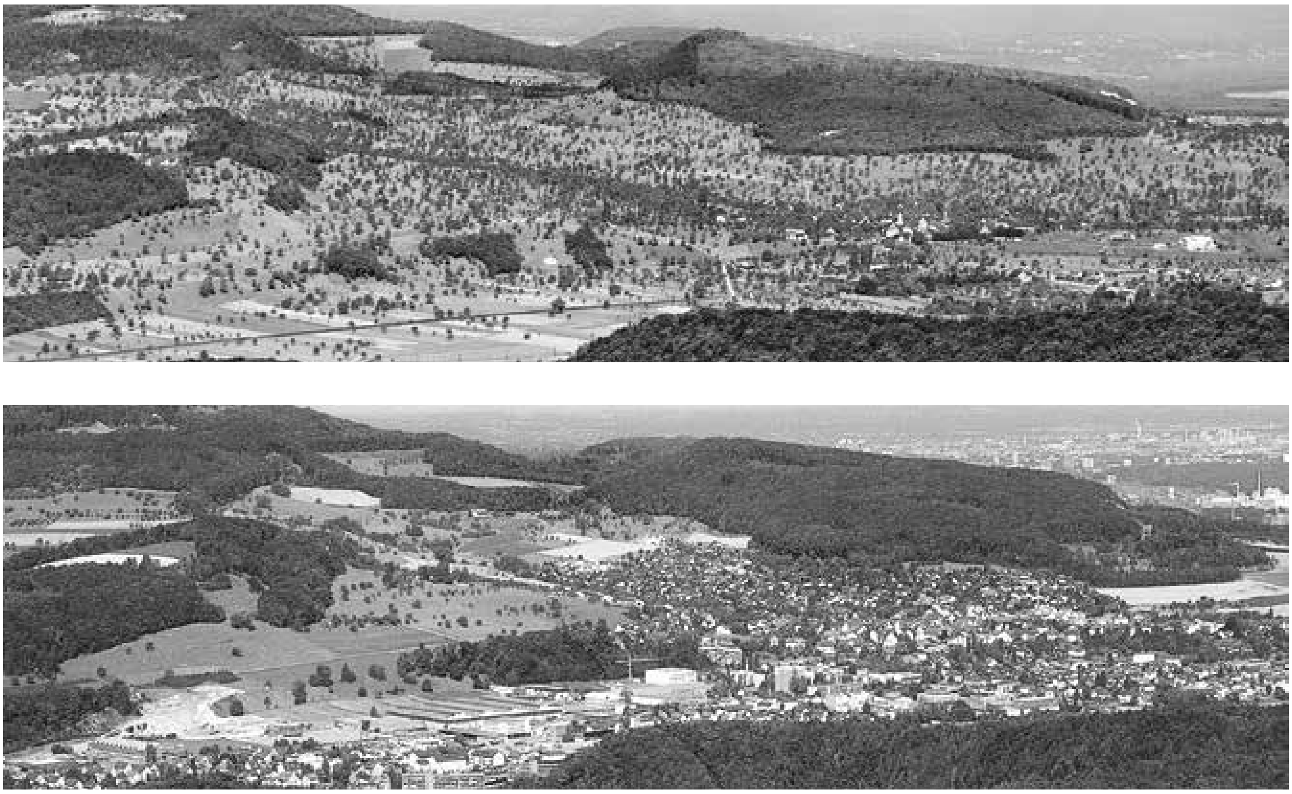


Photo 1.1 View of Frenkendorf (Switzerland) before 1909 (top panel) and in 1999 (bottom panel) from the Liestal watchtower

Source: © K. Lüdin, Fotoarchiv Druckerei Lüdin AG, Liestal (Frenkendorf 1909); © K. M. Tanner, Seltisberg (Frenkendorf 1999).

1.2.1 Definition of urban sprawl

Every meaningful method for measuring the degree of urban sprawl needs to be based on a clear definition of 'urban sprawl', which disentangles the causes and consequences of urban sprawl from the phenomenon of urban sprawl itself, since urban sprawl may have differing causes and consequences in different regions and regulatory contexts. The European Environment Agency (EEA) has described sprawl as 'the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas' (EEA, 2006b). Similarly, the Swiss FOEN uses the term to refer 'to the uncontrolled spread of towns and villages into undeveloped areas' (FOEN, 2015). To identify the most important components of urban sprawl that can serve as a basis for a quantitative method, a systematic comparison of definitions is helpful (Jaeger et al., 2010b). The literature provides a variety of definitions for urban sprawl (e.g. Ewing, 1997; Brueckner, 2000; Galster et al., 2001; Gillham, 2002; Squires, 2002; Burchell and Galley, 2003; Ewing et al., 2003). The examples in Table 1.1 illustrate this variety of perspectives.

The comparison of definitions from the literature reveals that there is no general agreement about the exact definition of urban sprawl (Wilson et al., 2003; Siedentop, 2005). In addition, most definitions are too vague to serve as a basis for measurement (Galster et al., 2001; Besussi and Chin, 2003; Jaeger et al., 2010b). As a result, many measures of urban sprawl are affected by a confusing variety of differing, and sometimes contradictory, interpretations of the term 'urban sprawl', and findings from different studies cannot usually be compared with each other and, therefore, may be difficult to interpret consistently. A major reason for the prevailing confusion is that, in many studies, the term 'urban sprawl' has been used to cover the causes and consequences, as well as the different concepts, of urban sprawl. The causes include unimpeded and disorganised growth, the aimless and unsystematic development of landscapes, increased demands for living in green surroundings, the building of second homes and the demand for inexpensive building lots (see Section 1.3). The consequences include the diminution of landscape quality, the loss of arable soil, the loss of recreational areas, a lack of clearly defined open spaces, the functional and spatial separation of areas in which people live and in which people work, the dysfunctionality of built-up areas for people and large numbers of commuters. Such causes and consequences should be distinguished from the phenomenon of urban sprawl per se.

Table 1.1 Definitions of urban sprawl from the English and German literature (seven examples) and the definitions used in this study

Definition	Source
'Urban sprawl is commonly used to describe physically expanding urban areas. The European Environment Agency (EEA) has described sprawl as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas. Sprawl is the leading edge of urban growth and implies little planning control of land subdivision. Development is patchy, scattered and strung out, with a tendency for discontinuity. It leap-frogs over areas, leaving agricultural enclaves. Sprawling cities are the opposite of compact cities — full of empty spaces that indicate the inefficiencies in development and highlight the consequences of uncontrolled growth'.	EEA, 2006b: 6
'The term 'urban sprawl' refers to the uncontrolled spread of towns and villages into undeveloped areas'.	FOEN, 2015
Sprawl = 'on the one hand, the spilling over of urban-type buildings into the suburban and agrarian areas, and on the other hand, the disorganised growth of sporadic beginnings of settlements in agrarian regions (separate farms, houses of farm workers, secondary occupation settlements) as well as in early industrialised or commercially permeated areas where ironworks, foundries and mines served as starting points of such sprawlings. In addition, the term is also applied to the unsystematic positioning of (weekend) houses and groups of houses that are only temporarily occupied outside of closed settlement areas'. German original: *Zersiedelung = 'einerseits das Ausufern städtischer Bebauung in den vorstädtischen und agrarischen Raum hinein, andererseits das ungeregelte Wachstum sporadischer Siedlungsansätze sowohl in Agrargebieten (Einzelhöfe, Landarbeiterwohnungen, Nebenerwerbssiedlungen) wie auch in früh industrialisierten oder gewerblich durchsetzten Räumen, wo Eisenhämmer, Hütten und Bergwerke als Ansatzpunkte derartiger Zersiedelungen dienten. Schliesslich wird der Begriff auch angewendet auf die planlose Ansetzung von nur zeitweilig bewohnten (Wochenend-)Häusern und Häusergruppen ausserhalb geschlossener Siedlungsräume'.*	Akademie für Raumforschung und Landesplanung, 1970: 3863
'Sprawl: the unchecked growth of settlements, taking effect in the area. The danger of sprawl in a landscape is particularly high in the fringe of the large cities, not only through expansive residential building activities, but also through economic institutions that are extensive in area (industrial businesses, airports, etc.). In recent time, sprawl particularly threatens attractive nearby recreational areas through increased building of weekend houses'. German original: 'Zersied(e)lung: das unkontrollierte, flächenhaft wirkende Wachstum von Siedlungen. Die Gefahr einer Z. der Landschaft besteht vor allem am Rande der grossen Städte, und zwar nicht allein durch eine ausgedehnte Wohnüberbauung, sondern auch durch flächenextensive Wirtschaftseinrichtungen (Industriebetriebe, Flughäfen usw.). Die Z. bedroht in jüngerer Zeit durch einen verstärkten Wochenendhausbau besonders reizvolle Naherholungsgebiete'.	Leser and Huber-Fröhli, 1997
'Sprawl, is an unplanned, unsystematic, area-intensive outward growth mainly of city-type settlements into the rural space and is a consequence of progressive urbanization. The wish for living in green places, for weekend houses, quickly accessible shopping centers, cheap industrial areas, and transportation infrastructure occupies much space, and if there are no conditions posed by regional planning and environmental protection, then construction will happen at places where it is cheapest. In this way, open spaces, recreational areas, and ecological compensation areas are lost, become dissected or downsized and loose their ecological and socio-economic functions'. German original: *'Zersiedlung, ist ein ungeplantes, konzeptloses, flächenintensives Hinauswachsen vor allem von städtischen Siedlungen in den ländlichen Raum und ist eine Folge der fortschreitenden Verstädterung und Urbanisierung. Das Bedürfnis nach Wohnen im Grünen, nach Wochenendhäuschen, schnell erreichbaren Einkaufszentren, billigen Industriegebieten und Verkehrsbauten benötigt viel Platz, und ohne Auflagen der Raumplanung und des Umweltschutzes wird dort gebaut, wo es am billigsten ist. Freiflächen, Erholungsgebiete und ökologische Ausgleichsflächen gehen dadurch verloren, werden zerschnitten oder verkleinert und verlieren ihre ökologische, wie auch sozioökonomische Funktionalität'.*	Landscape Gesellschaft für Geo-Kommunikation, 2000–2002: 469
Sprawl = 'the process in which the spread of development across the landscape far outpaces population growth. The landscape sprawl creates has four dimensions: a population that is widely dispersed in low-density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centers, such as downtowns and town centers. Most of the other features usually associated with sprawl — the lack of transportation choices, relative uniformity of housing options or the difficulty of walking — are a result of these conditions'.	Ewing et al., 2002

Table 1.1 Definitions of urban sprawl from the English and German literature (seven examples) and the definitions used in this study (cont.)

'Ultimately, what distinguishes sprawl from alternative development patterns is poor accessibility of related land uses to one another. ... Another characteristic common to all sprawl archetypes is a paucity of functional open space'.	Ewing, 2008
'Urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape [is affected by urban sprawl] if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high. The more area built over in a given landscape (amount of built-up area) and the more dispersed this built-up area in the landscape (spatial configuration), and the higher the uptake of built-up area per inhabitant or job (lower utilization intensity in the built-up area), the higher the degree of urban sprawl. The term 'urban sprawl' can be used to describe both a state (the degree of sprawl in a landscape) as well as a process (increasing sprawl in a landscape). The causes and consequences of urban sprawl are distinguished from the phenomenon of urban sprawl itself, and therefore are not a part of this definition'.	Used in this study. Source: Jaeger and Schwick, 2014

Note: More definitions from the literature are presented in Jaeger et al., 2010b.

A systematic evaluation of the existing definitions of urban sprawl showed that most definitions have three dimensions in common (Jaeger et al., 2010b):

1. the expansion of urban areas;

2. the scattering of settlement areas, that is how densely clumped or widely dispersed the buildings and patches of built-up areas are within the landscape (area-intensive growth);

3. low-density development (i.e. high land uptake per person).

Taking these common characteristics into account, this report uses the following definition (see also Figure 1.1):

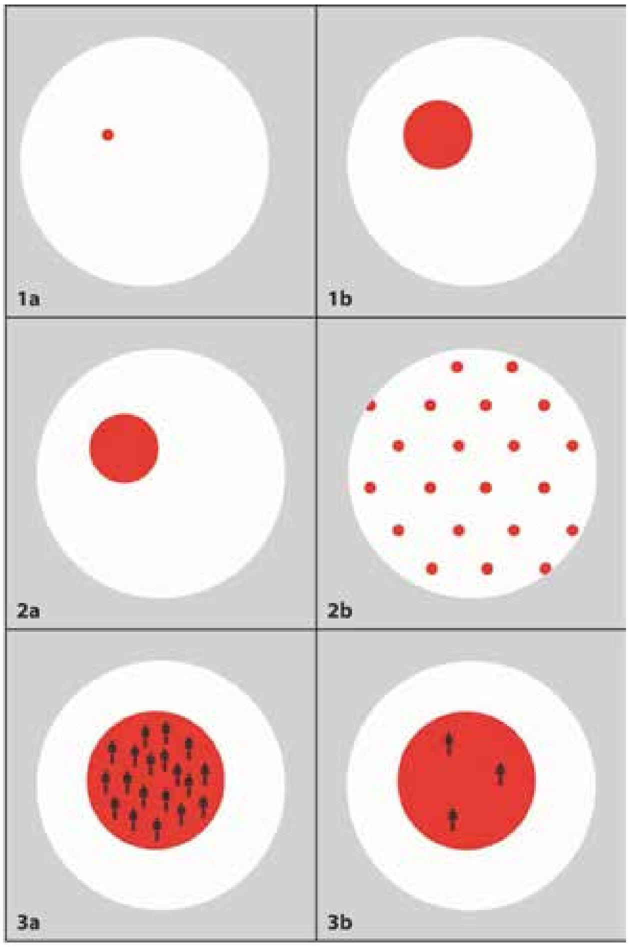
> Urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape is affected by urban sprawl 'if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high. The more area built over in a given landscape (amount of built-up area) and the more dispersed this built-up area in the landscape (spatial configuration), and the higher the uptake of built-up area per inhabitant or job (lower utilization intensity in the built-up area), the higher the degree of urban sprawl' (Jaeger and Schwick, 2014).

Accordingly, urban sprawl is a matter of degree, that is a gradient between low and high levels of sprawl. The opposite of sprawl has been described as a provident and frugal way of using the land, including urban development that is compact (spatial arrangement) and dense (low land uptake per person) (EEA, 2006b). This definition of sprawl relates to a landscape perspective and to the definition of 'landscape' in the European Landscape Convention, where '*Landscape* means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (Council of Europe, 2000). The causes and consequences of urban sprawl are distinguished from the phenomenon of urban sprawl itself, and therefore are not a part of this definition (Jaeger et al., 2010b). However, some definitions of urban sprawl are based on certain effects of sprawl, such as large commuting distances or paucity of functional open spaces (Table 1.1, see also Box 2.3 in Section 2.2).

The term 'urban sprawl' can denote both a state (i.e. the level of urban sprawl at a particular point in time) and a process (i.e. the temporal change in the level of sprawl). We use the term in both senses in this report, if it is clear from the context which of the two meanings is meant (otherwise we indicate explicitly if we are referring to a state or a process). For example, some authors define urban sprawl as a situation in which built-up areas expand more rapidly than the population. This concept refers to a reduction in density (i.e. the third dimension in Figure 1.1) and is an important indication of the **process** of sprawl. However, this approach does not necessarily imply that a development, in which the rate of expansion of built-up areas is lower than the rate of population growth, is sustainable.

According to this definition, buildings contribute to sprawl. Since roads and railway lines outside of towns and cities are not buildings, they are disregarded by measures of sprawl. Rather, they are included if landscape fragmentation is being measured (e.g. EEA and FOEN, 2011a). Many other aspects also affect or are affected by urban sprawl and are sometimes used

Figure 1.1 The three dimensions of urban sprawl



Note: In a landscape (white), urban sprawl is higher if (1) the built-up area (red) is large (top panel, right column), (2) the built-up area is dispersed (middle panel right) or (3) the land uptake per person is high (i.e. the utilisation density is low) (bottom panel, right) (the symbols indicate the inhabitants and jobs in the built-up areas).

Source: Modified from Schwick et al., 2012.

as indicators of urban sprawl; for example, a poor spatial combination of land uses (Galster et al., 2001), poor street connectivity, and car dependency are used as indicators of sprawl. For example, Torrens (2008) used 42 different metrics to assess sprawl. However, the relationship between these indicators and urban sprawl is not always clear and, therefore, they should be used with caution.

Some definitions (mostly from the North American literature) include three more aspects of urban sprawl: (1) little planning control with regard to land subdivisions; (2) poor accessibility among related land uses; and (3) a paucity of functional open space (Ewing, 1994; Ewing, 2008). However, the first of these aspects does not always apply, since various areas that are affected by urban sprawl have been planned in this way. Rather, little planning control is, among others, a common **cause** of urban sprawl and should be distinguished from the phenomenon of sprawl itself. Furthermore, it is more appropriate to consider the other two aspects as **consequences** of urban sprawl rather than as aspects of the core of the phenomenon. In Europe, accessibility is relatively good (much better than in most parts of the USA) as a result of a well-developed public transport system, even in rural and sprawled areas. In addition, the characteristics of poor accessibility and paucity of functional open space can be applied meaningfully only to cities, and these aspects are not very helpful for defining sprawl in rural areas. It is conceivable that sprawled regions can be functional in terms of accessibility and open space, and that non-sprawled regions can be dysfunctional in these regards. The relationships between the degree of sprawl and the levels of accessibility and the paucity of open space should be investigated quantitatively in future studies, and will not be considered as part of the definition of urban sprawl in this report.

In this report, the term 'urban sprawl' also includes rural sprawl and peri-urban sprawl. The terms 'built-up area', 'settlement area' and 'urban area' are used synonymously, and the term 'urban patches' is used to denote patches of built-up areas; 'urban points' (or 'urban locations') are points located within urban areas.

The distinctions between urban development, urban growth and urban sprawl

Urban development can take place in different forms. The definition of the three dimensions of urban sprawl helps to distinguish urban sprawl from other forms of urban development. **Urban development**, in the context of this report, denotes any change in built-up areas with regard to their spatial extent, their spatial arrangement or their utilisation density (*UD*). This includes not only increases in their spatial extent, but also the removal of built-up areas and changes in land uptake per person, that is per inhabitant or job (*LUP*), as a consequence of population changes (e.g. a decline in a population) (Figure 1.2). Urban growth and urban sprawl are particular forms of urban development. The term **urban growth** simply indicates an expansion of built-up areas, irrespective of their spatial distribution (which may increase or decrease) and the change in *LUP* (which may also increase or decrease). The characteristics of urban growth and urban sprawl overlap to a large degree (Figure 1.2). All else being equal, **urban sprawl** denotes an increase in the extent of built-up areas, an increase in *DIS* or an increase in *LUP*, or a combination of changes in these three dimensions; therefore, a change in sprawl depends on the relative importance of these three contributions. For example, if all three dimensions (i.e. extent, *DIS* and

LUP) increased, the resulting increase in sprawl would be maximal. If, however, *DIS* and *LUP* decreased, the level of sprawl can decrease, despite an increase in the extent of the built-up areas. Accordingly, a reduction in urban sprawl does not necessarily imply that urban growth is no longer possible. Through wise urban growth management (e.g. combined with densification, in-filling and brownfield recycling), it is possible to maintain a constant or even reduced level of sprawl but still allow some urban growth (this is sometimes referred to as 'smart growth') (Burchell et al., 2000; Downs, 2005).

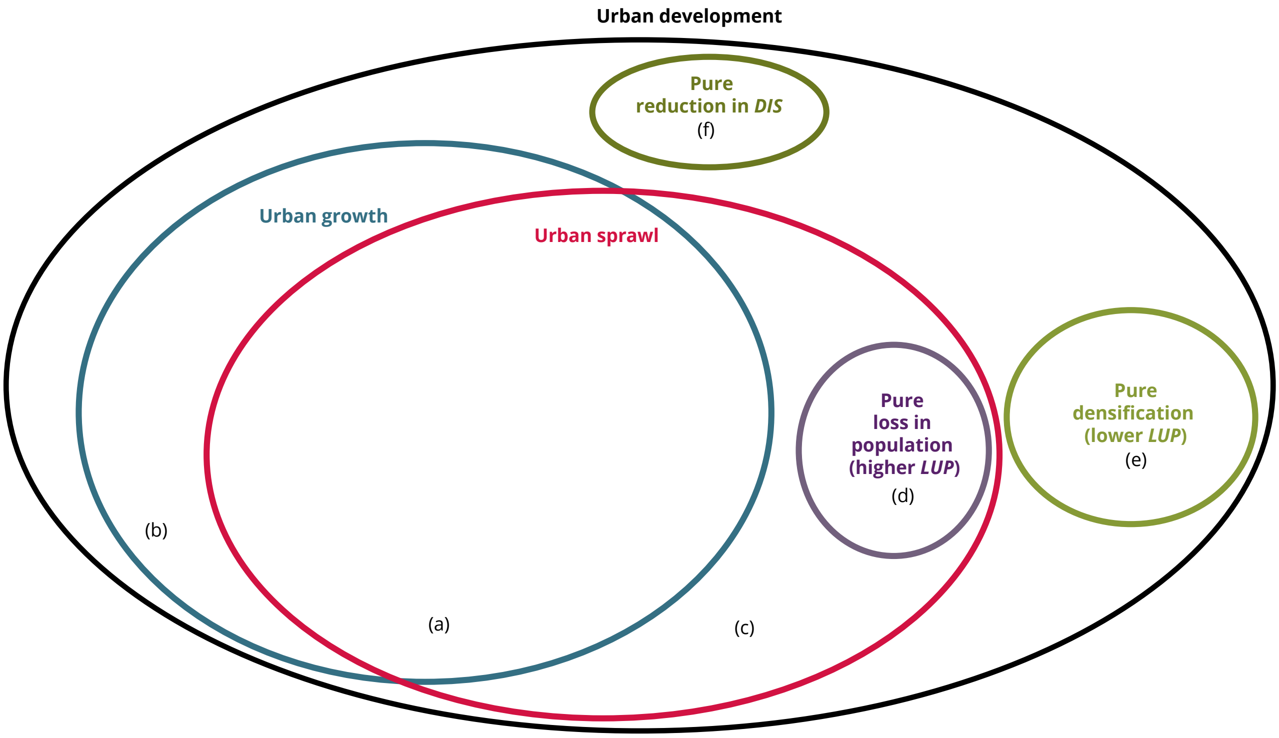
Urban growth and urban sprawl overlap to a large degree ((a) in Figure 1.2). Urban growth without urban sprawl is possible if densification (lower *LUP*) and a reduction in *DIS* take place at the same time (b). Urban sprawl is possible without urban growth (c) if the population declines and *LUP* increases (d). Densification while the built-up areas (and *DIS*) stay constant (e) results in lower *LUP* and a reduction in sprawl. A change in the spatial configuration of the built-up areas while their number and the *LUP* stay constant, and *DIS* decreases (f) results in a reduction in sprawl, but this event is rare.

The term **shrinking regions** refers to regions that have a declining population. This can be accompanied by an increase or a decrease in the extent of built-up areas. A decrease in built-up areas often takes the form of perforation, namely the removal of buildings at various locations all over the settlement areas, which makes cities less compact and leads to a higher *DIS* of the remaining built-up areas. Therefore, shrinking regions often exhibit urban sprawl, particularly if the extent of built-up areas, *LUP* and *DIS* continue to increase.

1.2.2 Overview of the positive and negative effects of urban sprawl

The effects of urban sprawl are cumulative, as are the effects of landscape fragmentation (EEA and FOEN, 2011a). The changes usually occur in a gradual manner, and, therefore, are often not perceived as dramatic by the general public for some time. While single new buildings are easily visible and assessed as 'not significant', their cumulative effects over longer periods of time are more difficult to observe and assess. As a consequence, single landscape alterations are easily marginalised and their cumulative impacts are often underestimated; this is a common problem associated with cumulative impacts. This issue has been called the 'pitfall of marginalisation'. It is only after several decades that the full extent of alterations and the resulting degradation of the landscape can be

Figure 1.2 Illustration of the relationships between urban growth, urban sprawl and other forms of urban development



Note: The letters (a)–(f) refer to the text within their areas.

evaluated. This section provides an overview of the effects of urban sprawl, followed by a more detailed discussion in Sections 1.2.3–1.2.5.

Urban sprawl has manifold consequences, and many of them are desired — otherwise there would be no sprawl. Therefore, the positive effects of sprawl are presented first (Nivola, 1999). Affordable single-family homes, with green surroundings and ample space between the houses, provide a classic example of sprawl, and are preferred by many people because they offer more privacy and a larger degree of freedom than apartment buildings (Bruegmann, 2005). People often prefer to have more space for themselves, a large garden and the possibility for children to play outside than to be close to their place of work.

A few publications argue in favour of urban sprawl. They claim that urban sprawl is a 'natural' process in a growing population and that countermeasures are an expression of state interventions, which are considered harmful to economic growth and to impair the freedom of people to make their own choices (Gordon and Richardson, 2000). These publications argue that there would be fewer green spaces for recreation if people were restricted to living within city boundaries, and noise and stress levels would be higher as a result of overcrowded streets and crammed public transport (Galea and Vlahov, 2005; Berry, 2007; Moudon, 2009). Thus, the movement out of cities to the fringes can be viewed as a natural response to prevent exposure to these stress factors and to allow people to experience the restorative effects of nature (Hartig et al., 1991; Grahn and Stigsdotter, 2003). Natural places are important for children, with regard to gaining experiences and physical education (Wells and Evans, 2003; Miller, 2005). Therefore, families tend to leave inner cities and move to city outskirts, in order to provide natural space for the development of their children. More recently, however, most authors argue that a well-designed public transport system is not overcrowded, and, on the contrary, is more enjoyable to use than driving a car, and that, in fact, overcrowded public transport is a sign of weak urban planning and not a feature of a dense city per se. They also point to many examples of dense cities, such as Copenhagen, which have many gardens and parks of all sizes and green infrastructures.

Some authors present sprawl as a stage in the 'natural development' of a city, which may start from a compact form and then decentralise as the population and economy grow. After some time, the sprawled areas can turn into more compact areas again by means of in-filling, the subdivision of parcels and higher density development (Torrens, 2006). However, this stage of sprawl can be meaningfully considered as 'natural' only during times of weak urban planning, and can be avoided altogether by strong planning.

Another potential advantage of urban sprawl relates to the economy and air pollution. Companies may tend to move to city outskirts because of the need for more space and to improve connections with the wider transport system (Ingram, 1998). Although this may increase the distances between residential areas and workplaces, and thus increase commuter traffic and air pollution, some authors argue that sprawl reduces freight transport into central city areas, and therefore reduces air pollution in cities and traffic congestion (Ingram, 1998). The decentralisation of both residential and employment areas is seen by some as an efficient way to reduce air pollution and the travel distances for commuters between work and homes (Ingram, 1998).

While many of these positive effects are important to some degree, urban sprawl has a large number of negative environmental, economic and social impacts (Ewing, 1994; Ewing, 2008; Johnson, 2001; Wilson and Chakraborty, 2013). For example, urban sprawl conflicts with conservation targets, agriculture and social development and, therefore, is a serious threat to sustainability (Haber, 2007). Urban sprawl is a prime example of a 'tragedy of the commons', that is the benefits of the use of a common resource — the landscape — are gained by individuals, while the detrimental effects are shared among all of society (Hardin, 1968). The landscape is the ultimate common resource (although property rights may restrict physical access to some parts of it), as it provides habitats for flora and fauna, it is the basis for most human activities and it supplies resources for most human needs. It provides the space essential for humans to live, as well as natural space, cultural space, economic space and recreational space. Urban sprawl appropriates landscape and is one of the most serious threats to sustainable land use. Soil is a finite resource, and its loss or destruction is irreversible (at least within a human lifespan). As soon as fossil fuels are proscribed because of the dangers of global warming, the demands for renewable energy will require large tracts of land and the ability of landscapes to provide these resources sustainably will decrease (i.e. there will be a decline in carrying capacity). Food production needs grassland and arable land with suitable soils; housing, industry, transport, landfill and recreational areas all take up further space. Therefore, these three demands (land, food and energy) will increasingly be in competition with each other, which is why Haber (2007) described them as the three central 'ecological traps' that are probably posing a stronger and more direct threat to humanity than any other environmental problems. People may be able to adapt, at least to some extent, to other environmental problems, but not to these three. If the demand continues to increase (since improvements in efficiency are limited and often problematic because of the ecological effects of intensification), there are simply no adaptations that could bypass these demands for land, food or energy. If current or future attempts to secure sustainable development ignore these three ecological traps, they will fail. This is the core message of the concept of 'carrying capacity', since increasing demands cannot be met forever by higher and higher efficiency. Therefore, Haber (2007) warns that land and fertile soil are disappearing at an alarming rate, and that people are underestimating and undervaluing this loss. Hence, efforts must be redoubled to preserve land and soil, by using them carefully and sparingly, based on reliable ecological science, monitoring and planning (Haber, 2007).

The negative impacts of urban sprawl are numerous and severe. The overview provided in Table 1.2 is based on literature with a focus on Europe, but a few exceptions were made in cases for which little information was found in the European literature. Although the impacts of urban sprawl may differ between Europe and other parts of the world, there are many similarities. The literature often does not distinguish clearly between the effects of urban growth, urban sprawl and urban development in general. Therefore, the table includes effects that are discussed in the literature as consequences of any of these three phenomena. The effects are usually most pronounced for urban sprawl.

Table 1.2 Environmental, economic and social effects of urban sprawl and/or urban growth

Theme	Consequences of urban sprawl	Sources (examples)
Environmental impacts		
Land cover	Land uptake for buildings and related infrastructure facilities, and loss of farmland	Camagni et al., 2002; Pauleit et al., 2005; Eigenbrod et al., 2011; Wilson and Chakraborty, 2013
	Removal and alteration of vegetation over larger areas	Pauleit et al., 2005
	Soil compaction, sealing of soil surfaces, loss of ecological soil functions, loss of water permeability, reduction of groundwater regeneration and reduced evapotranspiration, desertification	Ewing, 1994; Scalenghe and Marsan, 2009; Siedentop and Fina, 2010; Barbero-Sierra et al., 2013
Geomorphology	Local alterations to geomorphology (e.g. cuts, stabilisation of slopes) over larger areas	Rivas et al., 2006
Local climate	A change in microclimate conditions as a result of the urban heat island effect, which leads to reduced vegetation cover, reduced albedo, warming of surface temperature and increased variability in temperature	Taha, 1997; Zhou et al., 2004; Stone et al., 2010
	A modification of humidity conditions, for example reduced evapotranspiration, as a result of vegetation removal and soil sealing; a lower moisture content in the air because of higher solar radiation; stagnant moisture as a result of soil compaction; and increased variability in moisture	Taha, 1997
	Climatic thresholds and the modification of wind conditions as a result of the removal of vegetation and the construction of buildings	Song, 2005; Stone et al., 2010
Energy and climate change	Higher energy consumption and higher greenhouse gas emissions per person	Kenworthy et al., 1999; Borrego et al., 2006; Duffy, 2009; Waitt and Harada, 2012; Jones and Kammen, 2014
	Reduced carbon dioxide uptake as a result of the removal of vegetation, such as forest and grassland, over large areas	Hutyra et al., 2011
	A reduction in the capacity of the soil to act as a carbon sink	Lal, 2003
Air pollution, noise and light	Higher air pollution per capita as a result of vehicle exhausts, fertilising substances, dust, particles, road salt, oil, fuel and other substances which cause air and water pollution, and eutrophication	Borrego et al., 2006; Rich and Loncore, 2006; Navara and Nelson, 2007; Tu et al., 2007; Bart, 2010;
	Higher noise pollution (causing insomnia and other effects on health)	Slabbekoorn and Peet, 2003; Moudon, 2009
	Higher light pollution, modification of light conditions and other visual stimuli	Bennie et al., 2014

Table 1.2 Environmental, economic and social effects of urban sprawl and/or urban growth (cont.)

Theme	Consequences of urban sprawl	Sources (examples)
	The decoupling of material cycles of waste treatment (i.e. longer distances for waste transport and treatment counterbalance the positive effects of material recycling)	EEA, 2006b
Water	Hydrological alterations of watersheds as a result of the reduction of the quantity and quality of groundwater, and the lifting or lowering of the groundwater table	Jat et al., 2008; Wilson and Chakraborty, 2013
	Modification of surface water courses	Feyen and Dankers, 2009; Haase, 2009
	Water pollution, such as the pollution of rainwater by tire abrasion, dust and heavy metals, which washes into rivers	Tu et al., 2007
	A higher risk of leakages per capita (there will be more leakages as the network of pipes increases)	Pauliuk et al., 2014
	Drainage, faster removal of water and increased risk of flooding (e.g. because of sealed surfaces)	Haase, 2009; Wilson and Chakraborty, 2013
	Diminished hydrological dynamics of wetlands around sprawled cities	EEA, 2006b
	Increased water consumption per capita	March and Saurí, 2010
	Competition between agricultural irrigation and water use by city dwellers (e.g. in dry summers)	EEA, 2006b
Flora and fauna	The loss of habitats for native species; sometimes creation of new habitats with special conditions	Alberti, 2005
	The loss of soil biodiversity	Turbé et al., 2010
	The reduction of habitat areas below the required minimum, the loss of species and the loss of biodiversity	Alberti, 2005
	Habitat alteration and higher disturbance rates	EEA, 2006b
	Higher numbers of invasive species and the spread of invasive species as a result of changes in climatic conditions	Nobis et al., 2009; Scalenghe and Marsan, 2009; Shochat et al., 2010
	The reduced resilience of ecosystems	Scalenghe and Marsan, 2009; Shochat et al., 2010
	The impoverishment or alteration of species' communities	McKinney, 2006, 2008; Raupp et al., 2010
	The modification of food webs as a result of altered food availability	Faeth et al., 2005
	The increased fragmentation of the landscape: barrier effect, habitat fragmentation, disruption of migration pathways, impediment of dispersal, increased road mortality of wildlife, isolation of populations, degradation of ecological networks and loss of existing green infrastructure	Alberti, 2005; EEA, 2006b; EEA and FOEN, 2011a
	Genetic isolation and increased inbreeding, and disruption of metapopulation dynamics	Alberti, 2005; EEA, 2006b
	A restriction of the re-colonisation of empty patches of habitat	McKinney, 2008
Landscape scenery	Visual stimuli and noise	Slabbekoorn and Peet, 2003; Moudon, 2009; Bennie et al., 2014
	The increasing penetration of the landscape by built-up areas	Pauleit et al., 2005
	Landscapes can be read and interpreted less because of visual breaks caused by the contrasts between nature and technology	Ewald and Klaus, 2009
	Changes in the character and identity of the landscape	Ewald and Klaus, 2009; Marull et al., 2010; Müller et al., 2010
	The increased exploitation of river beds and the expansion of quarries for construction materials	EEA, 2006b
Land use	Loss of agricultural land and highly fertile soils (non-renewable resources)	Wilson and Chakraborty, 2013
	The uptake of agricultural land leads to the intensification of agricultural production elsewhere and encourages mass production	Peña et al., 2007; Eigenbrod et al., 2011
	The reduced recreational quality of natural and semi-natural areas	White et al., 2013
	Conflicts with other land-use interests because of a decrease in the availability of land for agriculture, renewable energy supply and industrial purposes; higher pressure on protected areas; and conflicts with conservation management because of light and noise pollution and recreational activities	Haber, 2007

Table 1.2 Environmental, economic and social effects of urban sprawl and/or urban growth (cont.)

Theme	Consequences of urban sprawl	Sources (examples)
Economic impacts		
	Higher costs for transport associated with commuting for households	Camagni et al., 2002; Bento et al., 2005; Travisi et al., 2010
	A higher demand for transport, increased car use and a higher cost for public transport infrastructure	Ewing, 1997; Kenworthy et al., 1999
	Higher costs associated with traffic congestion and the extension of urban infrastructure in newly developed regions	Hortas-Rico and Solé-Ollé, 2010; Klug and Hayashi, 2012; Cinyabuguma and McConnell, 2013
	Higher costs as a result of higher energy consumption per person	Kenworthy et al., 1999
	Higher public service costs and higher expenditure for construction and maintenance of infrastructure per capita (roads, electricity, water provision pipes, wastewater collection pipes, municipal garbage collection, snow removal, etc.)	Ewing, 1997; Kenworthy et al., 1999; Pauliuk et al., 2014
	Higher material use for construction per housing unit	Roy et al., 2015
	A reduction in food production and self-sufficiency, and a higher dependence on imported food	Haber, 2007; Wilson and Chakraborty, 2013
	An increased demand for raw materials, such as concrete, the expansion of quarries and the over-extraction of gravel from river beds	EEA, 2006b
	Changes in the distribution of populations relative to the locations of ecosystem service supplies, which can reduce the per capita supply and increase the costs of service provision	Eigenbrod et al., 2011
	The degradation or loss of various ecosystem services, and higher costs for their substitution or restoration by technology	Cumming et al., 2014
	Environmentally degraded urban areas are less attractive to new investors and their highly qualified employees	EEA, 2006b
	Economic losses in touristic areas in which the landscape scenery has been degraded	EEA, 2006b
Social impacts and quality of life		
	Desired place to live for many people because low-density housing offers more privacy and larger garden areas than densely built-up parts of cities	Bruegmann, 2005
	A higher proportion of single households, which leads to a more resource-intensive living style	Dura-Guimera, 2003; Howley, 2009
	A greater segregation of residential development based on income	Thurston and Yezer, 1994; Power, 2001; Brade et al., 2009; Cassiers and Kesteloot, 2012
	Longer commuting times and a reduction in social interaction	Putnam, 2000
	Respiratory problems (e.g. asthma) as a result of more air pollution	Frumkin et al., 2004
	Insomnia and other effects on health as a result of higher noise pollution and the heat island effect	Frumkin et al., 2004
	Increased obesity, stress and decreased physical activity	Costal et al., 1988; Ewing et al., 2003; Garden and Jalaludin, 2009
	Reduced human benefits from groundwater and conflicts as a result of competition for groundwater	EEA, 2006b

The lack of terminological clarity may, to some degree, be a reason for differing views in the literature regarding whether certain effects of urban sprawl are positive or negative. Another reason for differing views on urban sprawl is the lack of internalisation of the external costs. If the external costs are neglected, then the benefits appear much more positive than they really are, because others will have to pay for these costs (e.g. future generations). Some effects can even be viewed from two perspectives in cases in which an overall negative effect of sprawl is diluted over a large area resulting in a lower concentration; this could be interpreted by some authors as a positive effect of sprawl. For example, total air pollutant emissions are significantly higher in more dispersed urban areas, than in less dispersed urban areas with the same number of housing units, but they are distributed over a much larger area (Cieslewicz, 2002). Therefore, the concentrations of air pollutants at a particular location in the more sprawled area are lower, even though the total amount of pollutants emitted is much higher. Author opinions differ on whether this constitutes a positive or a negative effect of urban sprawl; however, most agree that the larger total amount of pollutants emitted constitutes a more important negative effect. The dilution of pollutants over large areas is not the only way to reduce their concentrations. Many cities have reduced air pollutant concentrations in dense urban areas by a modal shift to public transport and by implementing freight transport regulations which allow only specific types of non-polluting vehicles.

1.2.3 Environmental impacts

Urban sprawl can affect landscapes through three main processes: transformation, degradation and fragmentation. The transformation of formerly pristine or agricultural lands into built-up areas is visually the most obvious effect (Table 1.1). Valuable habitats and agricultural soils are lost (Scalenghe and Marsan, 2009). Between 2000 and 2006, for example, 46 % of the land taken up by urban and other artificial land development in 37 European countries was agricultural (EEA, 2013). In Estonia, the master plans for the development of the capital city, Tallinn, between 2000 and 2008 covered an area of 724 ha and 45.3 % of the new residential developments have been established on agricultural land (Roose et al., 2013). In the Alicante region of Spain, urban areas grew significantly, from 0.3 % to 6.5 %, in 54 years. Non-irrigated crops were affected most and experienced a decline of 61 % (Peña et al., 2007). Further examples of cities that have experienced high land uptake include Bratislava (a 302 % increase in land uptake from the 1950s to the 1990s), Prague (a 154 % increase from the 1950s to the 1990s) and Warsaw (a 268 % increase between 1969 and 1996) (Szirmai et al., 2011), and countries such as Romania, in which the expansion of built-up areas between 1990 and 2008 in eight cities was about 280 %; furthermore, 86 % of 250 cities have reported concerns about urban sprawl (Suditu et al., 2010).

With the spread of built-up areas in the landscape, natural and semi-natural areas are being partitioned into smaller patches and reduced in size. This fragmentation affects the resilience of ecosystems, because smaller habitats are more prone to isolation, lack of sufficient food resources and reduced variability in habitat structure (Fischer et al., 2006). In addition, disturbances as a result of human activities (e.g. because of proximity to residential and commercial areas), the invasion of non-native species, traffic noise, and air and water pollution also negatively affect ecosystems. As a consequence, wildlife populations decline and are reduced in their genetic diversity (Trombulak and Frissell, 2000; Niedziałkowska et al., 2006), become more vulnerable to stochastic events, and are more easily driven to extinction (Burkey, 1989). The observed impacts of urban sprawl on food production and biodiversity have encouraged ideas about strengthening urban agriculture and urban biodiversity (Vallianatos et al., 2004), which may potentially counterbalance some of the loss of agricultural lands; however, these approaches are likely to alleviate the problem to only a relatively small extent.

Energy use per person for transport in low-density built-up areas is an order of magnitude higher than in high-density urban areas (Kenworthy et al., 1999), and, accordingly, low-density areas are less sustainable. This issue will be even more important in the future because energy production will need to be based on sustainable land-use practices in the post-fossil fuel era which will further increase the competition for land (Haber, 2007).

Land uptake for urban development often increases the risk of natural hazards, partly because urban development increasingly takes place in locations in which the risk of natural hazards is higher. For example, the extension of impervious surfaces and the straightening and channelling of streams in association with urban development often exacerbate flood events (Feyen and Dankers, 2009; Barredo and Engelen, 2010). As a result of climate change, strong precipitation events are expected more frequently, which will aggravate such floods (Kundzewicz et al., 2005; Lehner et al., 2006). Sprawled urban areas contribute substantially to temperature increases ('heat island effect') through the decrease in evapotranspiration due to the loss of vegetation, the decrease of the albedo caused by dark buildings, heat trapping by buildings, and the generation of additional heat by vehicles and generators (Oke, 1973; Akbari and Matthews, 2012). A review of climate change in urban areas identified the most sprawled areas in the federal German state of North Rhine-Westphalia (NRW) as having the highest potential to develop heat islands (Kuttler, 2011). A study conducted in the USA showed a doubling of the annual number of extreme heat events in the most sprawled cities in comparison with the most compact cities (Stone et al., 2010). Zhou et al. (2004) attributed the warming of mean surface temperature of 0.05 °C per decade in China to urbanisation. Moreover, urban sprawl requires the increased use of cars and, therefore, leads to increased emissions of carbon dioxide, which also contribute to climate warming (Bart, 2010). With increasing global temperature, urban sprawl is more often associated with heat waves, which will increase incidences of heat-related fatalities and the use of energy-demanding cooling systems (Kovats and Hajat, 2008).

1.2.4 Economic impacts

Urban sprawl is often viewed as advantageous economically because it is accompanied by the construction of buildings in locations in which land is inexpensive. A major part of economic growth results from the expansion of urban land use (Nivola, 1999). The loss of ecosystem services may lead to new jobs if these services need to be restored or substituted by technology or imported from elsewhere. However, many costs are omitted from calculations of the economic benefits of sprawl: increases in expenditure for the construction and maintenance of infrastructure are, to a large degree, paid by the general public, and the costs associated with the environmental, social and health effects of sprawl are generally not considered (Table 1.2). Instead, these costs are externalised, that is they are paid, or will have to be paid, for by others (e.g. the public or future generations). This includes many ecosystem services (Cumming et al., 2014), which, before the urban sprawl, were provided without any cost, but now are either diminished, lost, or need to be restored or replaced.

Sprawl also increases the distances between homes, workplaces and shopping places, which makes people more dependent on automobiles, particularly in areas in which the service levels of the public transport system are low (Box 1.2) (García-Palomares, 2010; Travisi et al., 2010). The increase in private car use can have a cascading effect on health (Ridder et al., 2008), which in turn affects the economic situation (Brueckner, 2000). Automobiles have impacts on human health in terms of air pollution, accidents, and stress due to traffic jams and noise (Costal et al., 1988). Consequently, health conditions deteriorate with increasing automobile density, which, in turn, leads to higher costs for health insurance and health services (Yang et al., 2008).

Suburbanisation often implies that many people leave inner city areas. An interesting example is the establishment of large shopping malls at city peripheries. These are often responsible for the closure of shops and businesses in city centres, the displacement of jobs from city centres to city peripheries, and the subsequent downgrading of the quality of life in city centres (known as 'central decay') (Evers, 2004). In many cases, however, these shopping malls have not provided the expected economic improvements, but, instead, have created new problems and costs for cities (which often lead to social segregation; see Section 1.2.5). A common problem is that many users of inner cities are not residents of the city centres and, therefore, do not pay for the services they use. 'Housing bubbles', such as those in Ireland and Spain, that arose before the financial crisis of 2006, have contributed to urban sprawl. Today, these neighbourhoods consist of empty buildings.

1.2.5 Social impacts

Among the social effects of urban sprawl (Table 1.2) are an increase in the time spent travelling between homes, places of work and places for other activities, and the formation of dormitory towns. A weak or no connection to public transport leads to a strong car dependency. Several recent studies indicate that increased car dependency has negative effects on health, particularly higher levels of inactivity and a higher frequency of obesity. The loss of agricultural fields leads to a reduction in the level of subsistence in sprawled regions and a higher dependence on imported food. Sprawl also affects the perception of the landscape. Built-up areas contribute significantly to the transformation of natural and traditional cultural landscapes into landscapes that are dominated by technical facilities. The line separating built-up parts and open parts of the landscape often becomes fuzzy, and can even disappear entirely. A recent survey of 2 800 households in Switzerland shows that the lowest scores for authenticity and landscape structure, in terms of mystery and coherence, were assigned to the rapidly growing suburban regions, that is the most sprawled regions (Kienast et al., 2015). Both urban and rural regions were assigned higher scores for authenticity and perceived landscape structure. Some studies demonstrate higher social segregation among groups in the populations of sprawled regions, with a lower level of participation in activities in the community. Two opposite processes may contribute to the spatial segregation of wealthy and less wealthy people: (1) the movement of the financial sector or wealthy citizens into certain neighbourhoods of the city core often increases the prices of residential areas and displaces less affluent people away from these neighbourhoods (Table 1.2); (2) conversely, the moving of businesses and wealthy residents away from certain neighbourhoods of the city cores can render them economically unattractive. A potential increase in the crime rate, a low level of education, an unalluring appearance of the neighbourhood and the lack of entertainment (e.g. cinemas, restaurants and bars) may drive more people who can afford to live on the outskirts of the city to move away from these parts of the city core, which further impoverishes social life.

The impacts of urban sprawl on society are best described in literature on North American history (Logan and Schneider, 1984; Clark, 1986; Rusk, 2006). In particular, in the 1950s and 1960s, city zones were created in which only people with relatively high incomes could live (Margo, 1992; Lawrence, 2005). This rather extreme approach to urban planning should be avoided in Europe. Another extreme form of urban development is the creation of 'gated communities', which are also related to urban sprawl to some extent. 'Gated communities' have been developed in North America and some developing countries (Atkinson and Blandy, 2005; Le Goix, 2005). They are still rare in Europe, but 'gated communities' have been observed in 10 countries in Europe (Cséfalvay and Webster, 2012); however, there is a concern that these communities increase inequality and aggression, and negatively affect social cohesion (Cassiers and Kesteloot, 2012).

1.3 Drivers of urban sprawl

A variety of factors drive the proliferation of sprawled areas. Although a few studies link sprawl to only one major driver, for example 'car-based living' (Glaeser and Kahn, 2004) or the shift from public transport to highway construction (Lawrence, 2005), empirical results underline a multifaceted process (Brueckner, 2000; Anas et al., 1998). The following categories can be used to classify drivers of urban sprawl: demographic, socio-economic, political, technological and geophysical (Hersperger and Bürgi, 2009; Christiansen and Loftsgarden, 2011; Habibi and Asadi, 2011). A distinction of pull and push factors is possible (Siedentop et al., 2009), that is attracting and promoting forces, but this report does not use this classification because some drivers can act as both pull and push factors (e.g. gross domestic product (*GDP*)).

Box 1.2 Urban sprawl and public transport

The ease with which settlements can be linked together by means of public transport largely depends on the density of the built-up areas. There needs to be a minimum density of inhabitants or jobs to justify the provision of services. A high level of sprawl is accompanied by highly dispersed buildings and low land utilisation.

An urban area is regarded as adequately served by bus or tramway if the nearest bus or tram stop is no more than 400 m (as the crow flies) away. The time required to walk to the stop is also important, but for the sake of simplicity, we will assume that there are no obstacles in the way. The area of the circle around this stop would occupy 50 ha. Two theoretical examples of such 50-ha urban areas are described below.

- An urban area that is occupied by single-unit detached houses: apart from its actual footprint, each house will be surrounded by its associated land and will require access roads. In total, we will assume that each house takes up an area of 1 000 m^2. If an average of 2.5 people live in each house, then 1 250 people would live in the entire 50-ha area.
- An urban area that is densely built up with high-rise apartment blocks and office buildings: 10 000 or more people would live or work in such a neighbourhood.

In the first example, because of its low population, the area with single-unit houses would justify only an hourly bus service; therefore, public transport would not be a very attractive option for its inhabitants. Experience shows that in places such as this, only 10 % of the inhabitants use public transport, which, in our example, would be just over 100 people. Accordingly, the costs of a bus service would not even be met by tickets sold to users.

In contrast, in the second example, the number of people and jobs in this densely built-up area would be high enough to justify, not only a bus service, but also a tram or, possibly, a suburban rail connection. The experiences of the Zurich transit authority suggest that if the time between two services of the same bus or tram line is halved, there is a 1.5-fold increase in the number of people using public transport. A frequency of 30 minutes attracts 15 % of the population to public transport; a frequency of 15 minutes attracts 22.5%; and a frequency of 7.5 minutes attracts as much as 33.75 % of the population. On this basis, in theoretical example 2, the percentage of people using public transport would be 34 %. Therefore, assuming a population of 10 000, approximately 3 400 people would use public transport every day. It is perfectly conceivable that such a high rate of public transport use would greatly boost cost effectiveness.

These considerations also imply that the general public pays twofold for the drawbacks of inefficiently utilised land: a larger portion of the countryside has been used up and is now unavailable for other types of use, and a larger portion of public transport costs are uncovered while the level of service is low.

1.3.1 Demographic drivers

The size and structure of the population have been shown to affect the extent of built-up areas. Obviously, all else being equal, the larger the population, the more space will be required to accommodate all the people. Kasanko et al. (2006) have provided an overview of urban sprawl in 15 European cities between the 1950s and 1990s. They found that, although the annual growth rate in the built-up areas of these cities had declined to 0.75 % per year by the end of the 1990s, population growth was a major driver throughout the time of urban expansion. However, the effect of population growth is expected to be small in Europe in the future, because the European population is predicted to decline until the end of the century (Pelletier, 2013). However, urban sprawl has continued to increase, even in many regions in which population decline is already apparent (Couch et al., 2005; Hoymann, 2011; Cirtautas, 2013). Population shrinkage is often related to the perforation of compact cities, through the demolition of buildings, while land consumption and the extension of built-up areas outside city centres are ongoing (Nuissl and Rink, 2005; Hoymann, 2011; Cirtautas, 2013). The degradation of city centres can also contribute to inhabitants searching for more desirable areas. This is particularly relevant for the cities of post-communist countries, which have unattractive city centres. Therefore, the renovation of city centres could be an important contribution to stopping sprawl in these cases.

Substantial migration among European regions has also contributed to urban sprawl (Bontje, 2001). For example, the number of single-family houses in Poland increased substantially (by approximately 15 %) between 2002 and 2011, even though population growth (0.74 %) was an order of magnitude lower in the same period (Adamczyk et al., 2013). This was, to some extent, as a result of people returning to Poland after having worked for many years abroad in countries with higher incomes (e.g. the United Kingdom); these people returned to Poland as it became possible to realise the dream of owning their own homes. This dream of a single-family house is particularly apparent in eastern Europe, because, previously, many people lived in buildings made from pre-fabricated slabs (Becker and Heller, 2009; Szirmai et al., 2011).

Migration, however, does not apply to only the economically disadvantaged. For example, elderly people tend to migrate to regions that offer climatic, cultural and social amenities (King et al., 1998; Illés, 2006; Haug et al., 2007). The strong relationship between people's age and the number of single households (Haase et al., 2007) and housing areas (Kroll and Haase, 2010) suggests that regions with a higher proportion of elderly people are more likely to be sprawled, particularly in coastal areas. European societies are ageing continuously because of improved health (UN, 2012), which contributes, to some degree, to urban sprawl in regions attractive to elderly people.

1.3.2 Socio-economic drivers

Gross domestic product per capita (*GDP*c) reflects the output per inhabitant in a given region. Because of the social representation of desirable lifestyles, reinforced by advertisements that promote increased consumption levels, a higher income is often related to buying a detached house in the urban periphery rather than an apartment in the core of the city; accordingly, a higher *GDP* has been shown to stimulate urban sprawl in individual countries (Bresson et al., 2004; Barbero-Sierra et al., 2013) on the European continent (Bosker and Marlet, 2006) and worldwide (Bertaud and Malpezzi, 2003). However, a higher *GDP* could also be a result of urban sprawl.

Moreover, *GDP* can induce a chain of further socio-economic factors that drive urban sprawl. For example, a high *GDP* is linked to a high level of possession and use of automobiles, which facilitate everyday life in terms of flexibility, accessibility and perceived savings of time (Torrens, 2006). Automobile dependency is considered the main driver of urban sprawl by Glaeser and Kahn (2004). In order for automobile use to provide the advantages of flexibility, accessibility and time savings, a well-developed road network is required; this, in turn, contributes further to the development of sprawled urban areas because people tend to settle in the suburbs or farther away from the city (Verburg et al., 2004; Müller et al., 2010). The road network provides accessibility to areas outside the city, which attracts companies to these areas and thus enhances the economic competitiveness of the city (Rogerson, 1999; Gospodini, 2002); this, in turn, may reinforce the attractiveness of suburban areas for industry, commerce and people, and initiates a vicious circle of factors that leads to higher *LUP* (Anas et al., 1998). Shifts in the orientation of the economy towards services are related to changes in the built-up environment: large office parks are often constructed at the fringes of cities because it is expensive to build in the more dense areas of cities. This contributes to the expansion of cities; however, at the same time, many sites, such as former industrial areas, have been abandoned and are not used, particularly if they require decontamination.

Another important socio-economic factor is lifestyle. In recent decades, a change in social structure, in terms of higher incomes and liberalisation with regard to the roles of men and women, has promoted a preference for individual life fulfilment (Buzar et al., 2007; Halás and Formanová, 2010); this has contributed to the decline in household size and the increase in the number of households (Eichhorn et al., 2009). The observed correlation between lower household size and the higher demand for new residential areas confirms the relationship between built-up areas and the number of people deciding to live alone (Haase et al., 2007; Sabbagh and Neef, 2007).

1.3.3 Political drivers

Politics has the power to establish legislation that can promote sustainability and prevent urban sprawl. Planning systems, legislative stipulations, subsidies and taxes play an important role in driving or moderating urban sprawl. The German government, for example, subsidises urban sprawl by offering tax relief on 50 % of investments made in new houses (Nuissl and Rink, 2005). The costs of acquiring ground, building houses and schools, and developing the infrastructure and public transport services for new residential areas are usually shared among all citizens; however, sometimes, only a wealthy minority benefit from living in these newly developed areas (Wiewel et al., 1999). Subsidies for commuting and the acquisition of automobiles also promote urban sprawl (Su and DeSalvo, 2008). Stipulations, on the other hand, can control the creation of built-up areas and can promote an increase in the density of a given built-up area (Bertaud and Brueckner, 2005). For example, Cheshire and Sheppard (2002) showed that the urban area of the town of Reading, south-east England, would increase by 26 % if existing restrictions related to the green belt were softened.

1.3.4 Technological drivers

There were tremendous technological developments in the 20th century. Before this age of industrialisation, places of work and living, in cities or villages, were close to each other. The demand for labour by large factories imposed the migration of people from rural to urban areas because the lack of motorised transport forced employees to live in residential areas close to such factories. The availability of automobiles diminished the importance of living in the proximity of places of work (Knowles, 2006) and, together with high costs of living in central urban areas, was a strong driver of a more dispersed urban form (Anas et al., 1998). As technological development continues, further innovations in communication technologies and automatisation are likely to render working from home more feasible (Hardill and Green, 2003; Kurz and Rieger, 2013). This technological change may reduce the need for commuting, which could result in an even higher dispersion of dwellings in the landscape and a further increase in urban sprawl.

1.3.5 Geophysical drivers

Several geophysical components have been shown to affect the development of built-up areas. The topography and the presence of irreclaimable areas, that is areas that are unsuitable for construction (e.g. glaciers, lakes, etc.), limit the availability of space for built-up areas and, therefore, reduce the possibility of urban sprawl. However, some studies have produced conflicting results (Siedentop et al., 2009) and suggest that the differences are mainly due to different types of irreclaimable area. According to these studies, the spread of residential and industrial areas is less feasible in mountainous environments than on land reclaimed from the sea (Lo and Yang, 2002; Verburg et al., 2004).

The presence and the ease of the exploration of resources are potential drivers of urban sprawl. The occurrence of coal in the Ruhr region (Germany) and in the Upper Silesia basin (Poland) attracted millions of people during the rise of industrialisation and, therefore, the largest agglomerations of cities are found in these regions. Fertile soils are an important resource for agricultural production, with most arable lands being located in almost flat areas. In Switzerland, 47 % of the valleys and lowlands is agricultural land, whereas only 14 % of the undulating landscape is agricultural (Bundesamt für Statistik, Schweiz, 2013). These agricultural land-rich areas are prone to construction and soil sealing if they are located close to existing urban areas because they are inexpensive and are under pressure to be transformed into residential or commercial areas (Mann, 2009; Grigorescu et al., 2012).

1.4 Urban sprawl in Europe: objectives and main results

Although the significance of the urgent challenge of urban sprawl has been recognised at the European level, the monitoring of urban sprawl in Europe has still not been established. This report aims to help close this gap. So far, there exists an EEA indicator of only land take (CSI 014/LSI 001; EEA, 2013), and an indicator of land recycling is in preparation.

The emphasis of this report is on the comparison of the degree of urban sprawl among the various regions in Europe, and on the relative importance of the likely socio-economic and geophysical causes of high, or low, degrees of urban sprawl. To achieve these objectives, predictive models, based on statistical methods, have been built as part of this project. Regions that are significantly more, or less, sprawled than expected, according to the predictive models, have also been identified.

In summary, the project had three parts and their objectives were:

1. to quantitatively analyse urban sprawl in Europe on three scales, to map the degree of urban sprawl and to perform spatial comparisons;

1. to determine the correlations between urban sprawl and socio-economic and geophysical factors, such as population density and economic performance; to determine their relative importance; and to identify regions that exhibit particularly high or low degrees of sprawl relative to the predicted values;

2. to re-calculate the degree of urban sprawl at a second time-point in order to assess the rate at which sprawl is increasing and to characterise the rate of change in relation to the socio-economic factors used by the predictive models.

More explicitly, this project aimed to answer the following research questions:

1. What is the degree of urban sprawl in Europe today? What are the differences between the various countries and NUTS-2 regions, and on the scale of the LEAC 1-km^2 grid?

3. How much did the degree of urban sprawl increase between 2006 and 2009? Are there any regions in which sprawl has decreased?

4. How suitable are the different data sources (i.e. Corine Land Cover (CLC), the pan-European High Resolution Layer of Imperviousness Degree (HRL IMD) and the Urban Atlas data sets) for the analysis of urban sprawl? How well do the results of this European study correspond with the results for Switzerland (based on data from the national land-use/land-cover data set for Switzerland (Vector25) (Schwick et al., 2012)?

5. What are the relationships between the degree of urban sprawl and socio-economic and geophysical factors? What is the relative importance of these factors, that is which factors are the most significant determinants of the degree of urban sprawl in Europe?

6. Which statistical methods and which models are most suitable for predicting the degree of urban sprawl in Europe?

7. Which regions in Europe exhibit higher, or lower, degrees of urban sprawl than would be expected based on the models' predictions? How well do the predictive models for 2006 predict the changes in urban sprawl between 2006 and 2009?

8. What are the implications and options for monitoring, planning and policymaking?

This report provides, for the first time, an assessment of urban sprawl at the European level using the weighted urban proliferation (*WUP*) method (Box 1.3). The results provided by this study are intended to contribute to more sustainable political decision making and urban and regional planning throughout the European continent. The results are presented, for two points in time (i.e. 2006 and 2009), for the EU-28 + 4; for more than 280 NUTS-2 regions; and for the 1-km^2 LEAC grid. We aimed to include as many European countries as possible. As a result, we were able to include data for nine additional countries and territories, but the data are not reliable or complete in all cases. These countries and territories are Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Monaco, Montenegro, San Marino, Serbia, as well as Kosovo under UNSC Resolution 1244/99, and Turkey (not part of EFTA), for which we have some results at the country and NUTS-2 levels, but not at the 1-km^2-grid level. When available, these results were included in the maps and tables in Annex 1. Countries for which data were not available (e.g. Andorra) or not reliable (e.g. the Holy See/Vatican City State) are not included.

A wide range of urban sprawl values (measured in urban permeation units (UPU) per square metre of landscape were found): for example, low values were obtained for large parts of Scandinavia (< 1 UPU/m^2) and high (> 4 UPU/m^2) to very high (> 6 UPU/m^2) values were obtained for western and central Europe. Two major clusters with high-sprawl values were identified: one located in north-eastern France, Belgium, the Netherlands, and a large part of western Germany; and the other located in a large part of the United Kingdom. The overall value of *WUP* in Europe (32 countries combined) increased from 1.56 UPU/m^2 in 2006 to 1.64 UPU/m^2 in 2009 (i.e. by 5 % in 3 years, or 1.7 % per year for this period).

Urban sprawl, as measured by *WUP*, also increased in most European countries by more than 1 % per year between 2006 and 2009, and in many countries by even more than 2 % per year. This is also the case for most

Box 1.3 Descriptions of the most important technical terms used in this report

WUP	Weighted urban proliferation (*WUP*) is the metric used in this study to quantify urban sprawl in any given reporting unit. It is the product of the *DIS*, a weighting of *DIS*, the percentage of built-up area (*PBA*) in the reporting unit and a weighting of the *LUP*. It is measured in urban permeation units (UPU) per square metre of landscape (UPU/m^2) (see detailed explanation in Chapter 2). The range of values of *WUP* depends on the scale of the analysis, which is specified by the horizon of perception (*HP*) (Section 2.2). The meanings of the ranges of low and high *WUP* values are explained in Table 2.1 (Section 2.2).
PBA	The percentage of built-up area (*PBA*) is the ratio of the size of the built-up areas to the size of the total area of the reporting unit and is given as a percentage.
DIS	The *DIS* quantifies the spatial distribution of built-up areas (dispersion), expressed as UPU per m^2 of built-up area. The further apart the buildings (or locations within built-up areas), the larger the value of *DIS*. Therefore, more compact built-up areas have lower values of *DIS* than less compact built-up areas.
UP	Urban permeation (*UP*) is a measure of the permeation of a landscape by built-up areas. It accounts for the *DIS* and the *PBA* in the reporting unit. It is measured in UPU per m^2 of landscape. The range of *UP* values depends on the *HP* (Section 2.2).
UD	The metric of utilisation density (*UD*) measures the number of people working or living ($N_{\text{Inh + Jobs}}$) in a built-up area (per km^2). Built-up areas with more workplaces and/or inhabitants are considered more intensively used, and hence less sprawled, than areas with a lower density of workplaces and/or inhabitants. The *UD* values can range from zero, which indicates that no people use the built-up area (e.g. areas of abandoned or unfinished constructions), to very high (i.e. > 20 000/km^2).
LUP	Instead of using the *UD*, the reciprocal can also be used, that is the area of land used per inhabitant or workplace (*LUP*). High *LUP* values indicate that more space is used per inhabitant or workplace, which is considered less sustainable, than low *LUP* values. Values can range from zero to very high (i.e. > 1 000 m^2 per inhabitant or job).
NUTS-2	The NUTS classification system divides the territory of the EU using a hierarchical system of spatial units, which facilitates the collection of regional statistical information for socio-economic analyses and for framing policies. Partitioning at the NUTS-2 level is based on population size and involves the assembly of smaller administrative units.
LEAC grid	The LEAC grid is used by the EEA to assess ecosystem properties and functions that play an important role in policymaking at the regional scale (Romanowicz et al., 2006). The LEAC grid is the European reference grid applied to activities in accordance with LEAC and has a resolution of 1 km^2.
CLC	The Coordination of Information on the Environment (Corine) Land Cover (CLC) system classifies land cover on the basis of satellite images. It describes changes in land use over time and the related environmental impacts (the most recent data are from 2012). Nowadays, this system is part of Copernicus Land Monitoring Services.
HRL	The pan-European high resolution layers (HRLs) from the Copernicus Land Monitoring Service are produced for five themes: (1) the level of sealed soil ('imperviousness degree' (IMD)), (2) 'Forest', (3) 'Permanent grassland', (4) 'Wetlands' and (5) 'Water bodies'. All HRLs cover 39 countries in Europe and are available in the original 20 m × 20 m spatial resolution (from satellite images), and as a validated 100 m × 100 m product (the most recent data are from 2009, but the 2012 update is in progress). The HRL IMD provides more detailed information about sealed surfaces than CLC data or any other existing layers of land-use data (e.g. Urban Atlas).

NUTS-2 regions. The analysis of sprawl at the 1-km^2-grid level showed that sprawl is most pronounced in wide rings around city centres, along large transport corridors and along many coastlines (particularly in the Mediterranean countries). Future studies of additional time-points will allow more detailed temporal comparisons of sprawl.

Most of our hypotheses about the likely drivers of urban sprawl were confirmed by the statistical analyses. The six most relevant variables that affect urban sprawl are population density, road density (all road types from motorways to local roads), the number of cars per 1 000 inhabitants, household size, railway density and governmental effectiveness, along with two environmental variables (relief energy and net primary production). The amount of variation in the level of urban sprawl and its three components, as explained by the predictor variables, on the NUTS-2 level was high and ranged from 67 % to 94 %.

There is an increasing need for, and interest in, the inclusion of indicators of urban sprawl in systems for monitoring sustainable development, the state of the environment, biodiversity and landscape quality. The results presented in this report are intended to be used for this purpose, and they can be updated on a regular basis.

The results demonstrate that there is an urgent need for action. Urban sprawl has serious long-term consequences and more efforts are needed in order to protect forests, agricultural soils and other open spaces from urban sprawl. Urban sprawl has never been so high in Europe as it is today. It presents a fast-growing problem that is now out of control in many parts of Europe. Therefore, this report also discusses how the *WUP* method can be used as a tool for urban sprawl analysis as part of urban and regional planning, and for performance review. In addition, the report identifies the most immediate priorities and future research needs.

2 Measurement of urban sprawl, base data, and hypotheses about potential drivers

This chapter provides a brief overview of the approaches available for the quantification of urban sprawl (Section 2.1) and explains the method that was applied in this study (Section 2.2). The base data are presented in Section 2.3, while Section 2.4 explains the predictive models and hypotheses, which were tested in the statistical analysis, with regard to the likely drivers of sprawl.

2.1 Methods for measuring urban sprawl

The many aspects of urban sprawl, and the diversity of the definitions of urban sprawl, can pose a challenge to its quantification. Accordingly, previous studies have deployed a variety of approaches, which relate to differing interpretations of urban sprawl. Since there is no general agreement regarding the definition of urban sprawl (Section 1.2.1), there is no general agreement on how to quantify it. One way of classifying the existing methods is to group them in terms of complexity.

2.1.1 Group 1: Use of many variables in parallel

Some authors consider many variables together in order to capture urban sprawl. For example, Galster et al. (2001) applied eight spatial dimensions (density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity) to describe urban sprawl in 13 large cities in the USA. Similarly, Solon (2009) studied urban sprawl in the Warsaw metropolitan region using seven landscape metrics (spatial share, mean patch size, patch size coefficient of variance, mean shape index, mean nearest neighbour distance, mean proximity index, and interspersion and juxtaposition index). Several authors used variables related to spatial analysis, but their relationship to sprawl is not always clear and may, in fact, be questionable. For example, Tsai (2005) compared sprawled and compact cities using information about population, metropolitan density, the degree of equal distribution and the degree of clustering, and added measurements of statistical dispersion (using the Gini coefficient) and spatial relatedness (using Moran's I). Hasse and Lathrop (2003) considered five indicators (density of new urbanisation, loss of prime farmland, loss of natural wetlands, loss of core forest habitat and an increase of impervious surface) to measure urban sprawl in New Jersey, USA. Torrens (2008) identified 11 characteristics of sprawl and used no less than 42 metrics related to seven of these characteristics (urban growth, density, social factors, land-use factors, diversity, fragmentation, decentralisation and accessibility) in his study on Austin, Texas, in the USA. These methods provide a plethora of information, but one disadvantage of the approaches based on these spatial variables is that it is often not clear which of them best describes urban sprawl, that is how exactly the variables relate to urban sprawl (and what definition of sprawl they are based on) and how they are related to each other. This is problematic because the results and interpretations often differ between the variables chosen and are sometimes blurred by antagonisms between several variables. For instance, if one variable increases and another decreases, but both are used as indicators of sprawl in parallel, how much would each of them contribute exactly to sprawl, and, as a result, is overall sprawl increasing or decreasing? This important question requires clarification. As a consequence, group 1 approaches may lead to inconsistent results and other problems in cases in which findings from different studies are being compared. Therefore, this report advocates a more systematic approach based on suitability criteria (see Section 2.2).

2.1.2 Group 2: Integration of many variables

Several authors went a step further and developed an approach that includes many indices and groups them into fewer variables, or dimensions, by applying some statistical models. For example, in their study of urban sprawl in Israel, Frenkel and Ashkenazi (2008) used 13 sub-indices and summarised them under two characteristics (configuration and composition). They measured each sub-index separately for each settlement unit and combined the values of the 13 sub-indices into an integrated sprawl index by using a weighting scheme (using factor loadings). All data, that is the sprawl index and the 13 sub-indices, were then used to describe the differences among the settlement units in terms of sprawl. Siedentop and

Fina (2010) gathered information on nine indicators that were intended to describe density, pattern and surface characteristics of built-up areas in Germany. These indicators were then further processed through a statistical analysis (principle component analysis or cluster analysis) to derive information about urban sprawl. These more complicated methods have the advantage that they integrate the information from the sub-indices. However, they also have the disadvantage that the additional steps, particularly the use of statistical models, often make the relationship of each sub-indicator to the overall sprawl index less transparent and the relationship to any particular definition of urban sprawl difficult to establish. For example, the determination of principal components depends on the particular set of landscapes used as input data for the statistical analysis, and the factor loadings may differ between different input data sets, which makes direct comparisons of the integrative measures impossible.

2.1.3 Group 3: Measures based on one or a few variables

A third group of studies tried to simplify the measurement of urban sprawl by using a single measure or an index based on only a few variables. For example, Yue et al. (2013) used a sprawl index based entirely on population measures in high- and low-density growth areas and their relationship to the total population to analyse urban sprawl in Hangzhou, China. Arribas-Bel et al. (2011) assessed urban sprawl in 209 larger urban zones (LUZs), now known as functional urban areas (FUAs), in Europe using information about connectivity, decentralisation, density, scattering, the availability of open space and the land-use matrix, which were integrated into a self-organising map algorithm. Similarly, Ewing et al. (2003) applied the Rutgers-Cornell sprawl indicator to measure sprawl in 83 metropolitan areas in the USA. This indicator consists of information about residential density, plot size, land-use mix, the degree of centering, and street accessibility. In contrast, Horner (2004) studied urban structure in terms of accessibility in a sample of US metropolitan areas. He found that residential accessibility patterns are concentric if the central urban area is the most attractive part of a region, while employment accessibility tends to be more decentralised, which facilitates decentralised suburban growth. Jat et al. (2008) used information about patchiness and mapped densities from satellite images in order to document urban sprawl. The Organisation for Economic Co-operation and Development (OECD) has used a very basic urban sprawl index to measure 'the growth in build-up area over time adjusted for the growth in population. When the population changes, the index measures the increase in the built-up area over time relative to a benchmark where the built-up area would have increased in line with population growth. The index is larger (smaller) than zero when the growth of the built-up area is greater (smaller) than the growth of population, i.e. the density of the metropolitan area has decreased (increased)' (OECD, 2013: 30). This means that it detects only changes in *LUP*. The major drawback of analyses that consider only one aspect of urban sprawl is that such measures miss other major characteristics of the settlement areas in space and hence provide an incomplete picture. For example, this is apparent in the use of entropy for the measurement of sprawl (Yeh and Li, 2001). At first sight, entropy may be a promising metric of sprawl because it captures the distribution of built-up areas among a set of zones covering the reporting unit (e.g. a regular grid), which can be interpreted as a form of clumping, or dispersion, among these cells. However, entropy does not capture the dispersion of urban areas because it is insensitive to any spatial rearrangement of the built-up areas among the zones, required for the analysis of entropy, and also within each of these zones; furthermore, it violates several other essential conditions of any meaningful metric of urban sprawl (Nazarnia, 2012).

Each of the approaches described above has its strengths and weaknesses, but these metrics either do not capture enough of the dimensions of urban sprawl, are difficult to apply intuitively, or have the potential to lead to unresolved antagonisms between sub-indicators. To overcome these obstacles, Schwick et al. (2012) and Jaeger and Schwick (2014) have proposed a new measure, namely *WUP*, which consists of three components and two weighting functions (Section 2.2). Although the development of other measures of urban sprawl is likely to continue, it has been shown that the *WUP* method captures urban sprawl well (Orlitová et al., 2012) and is a more suitable method than most previously used approaches (based on 13 suitability criteria).

2.2 Weighted urban proliferation and its components

To measure the degree of urban sprawl, we used the *WUP* method. This metric has three components that correspond to the three dimensions included in the definition of urban sprawl used in this report (Figure 1.1). These dimensions are (1) the percentage of built-up area (*PBA*), (2) the *DIS* and (3) the *LUP* (Figure 2.1), and are described in more detail below.

1. The *PBA* measures the size of the built-up area (as a percentage of the landscape or reporting

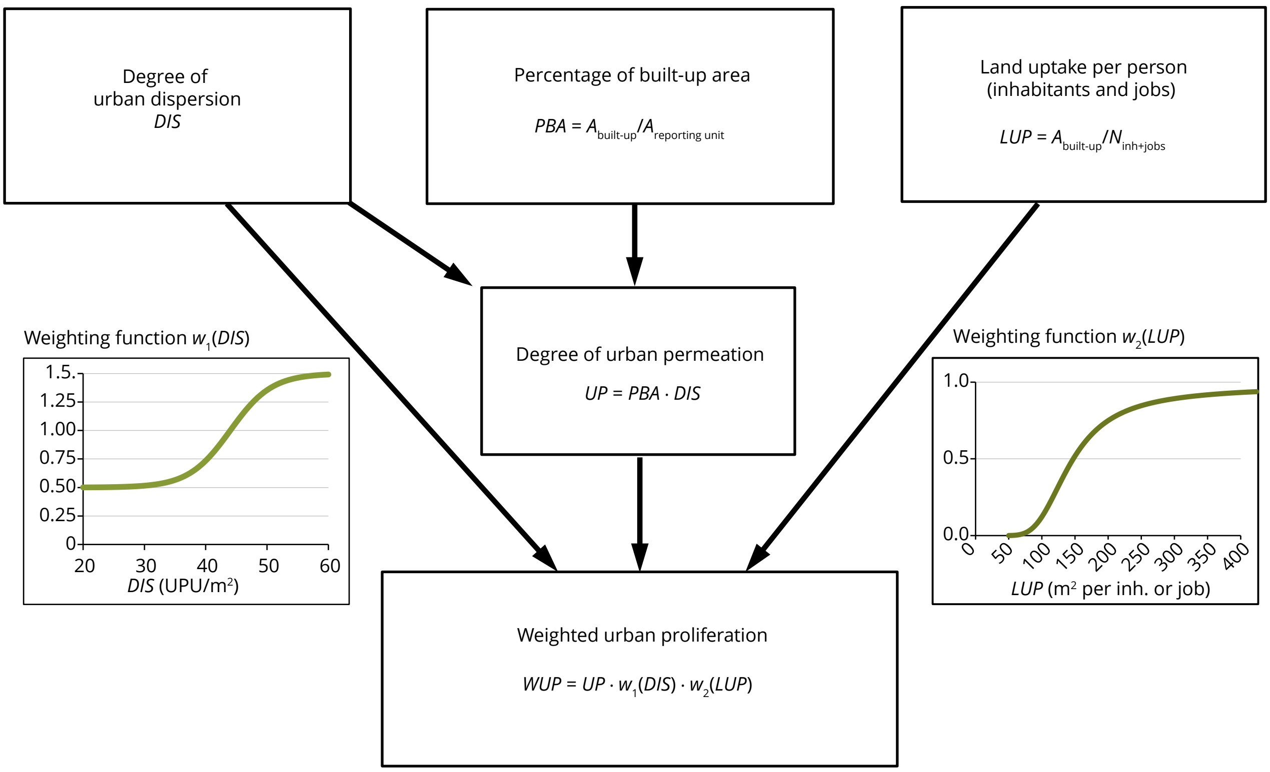
unit). Values for landscapes of differing sizes can be directly compared because the *PBA* value does not depend on the size of the particular area of landscape (i.e. it is an intensive metric).

2. The *DIS* characterises the settlement pattern from a geometric perspective and is based on the distances between any two points within built-up areas (up to a maximum distance called the horizon of perception (*HP*), see Box 2.3). The further apart the two points, the higher their contribution to *DIS*. This metric is expressed as UPU/(m^2 of built-up area). Higher *DIS* values indicate a higher dispersion (between 0 and 49.7 UPU/m^2). Dispersion is weighted by the $w_1(DIS)$ function in order to allow parts of the landscape in which built-up areas are more dispersed to be more clearly perceived (by using a $w_1(DIS)$ value of > 1); compact settled areas are multiplied by a lower weighting (i.e. < 1) (if *DIS* equals the 1960 Swiss average of 43.986 UPU/m^2, the $w_1(DIS)$ = 1). The values of $w_1(DIS)$ are between 0.5 and 1.5 (Jaeger and Schwick, 2014).

3. The *LUP* describes the use of a built-up area by people that work and/or live in that area. Built-up areas with many inhabitants and employees are considered to be better used and, accordingly, are less sprawled. Alternatively, the intensity of use of a built-up area can be described by the reciprocal of *LUP*, that is by considering the utilisation density (*UD*). Accordingly, the metric includes a weighting factor, $w_2(LUP)$, which is always less than 1. If the *LUP* is higher than 250 m^2/inhabitant or job, the $w_2(LUP)$ is close to 1. If it is less than 100 m^2/ inhabitant or job (e.g. in city centre areas), the $w_2(LUP)$ is close to 0 because such areas are not considered to be sprawled. Accordingly, if the *UD* is less than 4 000 inhabitants and jobs per km^2, the weighting factor is close to 1, and if it is more than 10 000 inhabitants and jobs per km^2, the weighting factor is nearly 0. A value of 4 500 inhabitants and jobs per km^2 corresponds to the limit of 400 m^2 of urban area per inhabitant (without taking jobs into consideration) suggested by the Swiss Federal Council in 2002 as a maximum acceptable average value (Swiss Federal Council (Schweizerischer Bundesrat), 2008, p. 27).

The product of *PBA* and *DIS* is called urban permeation (*UP*) because it describes the degree to which the

Figure 2.1 The relationships between the *WUP* metric and its components *DIS*, *PBA* and *LUP*



Note: The *DIS*, *PBA* and *UD* (= 1/*LUP*) are intensive metrics. $A_{reporting\ unit}$, area of the reporting unit (the landscape studied); $A_{built\text{-}up}$, size of built-up area in the reporting unit; $N_{inh + jobs}$, number of inhabitants and jobs in the built-up area of the reporting unit. The shapes of the weighting functions are shown in the boxes as indicated.

landscape is permeated by patches of built-up area (Figure 2.1). It represents the spread of built-up areas in a landscape. We have found that it is useful to consider *UP* in addition to the three components of *WUP*. Therefore, we sometimes refer to *UP* as another component of *WUP*, although, strictly speaking, it is the product of two components of *WUP* (*PBA* and *DIS*). *UP* is expressed in UPU/m² of land. *UP* values for landscapes of differing sizes can be directly compared because *UP* is an intensive metric, that is its value does not depend on the size of the landscape (Jaeger et al., 2010a).

The product of *PBA*, *DIS*, its weighting function $w_1(DIS)$ and the weighting function of *LUP* yields *WUP* values (Figure 2.1). Thus, this metric is based on three intuitive components and accounts for any dispersion of built-up areas:

$$WUP = UP \times w_1(DIS) \times w_2(LUP).$$

(Alternatively, the formula for *WUP* can be written as $WUP = PBA \times w_3(DIS) \times w_2(LUP)$, where $w_3(DIS)$ is a slightly different weighting function: $w_3(DIS) = DIS \times w_1(DIS)$). The higher the value of *WUP*, the more sprawled the landscape investigated.

Table 2.1 provides an overview of the metrics, their units and their ranges. Six categories of sprawl level can be distinguished *at the NUTS-2 level* based on *WUP* values:

1. values of < 1 UPU/m² indicate areas that are not sprawled;

2. values of 1–2 UPU/m² indicate areas that are slightly sprawled;

3. values of 2–4 UPU/m² indicate intermediate levels of sprawl;

4. values of 4–6 UPU/m² indicate areas that are highly sprawled;

5. values of 6–9 UPU/m² indicate very high levels of sprawl;

6. values of > 9 UPU/m² indicate extremely high levels of sprawl.

The larger the reporting units, the less variability is observed in *WUP* values (i.e. there are fewer extreme values), because the value of a group of smaller reporting units combined can never be more extreme than the individual values of the smaller reporting units. Accordingly, there is less variability in *WUP* values among countries than among NUTS-2 regions. The interpretation of *WUP* values should take this into account. Accordingly, the values that would be considered to indicate high levels of sprawl *at the country level* are lower than the values that would be considered to indicate high levels of sprawl at the NUTS-2 level; therefore, the corresponding six categories of sprawl *at the country* level are indicated by the following *WUP* values:

1. values of < 0.6 UPU/m² indicate areas that are not sprawled;

2. values of 0.6–1.5 UPU/m² indicate areas that are slightly sprawled;

3. values of 1.5–3 UPU/m² indicate intermediate levels of sprawl;

Table 2.1 The metrics used for measuring urban sprawl in this report

Acronym of the metric	Name of the metric	Unit	Range of low values (at NUTS-2 level)	Range of high values (at NUTS-2 level)
WUP	Weighted urban proliferation	UPU per m² of landscape	< 2 UPU/m²	> 4 UPU/m²
PBA	Percentage of built-up area	%	< 3 %	> 10 %
DIS	Dispersion of built-up areas	UPU per m² of built-up area	< 42.5 UPU/m²	> 45.5 UPU/m²
LUP	Land uptake per person (per inhabitant or job)	m² per inhabitant or job	< 111 m² per inhabitant or job	> 222 m² per inhabitant or job
UD	Utilisation density	Inhabitants and jobs per km² of built-up area	< 4 500 inhabitants and jobs per km²	> 9 000 inhabitants and jobs per km²
UP	Urban permeation	UPU per m² of landscape	< 2 UPU/m²	> 4 UPU/m²

Note: The relationships between these metrics are shown in Figure 2.1.

4. values of 3–4.5 UPU/m^2 indicate areas that are highly sprawled;

5. values of 4.5–6.5 UPU/m^2 indicate very high levels of sprawl;

6. values of > 6.5 UPU/m^2 indicate extremely high levels of sprawl.

We applied the cross-boundary connections (CBC) procedure (Moser et al., 2007) to the calculation of the sprawl metrics (Annex 2.1). This procedure removes any bias due to the boundaries of the reporting units used for quantifying landscape structure. It accounts for the visibility of buildings within the *HP*, regardless of which reporting unit the surrounding buildings are located in.

The *WUP* method effectively captures all types of settlement through the combination of its three components, that is it measures a rather complex phenomenon in a relatively simple way. The presentation of its three components as separate indicators is useful for the understanding and interpretation of the values of *WUP*. The combination of three sprawl components into one metric is an important advantage, compared with previous studies in which only single components of sprawl (e.g. built-up area) were reported, *DIS* was either neglected or difficulties were encountered with the quantification of *DIS* (Razin and Rosentraub, 2000; Yeh and Li, 2001), some causes or consequences of sprawl were included in the quantification (Torrens, 2008), or too many aspects of sprawl were integrated into single, less transparent indices (Frenkel and Ashkenazi, 2008), as discussed in Section 2.1. This advantage also makes it easier to communicate the results. The *WUP* method can be applied on any scale. The development of the *WUP* method was based on 13 suitability criteria (Box 2.1). It also meets the 34 requirements used for indicator selection for environmental reporting that were reviewed by Niemeijer and de Groot (2008).

Box 2.1 Suitability criteria for metrics of urban sprawl

Landscape metrics must meet several criteria. Their suitability can then be systematically checked using these criteria. This is done with simple tests using various landscape patterns. There are 13 suitability criteria for the metrics of urban sprawl (Jaeger et al., 2010b):

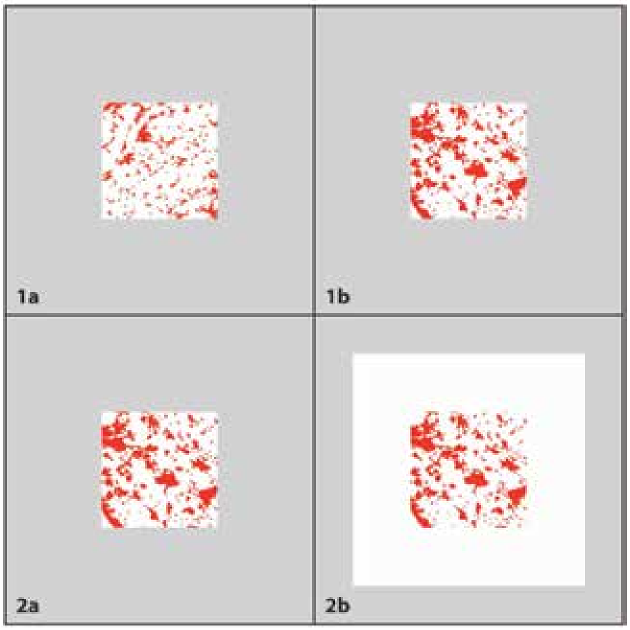
1. clarity (intuitive interpretation);
2. mathematical simplicity;
3. modest data requirements
4. low sensitivity if very small patches of settlement are included or excluded;
5. a monotonous response to increases in built-up area;
6. a monotonous response to increases in the distance between two built-up patches if they are within the scale of analysis;
7. a monotonous response to an increase in the dispersion of three built-up patches;
8. same direction of the metric's response to the processes in criteria 5, 6 and 7;
9. a continuous response to the merging of two built-up patches;
10. the independence of the metric from the location of the sprawl pattern within the reporting unit;
11. a continuous response to an increase in the distance between two built-up patches if they move beyond the scale of analysis;
12. mathematical homogeneity (i.e. intensive or extensive measure);
13. additivity (i.e. additive or area-proportionately additive measure).

These criteria vary in their importance: some are absolutely necessary, while others are desirable. Ideally, all criteria should be met as closely as possible. New metrics of sprawl should be systematically checked against these suitability criteria; the *WUP* method presented here was checked against these suitability criteria and was found to meet all suitability criteria well or very well (Jaeger and Schwick, 2014).

The qualitative aspects of sprawl are also important and need to be considered in regional planning (using qualitative methods). While the *WUP* method is not intended to replace such qualitative methods, it can complement them to improve the 'toolbox' of regional planners (see Section 4.3.1).

The *WUP* approach measures the degree of urban sprawl of a landscape that is delineated by a particular reporting unit. For example, to measure the level of sprawl of a city, the boundaries of the corresponding landscape must be specified. If a larger landscape that includes larger open areas (without built-up areas) is chosen, the degree of sprawl of this larger landscape will, accordingly, be lower (Figure 2.2, bottom panel). To compare cities of differing sizes (which is beyond the scope of this report because city boundaries usually do not coincide with NUTS-2 regions), the metrics in relation to the number of inhabitants could be used, such as *LUP* and sprawl per capita (*SPC*) (Jaeger et al., 2010a), or maps of *WUP* on the 1-km^2-grid scale (see examples in Section 3.1.3).

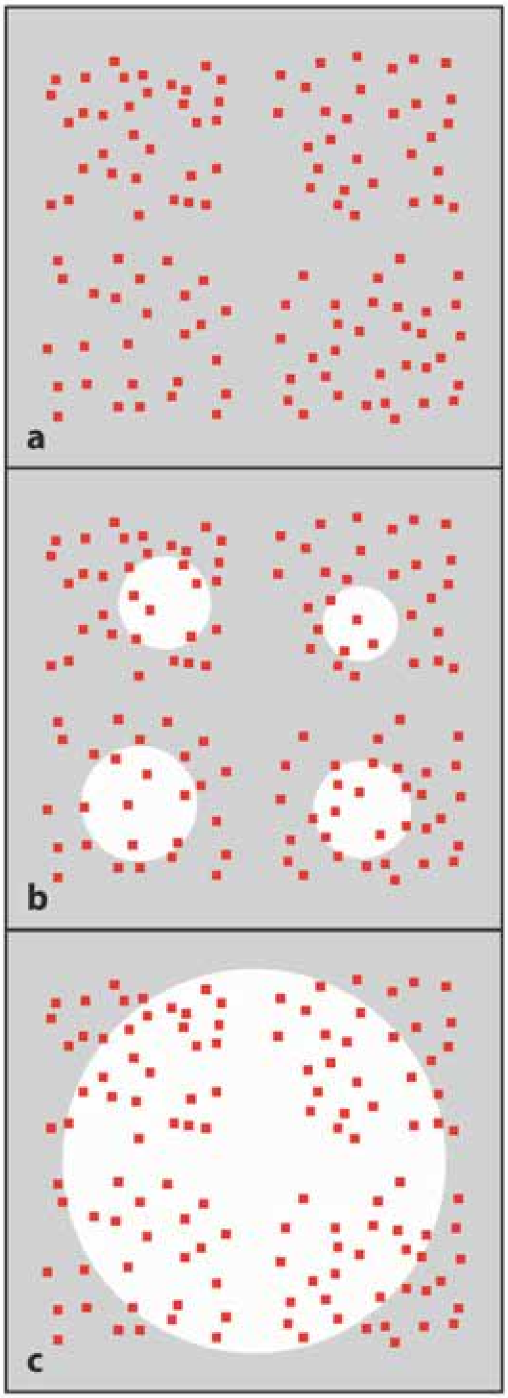
Figure 2.2 Illustration showing how the size of a study area can affect the values of *WUP* and *UP*



Note: In the top panel, two landscapes of the same size (white) that are permeated by areas of settlement (red) are shown. Landscape (1b) contains far more settlement areas than landscape (1a), and so *WUP* and *UP* are higher for landscape (1b). In the bottom panel, two landscapes with the same settlement areas, arranged in the same spatial pattern (and with the same *DIS*), are shown. Landscape (2b) occupies an area four times larger than that of landscape (2a). Therefore, *UP* and *WUP* for landscape (2b) are four times lower than they are for landscape (2a), as is the case for *PBA* (since $UP = A_{\text{built-up}}/A_{\text{reporting unit}}$ and $WUP = A_{\text{built-up}}/A_{\text{reporting unit}} \times DIS \times w_1(DIS) \times w_2(LUP)$).

Source: Schwick et al., 2012a.

Figure 2.3 The *HP* plays a significant role in the observation of sprawl



Note: In example (a), the landscape is strewn with single buildings. At a low *HP* (b), these buildings appear to be evenly distributed. At a high *HP* (c), it becomes apparent that the buildings are grouped into four parts of the landscape, and, from this perspective, *DIS* is less than its potential maximum (which is not visible on the scales used in (b)).

Source: Adapted from Dale and Fortin, 2005.

Box 2.2 What are UPUs?

Every variable consists of a numerical value and a unit. For example, the speed (*SP*) of a car may be given as *SP* = 50 km/h, where km/h is the unit of the variable *SP*. The unit of *DIS* is UPU/(m^2 of built-up area). Accordingly, the unit of *WUP* is UPU/(m^2 of landscape) (the weighting functions $w_1(DIS)$ and $w_2(UD)$ do not have a unit).

The following example serves to illustrate one UPU (urban permeation unit). Imagine a landscape size of 4 ha that includes a 1-ha square of built-up area, as follows:

Size of the reporting unit = 200 m x 200 m = 4 ha.

Size of the built-up area = 100 m x 100 m = 1 ha.

There are no other built-up areas within the surrounding 2 km.

Land uptake per inhabitant or job is 306 m^2.

The value of *PBA* in this landscape is 25 %, and the value of *DIS* is 8.93 UPU/m^2. *UP* results in *UP* = *PBA* × *DIS* = 2.23 UPU/(m^2 of landscape). If there are 33 inhabitants and jobs in this patch of built-up area, the *LUP* will be calculated as follows: *LUP* = 1 ha/33 = 306 m^2 per person. The two weighting functions result in $w_1(DIS) = 0.5$ and $w_2(LUP) = 0.896$. The value of *WUP* can then be calculated as the product, as follows:

$$WUP = UP \times w_1(DIS) \times w_2(LUP) = 2.23 \text{ UPU/(m}^2\text{ of landscape)} \times 0.5 \times 0.894 = 1 \text{ UPU/(m}^2\text{ of landscape)}.$$

The following four examples illustrate some common cases of the interplay between the three components of *WUP*.

1. In landscapes that include a compact village or a compact small town (photo a), *PBA* and *DIS* are low or very low, and the *LUP* is medium to high. As a result, the value of *WUP* is low. This is also the case for a landscape including several villages and towns, each of them compact and more than 2 km from each other (i.e. outside the *HP*).

2. In historically scattered landscapes in rural regions, the proportion of built-up area is very low (photo b). The value of *DIS* is very high (the buildings are closer to each other than 2 km). The value of *LUP* is usually high, but the resulting value of *WUP* is still low, because *PBA* is so low. However, if the built-up areas expand as a result of new residential and/or commercial buildings, the traditional character of the landscape will be modified (rural sprawl), *PBA* will increase and *WUP* will increase accordingly.

3. In suburban areas, there often are many built-up areas (high *PBA*), and they are typically spread out (very high *DIS*) (photo c). They are, to a large part, made up of single-family homes, so the *LUP* is high. In this case, all three dimensions contribute strongly to sprawl, resulting in a situation with the highest values of *WUP*.

4. In towns and cities that have a high *UD*, the *PBA* is high, its *DIS* is relatively high (with short, long and intermediate distances between buildings), but the *LUP* is very low (photo d). As a result of very *LUP* values, *WUP* is also very low in such towns and cities (at least in the centres for which *LUP* is low).

Box 2.2 What are UPUs? (cont.)

(a) Coeuve (Canton of Jura, Switzerland):
WUP = 7.12 DSE/m²; *DIS* = 27.7 DSE/m²; *LUP* = 962 m² per inh. or job

(b) Eggerstanden (Canton of Appenzell Innerrhoden, Switzerland):
WUP = 0.54 DSE/m²; *DIS* = 37.9 DSE/m²; *LUP* = 7143 m² per inh. or job

Box 2.2 What are UPUs? (cont.)

(c) Muralto/Minusio (Canton of Ticino, Switzerland):
WUP = 32.5 DSE/m^2; *DIS* = 47.2 DSE/m^2; *LUP* = 833 m^2 per inh. or job

(d) Lausanne (Canton of Vaud, Switzerland):
WUP = 0.001 DSE/m^2; *DIS* = 48 DSE/m^2; *LUP* = 30 m^2 per inh. or job

Photos a–d: © Sina Wild

Box 2.3 More information about the role of the horizon of perception

The *HP* represents the scale of analysis of urban sprawl and is used in the calculation of *DIS* (Figure 2.3). It accounts for the fact that urban sprawl can be perceived visually by a person within a certain distance. This approach corresponds to the definition of landscape in the European Landscape Convention, according to which '*Landscape* means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (Article 1 of the European Landscape Convention — Definitions; Council of Europe 2000). Very small *HP*s (less than 500 m) would result in a reduced perception of urban sprawl, because neither the spread of a larger town nor the expansion of neighbouring towns would be seen. For very large *HP*s (more than 10 km), on the other hand, the spread of a built-up area would be considered as in-filling rather than urban sprawl. A sensitivity analysis based on simulated scenarios of urban sprawl and real data from the Czech Republic used *HP*s between 1 km and 5 km and compared the results (Orlitová et al., 2012). The authors concluded that 2 km is the most suitable choice for the *HP* (see Annex A2.2 for details). Usually, there are only minor differences in the *DIS* values of patterns of urban sprawl as they are reflected by *HP*s between 1 km and 5 km (however, see Annex A2.2 for an example in which it differs). Therefore, this report used a *HP* of 2 km.

The *HP* reflects the intuitive idea of describing the average effort of delivering some service from all urban points (e.g. every building) to randomly chosen delivery points within a specified 'range of delivery' that represents the scale of the analysis (see below). For practical reasons, only one *HP* was used for this report, not a series of *HP*s. Values other than 2 km could also have been used if there was a particular reason that a different scale of analysis was of interest. All *HP*s are valid for the analysis of the spatial distribution of the built-up areas at a particular scale, since patterns can be dispersed and clumped at different scales (Figure 2.3), but some scales are more useful than others for studying urban sprawl. We used 2 km, as was used for the analysis of urban sprawl in Switzerland (Schwick et al., 2012; Jaeger and Schwick, 2014) and as recommended by Orlitová et al. (2012), for the following reasons:

1. The definition of sprawl used in this report is based on the visual perception of sprawl. Therefore, the choice of the *HP* was based on the following estimation: because of the curvature of the Earth, people with an eye height of 180 cm can see the surrounding area within a radius of 4.8 km (assuming there are no obstacles obstructing their view; calculated using the Pythagorean formula $x^2 + (6\,370 \text{ km})^2 = (6\,370 \text{ km} + 1.80 \text{ m})^2$, where 6 370 km is the average radius of the Earth). The actual view is often less than 4.8 km or larger than 4.8 km from elevated locations. As an alternative to a fixed value for the *HP*, a viewshed could be calculated for each point in the landscape, but this would require much more effort.

2. Values below 1 km are too small because, at such a small scale, the analysis would detect only situations in which two settlements had started growing towards each other, if those settlements were already within 1 km of each other. Therefore, 1 km appears to be the minimum value for the *HP*.

3. On the other hand, if an *HP* of 10 km or more is used, new built-up areas between two villages that are 8 km apart will appear as in-filling; however, this would, in fact, be interpreted as sprawl at the 2-km scale (leapfrog development). For example, villages in the Alps are often closer to each other than 5 km. Therefore, values for the *HP* of more than 5 km would be too large.

4. An *HP* of 2 km seems most suitable for practical reasons. The typical distances between two settlements in many European countries are between 3 and 5 km; the distances between villages that were founded hundreds of years ago are often in this order of magnitude, because the land between them was needed for agriculture to feed the people in the villages. Nowadays, these villages and towns often grow towards each other, and this will be detected by using an *HP* of 2 km.

The degree of *DIS* is the average weighted distance between any two points chosen randomly within the urban areas of the landscape investigated; the second point is chosen within a distance from the first point that is less than the *HP*. A weighting of the distances is necessary to meet the suitability criteria (in particular, criterion 7; see Jaeger et al. (2010b) and Jaeger and Schwick (2014) for a detailed explanation). The weighting can be intuitively understood as an indication of the effort required to deliver some service from one of the two points to the other within the starting point's 'range of delivery' (= *HP*), or to provide some kind of infrastructure between the two points. The value of *DIS* does not depend on the total amount of urban area because the average effort of all pairs of points is considered. Therefore, the further the newly built buildings from the existing ones, the higher the expected effort; and the more clumped the buildings (i.e. the closer they are to each other), the lower the expected effort.

Relatively large *HP*s can be used to capture the macrostructure of a settlement pattern. L. Dijkstra (European Commission, personal communication, 15 April 2015) explored the use of an *HP* of 20 km in order to reflect typical commuting distances and to strengthen the link between the measurement of sprawl and the functional aspects of urban sprawl, based on functional relationships between points within built-up areas. Highly sprawled areas are usually associated with larger commuting distances than less sprawled areas. Therefore, one interesting topic for future study may be the use of dynamic *HP* values that are based on empirical data on average commuting distances within each NUTS-2 region. This would correspond to a commuter-oriented definition of urban sprawl (rather than visual perception) and would result in even higher values of *WUP* for sprawled regions because they would be analysed using a larger *HP* value than regions with shorter commuting distances.

2.3 Base data and reporting units

The urban sprawl metrics were calculated using European soil sealing data obtained from the HRL IMD. They consist of pixels of 20 m × 20 m for all available European NUTS-2 regions. We used these data to identify built-up areas; in order to do this, a clear definition of a built-up area was required.

2.3.1 Definition of a built-up area

The definition of urban sprawl used in this report (Section 1.2.1) allows for any given user-defined delineation of 'built-up areas' (or 'urban areas'). These may include various types of settlement and buildings, ranging from places with urban character to villages to separate single buildings in the open landscape. Generally, a built-up area is defined as a surface covered by man-made structures. Roads and railways outside towns and cities are not included in this definition, since they are not perceived to be part of urban sprawl (but rather contribute to landscape fragmentation) (EEA and FOEN, 2011a). For any particular study, the definition of a built-up area must be chosen in a precise and unambiguous way to allow for comparisons between different regions and between different points in time. In most cases, there are more detailed data layers on 'built-up areas' available for smaller regions, but the data layers range from information regarding single lots within municipalities to national digital data sets to satellite data for large areas. For a comparison between different points in time, it is necessary to use the same delineation criteria of a built-up area.

In this report, we used information about built-up areas from the HRL IMD provided by the European Copernicus programme (Section 2.3.2). HRL IMD provides a data set related to all artificially sealed areas, including information on the level of soil sealing. Based on the comparative study by Orlitova et al. (2012), the imperviousness threshold for the differentiation of urban cells and non-urban cells was set at 30 %. As the HRL IMD provides a measure of soil sealing and not a measure of built-up areas directly, it was necessary to implement a correction factor for the calculation of the size of built-up areas in Europe (Section 2.3.2). This correction factor is based on the comparison of the results from the HRL IMD data set with the results from the Vector25 data set for Switzerland (see below).

2.3.2 High resolution layers

We used the pan-European HRLs of 2006 and 2009 for Europe, which were produced in the frame of GMES precursor activities, and the Geoland2 project (and for the 2012 and 2015 reference years, this was continued under Copernicus land monitoring services) to assess the extent of surfaces sealed with artificial buildings (Langanke et al., 2013). The HRL IMD contains 20 m × 20 m and 100 m × 100 m grid cell layers, which are both produced from satellite imagery at 20 m × 20 m resolution and detect all sealed surfaces at this resolution. The level of imperviousness was determined using an automatic algorithm based on a calibrated Normalized Difference Vegetation Index (NDVI) and ranges from 0 to 100 %.

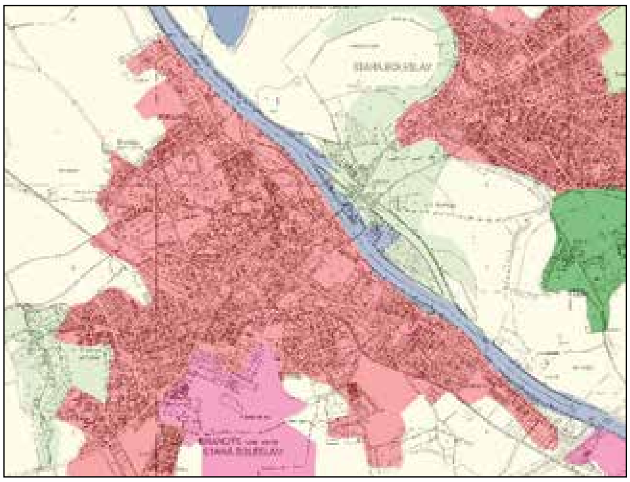
The HRL provides more detailed data (20 m × 20 m = 0.04 ha), with regard to sealed surfaces, than CLC (25-ha resolution for each time-point and 5-ha resolution for changes) and the Urban Atlas (0.25-ha resolution) (Map 2.1). Based on the results from a comparative study using various levels of imperviousness, a threshold of 30 % was chosen to differentiate urban and non-urban pixels (Orlitová et al., 2012).

A comparison of the CLC and the HRL with the Vector25 layer (Swisstopo 2002), which has a resolution of 3–8 m for Switzerland, has shown, however, that the CLC overestimates the extent of urban areas and underestimates their dispersion (Orlitová et al., 2012). While the HRL provided more similar results to those of the Vector25 layer, motorways and larger roads outside cities are still reproduced. Consequently, the difference between the results from the Vector25 and HRL for Switzerland (40.9 %) was used to correct the imprecision of the latter as described below.

Calculation of the linear correction factor for built-up areas

The Swiss Vector25 layer estimated that, for the entire country overall, built-up areas are 1.409-fold larger than those estimated by the HRL. The differences between these estimates are smaller for compact cities, and larger for more dispersed settlement areas, because Vector25 captures built-up areas at a higher resolution. Therefore, we applied a linear correction factor (*LCF*) based on the following two conditions: (1) no correction factor (i.e. *LCF* = 1) was applied if the sealed area, according the HRL, is 100 %; and (2) the extent of the impervious area in Switzerland (which is 4.25 % according to HRL) was corrected using an *LCF* of 1.408686 (resulting in the correct value of 5.987 % of built-up area). Using a simple linear function for the portion of impervious area ($0 < x < 1$) in the HRL, the correction factor was calculated as follows: $LCF(x) = 1.426826 - 0.426826 \cdot x$ (see Annex A3.4 for more detailed information).

Map 2.1 Examples from the land cover data layers CLC, the HRL IMD data set and Urban Atlas (for Brandys and Labem-Stará Boleslav in the Central Bohemian Region of the Czech Republic, located in the north-east of Prague)



Corine Land Cover

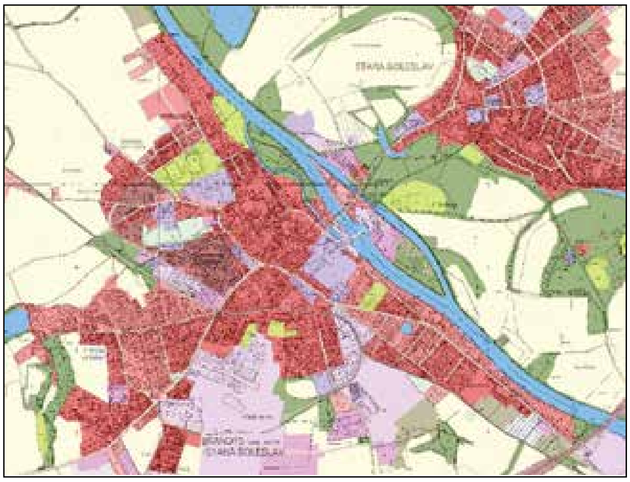
Classes: Hierarchical 44 classes

Temporal coverage: 1990, 2000 and 2006

Minimal Mapping units: 25 ha status/5 ha change

Spatial coverage: EEA-39 minus Greece and Kosovo under UNSCR 1244/99

Currently implemented as part of GMES initial operations land (GIO land)-pan-European component.



Urban Atlas

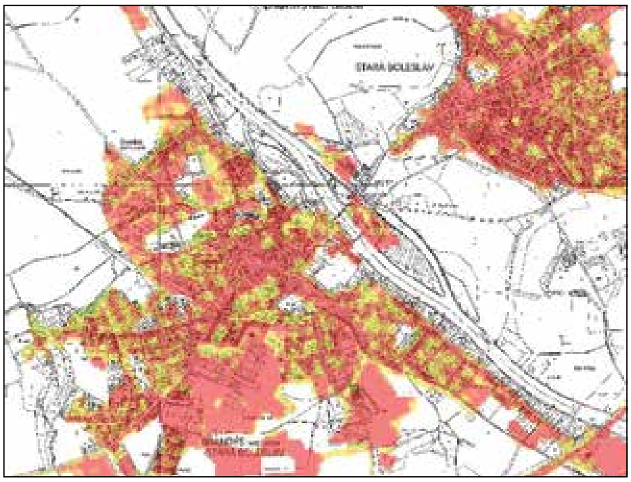
Classes: Hierarchical 19 classes

Temporal coverage: 1990, 2000 and 2006

Minimal Mapping units: 0.25 ha

Spatial coverage: EU-27 — not seamless coverage, > 300 selected Large Urban Zones (LUZs) covered

Currently implemented as part of GMES initial operations land (GIO land)-local component.



High resolution layer — imperviousness degree (HRL IMD)

Continuous raster of imperviousness degree: 0–100 %

Temporal coverage: 2006 and 2009

Resolution: 20 m

Spatial coverage: EEA-39

Validated as 100 m grid

Latest update available for the 2012 reference year (implemented as part of GMES initial operations land: GIO land). Continued as part of the Copernicus land services for the 2015 reference year.

Source: Orlitová et al., 2012.

We visually compared the European HRL IMD layer with Urban Atlas maps, since they were developed using more precise satellite imagery with the support of in situ data (national data) to verify the categorisation of the Urban Atlas land-cover types. Overall, their congruence is high (Annex A3.2), although there are some minor differences between the two data sets. Greenhouses are included in the built-up areas for both HRL IMD and Urban Atlas (Annex A3.3). Some areas (mostly in some parts of Finland and Sweden in 2009) were covered by clouds. The areas covered by clouds in 2006 were not included in the calculation of the metrics for 2006 and 2009 in order to ensure that the estimation of changes between these years was as accurate as possible (see Annex A3.1).

The delineation of countries and regions was provided by the EuroBoundaryMap version 5 (EBMv5_100m), which is used by the EEA for LEAC. The raster layer was downloaded from the EEA SDI (spatial data infrastructure) internal catalogue, and the vector version of the map was adapted in accordance with NUTS-2010 classification. For those regions for which the EBMv5_100m was not available (i.e. the Balkan regions and Turkey), an alternative source of NUTS vector data was downloaded from http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units (classification: NUTS 2010; scale: 1:3 million).

2.3.3 Numbers of inhabitants and jobs

Population and employment data at the European level were provided by Eurostat (see Annex A3.5 for detailed information). Employment data were recorded according to the locations in which the employed people live. Workers can be employed in the same NUTS-2 region as they live, but they may also travel to work to another region (in the same country or a foreign country). Therefore, we included information about commuting (Annex A3.5.1) to determine the number of jobs in the NUTS-2 regions according to the regions in which the jobs are located, because this provides more accurate results. In addition, not all jobs are full-time positions. Part-time workers use built-up areas for less time than full-time employees. In order to reflect this difference in *UD*, full-time equivalents were considered to present a more reliable picture of *LUP*. The correction factor for full-time equivalents was derived from data regarding full-time equivalents for Switzerland in the period 2000/2001. During this period, there were 3 965 000 jobs in Switzerland, which corresponded to 2 748 000 full-time and 1 217 000 part-time employees. This resulted in a correction factor of 0.50804 for the conversion of the number of part-time jobs into full-time equivalents. The total number of full-time equivalents is the sum of full-time jobs and the number of full-time equivalents for the part-time jobs (i.e. 2 748 000 + (0.50804 × 1 217 000) = 3 366 280) (see Annex A3.5.1 for more detailed information). The determination of this factor can be adjusted for different countries based on national data sets (if available).

The population data for the 1-km²-grid for 2006 and 2011 were available from the Geostat project (http://ec.europa.eu/eurostat/web/gisco/geostat-project). We determined the values for 2009 by interpolation between the 2006 and 2011 values (Annex A3.5.2).

2.3.4 Delineation of NUTS-2 regions

This study investigated urban sprawl on three levels:

1. country level (NUTS-0);
2. NUTS-2 level;
3. 1-km²-grid level.

The NUTS classification system provides a European standard with regard to geographical regions for statistical data collection. It consists of six levels, which are determined by administrative or geographical boundaries, and population size:

1. NUTS-0 is the country level;
2. NUTS-1 is the level of states/macroregions/regions with a population of between 3 million and 7 million;
3. NUTS-2 is the level of regions/provinces/states/prefectures with a population of between 800 000 and 3 million;
4. NUTS-3 is the level of counties/municipalities/cities with a population of between 150 000 and 800 000;
5. NUTS-4 and NUTS-5 are also called local administrative unit (LAU)-1 and LAU-2; the first of these represents districts and the second represents communities.

The NUTS classification has changed over time since its introduction at the end of the 1990s (EC 2011c). Some regions were split, merged or renamed, which complicates the comparison between different points in time (Annex A3.6). This report uses the NUTS-2 regions and their 2010 delineation. Values related to population and other variables for 2006 were adjusted to the 2010 delineation for regions for which the delineation changed between 2006 and 2010. Countries composed of a single NUTS-2 region are Cyprus, Estonia, the former Yugoslav Republic of Macedonia, Iceland, Latvia, Liechtenstein, Lithuania, Luxembourg and Malta.

The EEA 1-km^2 reference grid is available for each European country at http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2. The grid shape files of all 33 EEA member countries and six cooperating countries (EEA-39) were downloaded and merged.

2.4 Predictive models for urban sprawl: variables and hypotheses

In order to analyse the impacts of likely drivers of urban sprawl on *WUP* and its components, *DIS*, *LUP* and *PBA*, the available data from all European countries and NUTS-2 regions were used. The accessibility and completeness of the data set determined the number of possible variables for our statistical models. Accordingly, a few small countries, for which information was lacking (e.g. Monaco, San Marino and Vatican City), were not included in the statistical analysis. Some regions are neither covered by the list of NUTS-2 regions nor represent countries. A lack of data for calculating *WUP* also resulted in the omission of some regions from the analysis: the Isle of Man (England) (no code), Mount Athos (Greece) (no code), the Faroe Islands (FO), Svalbard (no code), Gibraltar (GI), Jersey (JE), Guernsey (GG) and Alderney (no code). The objective of including as much information as possible resulted in a smaller set of demographic, socio-economic, political and environmental drivers than we had aimed for at the beginning. The total number of variables was 15 at the country level and 12 at the level of NUTS-2 regions (Table 2.2).

If different variables covary, which indicates that they provide some similar information, this can contribute to the issue of multicollinearity in the regression analysis.

Table 2.2 Variables included in the statistical analysis

Variable	Definition	Unit	Source (original source; calculation of values)	Level (NUTS-0, NUTS-2)	Completeness
Demographic					
Population density	Number of inhabitants divided by size of the reporting unit	Inhabitants/km^2	Eurostat, some additions from national statistical offices	0, 2	100 %
Ageing index	Ratio of number of inhabitants of age 65 years and older to the number of inhabitants of age 14 years and younger (inhabitants age ≥ 65 y / inhabitants age ≤ 14 y) × 100	%	Eurostat, some additions from national statistical offices	0, 2	100 %
Socio-economic					
*GDP*c	*GDP*c indicates the market value of all goods and services produced in a country in a given year, divided by population size	PPS per capita; PPS is a fictive currency, which provides harmonisation between regions and countries	Eurostat	0, 2	100 %
Employment rate	Percentage of employed people aged 15 to 65 years	%	Eurostat	0, 2	100 %
Household size	Average number of inhabitants living in a household	Inhabitants/household	Eurostat	0, 2	100 %
Cars per 1 000 inhabitants	Average number of cars per 1 000 inhabitants	Cars per 1 000 inhabitants	Eurostat, some additions from national statistical offices	0, 2	100 %
Fuel price	Pump price for gasoline	USD per litre	World Bank	0	100 %

Table 2.2 Variables included in the statistical analysis (cont.)

Variable	Definition	Unit	Source (original source; calculation of values)	Level (NUTS-0, NUTS-2)	Completeness
Road density	Length of the road network in a given reporting unit, including all types of roads (roads with limited access/motorways, primary roads, secondary roads, local roads, unknown) per km^2	km/km^2	TeleAtlas; calculations by GISAT	0, 2	100 %
Rail density	Length of the railway network in a given reporting unit (including all types of railway system) per km^2	km/km^2	TeleAtlas; calculations by GISAT	0, 2	100 %
Geophysical					
Net primary productivity (*NPP*)	Amount of carbon (C) in kg produced per m^2 and per year	kg $C/m^2/y$	NASA MODIS MOD17A2/A3 Land Algorithm (Heinsch et al., 2003), calculations by WSL	0, 2	100 %
Relief energy	Vertical distance between the lowest and highest point in a given area, per area	m/km^2	Global 30 Arc-Second Elevation GTOPO30 (USGS 2015), calculations by Die Geographen Schwick & Spichtig	0, 2	100 %
Irreclaimable area	Area not suitable for construction, including lakes, glaciers, steep mountain slopes, rocky areas in mountains, swamps and beaches. It is expressed in the analysis as the percentage of the total area of the reporting unit.	%	CLC06, calculations by Die Geographen Schwick & Spichtig	0, 2	100 %
Fraction of coastal area	Length of the boundary of the reporting unit that is located on the sea. Proportion of the coastal length to the total boundary length	%	CLC06, calculations by Die Geographen Schwick & Spichtig	0, 2	100 %
Political					
History of communism		Binary (0,1)	Authors of this report	0, 2	100 %
Governmental effectiveness	Quality of public services, the quality of the civil service, the independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to its stated policies	Categorical	Kaufmann et al., 2010	0	100 %
Natural resource protection indicator (*NRPI*)	Indicator of the comprehensiveness of a government's commitment to habitat preservation and biodiversity protection by assessing whether or not a country is protecting at least 17 % of all of its biomes (e.g. deserts, forests, grasslands, aquatic and tundra)	–	Ciesin	0	100 %

Note: In the statistical analysis, the total number of countries was 35 and the number of NUTS-2 regions was 267 (Sections 3.3.1 and 3.3.2). Ciesin, Centre for International Earth Science Information Network; PPS, purchasing power standard; WSL, Swiss Federal Institute for Forest, Snow and Landscape Research.

Table 2.3 Data sources

Variables	Main source (original source; calculation of values)
Population density	Eurostat, total population on 1 January by age and sex — NUTS-2 regions File name: demo_r_d2jan URL: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_d2jan&lang=en
Ageing index	Eurostat, total population on 1 January by 5-year age groups and sex — NUTS-2 regions File name: demo_r_pjangroup URL: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_pjangroup&lang=en
GDPc	Eurostat, *GDP* at current market prices by NUTS-2 regions File name: nama_r_e2*GDP* URL: http://ec.europa.eu/eurostat/data/database?node_code=tec00114#
Employment rate	Eurostat, employment rates by sex, age and NUTS-2 regions (%) File name: lfst_r_lfe2emprt URL: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst_r_lfe2emprt&lang=en
Household size	Eurostat, number of households by degree of urbanisation of residence and NUTS-2 regions (1 000) File name: lfst_r_lfsd2hh URL: http://ec.europa.eu/eurostat/data/database?node_code=lfst_r_lfsd2hh# Household size was calculated by dividing population size by the number of households
Cars per 1 000 inhabitants	Eurostat, stock of vehicles by category and NUTS-2 regions File name: tran_r_vehst URL: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tran_r_vehst&lang=en
Fuel price	The World Bank, pump price for gasoline (USD per litre) File name: EP.PMP.SGAS.CD URL: http://data.worldbank.org/indicator/EP.PMP.SGAS.CD
Road density	TeleAtlas; calculations by GISAT
Rail density	TeleAtlas; calculations by GISAT
Net primary productivity (*NPP*)	NASA MODIS MOD17A2/A3 Land Algorithm (Heinsch et al., 2003), calculations by WSL
Relief energy	Global 30 Arc-Second Elevation GTOPO30 (USGS 2015), calculations by Die Geographen Schwick & Spichtig
Irreclaimable area	CLC0, calculations by Die Geographen Schwick & Spichtig
Fraction of coastal area	CLC06, calculations by Die Geographen Schwick & Spichtig
History of communism	Authors of this report
Governmental effectiveness	Indicator developed by Kaufmann et al. (2010) as part of the Worldwide Governance Indicators (WGI) project URLs: http://info.worldbank.org/governance/wgi/index.aspx#home; https://www.mcc.gov/pages/selection/indicator/government-effectiveness-indicator
Natural resource protection indicator (*NRPI*)	Ciesin, Earth Institute, Columbia University: *NRPI* The World Wildlife Fund provided the biome data, and the United Nations Environment Programme World Conservation Monitoring Centre provided the data on protected areas File name: nrmi-natural-resource-protection-child-health-indicators-2012 URL: http>//sedac.ciesin.columbia.edu/data/set/nrmi-natural-resource-protection-child-health-indicators-2012

Note: For a more detailed list of sources (e.g. for data from national statistical offices), see Annex 5. Ciesin, Centre for International Earth Science Information Network; WSL, Swiss Federal Institute for Forest, Snow and Landscape Research.

Multicollinearity can have an undesirable impact on the estimation of regression coefficients and their significances, and therefore corrections need to be applied (e.g. Faraway, 2005 and Montgomery et al., 2012). We evaluated the degree of multicollinearity among the predictor variables using variance inflation factors (VIF_j), which are defined as:

$$VIF_j = 1/(1 - R_j^2),$$

where R_j^2 is the coefficient of determination of the regression of each explanatory variable (and $j = 1$ to n) with all other explanatory variables. The VIF_j values express the amount of variation in a predictor that is explained by the other predictors. The product of the square root of the VIF_j for any given variable and its standard error indicates the amount of inflation.

Variance inflation factors larger than 5 are considered of concern, while those larger than 10 are considered critical. We therefore removed a priori redundant variables to reduce the probability of high VIF_j values. Several variables, such as levels of taxes, levels of interest rates, levels of subsidies for commuting and house construction, costs of living, income disparities within a country or region, land prices and house prices, could not be included because of this redundancy or a lack of sufficient data.

Because of this multicollinearity, we applied the ridge regression approach, which introduces a penalised term and removes variables (standardised) that have coefficients close to zero (Tibshirani, 1996; Bühlmann, and van de Geer, 2011). For more information about statistical questions, see Section 3.3.6 and Annex A5.

Each variable can have a different effect on the three components of urban sprawl, and the total effect on urban sprawl then depends on the balance of these effects on each of the components. In this section, we state the hypotheses with regard to the expected effects of each variable on *WUP*; these are derived from the impact of the explanatory variable on each component, as summarised in Table 2.4. We also

Table 2.4 Expected effects of each predictor variable on urban sprawl and its components

Variable	Urban sprawl (*WUP*)	Dispersion (*DIS*)	Urban permeation (*UP*)	Utilisation density (*UD*)	Land uptake per person (*LUP*)	Percentage of built-up area (*PBA*)
Demographic						
Population density	↗, then ↘	↗, then 0	↗	↘, then ↗	↗, then ↘	↗
Ageing index	? (0)	? (↗)	? (↗)	? (↘)	? (↗)	? (↗)
Socio-economic						
GDPc	↗	↗	↗	↘	↗	↗
Employment rate	↗	↗	↗	?	?	↗
Household size	↘	↘	↘	↗	↘	↘
Car availability	↗	↗	↗	↘	↗	↗
Fuel price	↘	↘	↘	↗	↘	↘
Road density	↗	↗	↗	↘	↗	↗
Rail density	↘ (?)	↘ (?)	↘ (?)	↗ (?)	↘ (?)	↘ (?)
Geophysical						
NPP	↗	0 (?)	↗	?	?	↗
Relief energy	↘	↘	↘	↗	↘	↘
Irreclaimable area	↘	↘	↘	↗	↘	↘
Fraction of coast	↗	↗	↗	↘	↗	↗
Political						
Communistic history *	↘	↘	↘	↗	↘	↘
Governmental effectiveness	↗	↗	↗	↘	↗	↗
Natural resource protection indicator (*NRPI*)	↘	↘	↘	↗	↘	↘

Note: '↗' indicates that the relationship between factors is expected to be positive (i.e. to lead to an increase in urban sprawl and/or its components) and '↘' indicates that the relationship between factors is expected to be negative (i.e. to lead to a reduction in urban sprawl and/or its components); '?' is used to indicate that the expected impact of a given factor is unclear (i.e. no clear expectation of the effect) and '0' indicates that no effects on urban sprawl and/or its components are expected. *NPP*, net primary productivity.
* The relationship with the *rate* of change in sprawl may be in the opposite direction to that indicated here (see Section 2.4.4).

assumed that the effects at the levels of countries and NUTS-2 regions would be the same. The statistical analysis reveals whether the empirical data are in agreement with or contradict our expectations, in which case we would need to reject a given hypothesis.

2.4.1 Demographic variables

Population density

As more people move to a particular landscape, *DIS* will initially increase (indicated by ↗ in Table 2.4), as the buildings spread in the region; however, at some point, *DIS* will stop increasing (indicated by 0 in Table 2.4) as a result of a more compact spatial arrangement of the buildings (e.g. larger houses with more apartments or more houses closer to each other will be built). The *PBA* and *UP* will increase as a result of an increase in the number of houses (↗), but *LUP* will begin to decrease (↘) at some point, because more people will have to share space in the same area. Therefore, the total effect of an increase in population density on urban sprawl should mostly be positive, but, at some point, the effect will become neutral and then negative (Table 2.4). However, the situation may be different in 'shrinking' regions. If the population of a region is declining, the remaining people will usually take up more land per person, particularly if efforts are being made to promote new urban development in order to make cities more attractive and retain or attract new people (i.e. *LUP* will increase (↗)). In this case, regions with relatively low populations are expected to exhibit higher levels of urban sprawl if the population is declining than if the population is increasing (see Section 1.3.1).

Ageing

The populations of European societies are ageing. Elderly people depend on particular services, such as health services, more than younger people, and may reside in sheltered homes or with their children (Rosso et al., 2011). Therefore, it is possible that *DIS* and *UP* will remain stable (0) or even decline (↘), since sheltered houses and apartments will be occupied by more people than single-family homes (i.e. *LUP* will decline (↘) as the average age of the population increases). If this is the case, such an older society will be associated with less sprawl. However, there are also regions in which elderly people tend to remain in their homes and live alone, rather than moving to a smaller place or sheltered accommodation; this results in a growing surface per capita, and, therefore, an increase in *LUP* (↗). In such cases, *DIS* and *UP* will continue to increase, because the younger generation will have to find space to live (i.e. in houses or other apartments) elsewhere. Furthermore, some elderly people have second homes, in places with a sunny climate, coastal regions and other attractive places, in which they live for part of the year, but keep their original dwelling for other parts of the year; the contribution of such second homes to sprawl will be relatively high. Some countries (e.g. Portugal) actively try to attract ageing people with high incomes. The net effect on urban sprawl in this case is expected to be positive. The situation with regard to elderly people differs among regions and, therefore, we suggest that, overall, there will be no effect, or only a minor positive effect, on urban sprawl; the relationship may be negative in cities of average attractiveness and positive in more attractive regions.

2.4.2 Socio-economic variables

Gross domestic product per capita

Gross domestic product per capita (*GDPc*) is defined as the market value of all goods and services produced in a country in a given year, divided by its population size. Because of the differences in prices for the same goods in different countries, different amounts are required to acquire the same product. In order to allow for comparisons among countries, an artificial currency was introduced, namely the purchasing power standard (PPS). *GDPc* (in PPS per capita) is thus an expression of the prosperity of the country. Lower *GDPc* values are associated with a higher risk of becoming unemployed. On the other hand, higher *GDPc* values are associated with higher incomes, and a higher probability of owning a car and building or acquiring a detached house (as discussed in Section 1.3.2); these factors lead to increases in *DIS* (↗), *UP* (↗) and *LUP* (↗). Therefore, a higher *GDPc* is expected to increase urban sprawl. For example, this happened during the housing bubble in Ireland in 2000–2007.

Employment rate

Employment rate is closely linked to *GDP*, since a higher *GDP* may be expressed as a stronger economy and more job opportunities. If all other variables are equal (including *GDPc*), the more people there are in employment, the better the existing working facilities will be utilised, and, therefore, there will be an increase (↗) in the *UD*. However, higher employment rates can also lead to an increase in the number of people that are financially able to purchase a home and a car, both of which would lead to an increase in *DIS* (↗) and *UP* (↗) values, and an increase in the amount of space acquired per person (i.e. an increase in *LUP* (↗)). We assume that the effects of *DIS* and *UP* would outcompete the effect of *UD*, and, therefore, urban sprawl would be expected to increase if employment rate increased (↗).

Household size

In general, a person in a household of one person uses more space per capita than a person in a household with more people. Therefore, larger household sizes are expected to be related to lower *DIS* and lower *UP*; furthermore, a larger number of people living together in single households will also decrease the *LUP* (↘). Therefore, we expect that larger household sizes would result in lower levels of sprawl. In regions with a relatively high *GDP*, people are less likely to live in a household with many other people.

Cars

Cars enable people to live in residential areas relatively far away from their places of work and have, therefore, been considered a major driver of urban sprawl (Section 1.3.2). The spread of suburban areas, and the resulting increase in *DIS* (↗) and *UP* (↗), would have been much less dramatic without cars. Most residential areas in the suburbs are single-family houses; such areas have arisen because land prices are lower in suburban areas than in city centres, and there is space available to establish these types of residential areas. Consequently, the same number of people utilise a larger built-up area (i.e. ↗ *PBA*) in a suburb than they would utilise in a city centre. Thus, an increase in the number of cars per inhabitant is expected to promote the spread of built-up areas in the landscape and, therefore, lead to an increase (↗) in urban sprawl.

Fuel prices

Higher fuel prices are likely to reduce the amount of unnecessary driving, in order to minimise expenses. Therefore, higher fuel prices are expected to decrease levels of urban sprawl (↘), *DIS* (↘) and *UP* (↘), because living closer to places of work and services (e.g. shopping facilities) would reduce car dependency. We also expect that higher fuel prices would have a negative effect on *LUP* (↘).

Roads and railways

Roads and railways are required for access to areas that are far from city centres, but their effects on sprawl are expected to differ. In particular, the growth of suburban areas relies on such infrastructure. The easier it is to commute to work from a remote place, the more attractive this place becomes for residences. Clearly, roads are a major promoter of *DIS* (↗). As the *DIS* and the settlement areas increase, so does *UP* (↗); the effect on *LUP* is also positive (↗) if possibilities for the residential development of single- or two-family houses far away from a city are enhanced, which is the case mainly with regard to road development, but also sometimes occurs in the case of public rail transport. However, the effect may be negative in cases in which people have easier access to workplaces and other facilities in more densely built-up areas, because railway stations are located there (↘). Overall, we expect the relationship between roads and sprawl to be positive, because of the strong effects on *DIS* and *UP*; this is supported by findings of previous studies (Moon, 1990; Knowles, 2006; Müller et al., 2010). However, railway lines, metro lines and tramways may have the opposite effect if they lead to the densification of an area. It is not clear how often urban planning overall has successfully applied public transport and densification in combination. We were optimistic and predicted that railways would be associated with a lower level of sprawl (Chapter 3 discusses whether or not this prediction is supported by the data). In our analysis, railway density is the length of the railway network in any given reporting unit, including all types of railway system, divided by the size of the reporting unit. Unfortunately, it was not possible to distinguish between different types of railways, such as the interurban, urban and suburban railway lines, so the variable encompasses all types.

2.4.3 Geophysical variables

Net primary productivity

Net primary productivity (*NPP*) is related to agricultural productivity. A higher productivity is also related to more job opportunities, which is why the pressure of human settlements is more pronounced in regions with higher *NPP*. *UP* will therefore be higher (↗), but this is more related to the demand for houses, and less to *DIS*. Ideally, highly valuable soils would be used more sparingly, but this may not be reflected strongly enough in property prices and legislation. Therefore, the effects on *DIS* and *UD* are unclear (0 or ?), which may be related to the many variables that contribute to high *NPP*. Therefore, we predict that an increase in *NPP* will be associated with a moderate increase in urban sprawl.

Relief energy and irreclaimable areas

Clearly, urban development is constrained by both high relief energy and a large proportion of irreclaimable areas, because these factors restrict the space on which to build, or mean that it would be very costly to do so (e.g. to build on steep slopes). Both variables are therefore expected to reduce the dispersion of buildings in the landscape (↘) and the amount of urban area (↘). Also, both variables force developers to use the remaining space in a more efficient manner to some degree, that is they are predicted to lead to a decrease in *LUP* (↘). Urban sprawl should, therefore, be lower in regions with higher relief energy or larger irreclaimable areas. Alternatively, the *WUP* values could be calculated only for the areas in which construction is possible, that is for adjusted reporting units from which the irreclaimable areas have been omitted. The *WUP* values can easily be determined with reference to only those parts of the study area (these values are given in Annex A3); these values are always larger than they are for the entire reporting unit because the irreclaimable areas have no built-up areas. If such adjusted values are used in statistical analyses, then the models should no longer include irreclaimable area as a predictor variable because the amount of irreclaimable area is zero in all adjusted reporting units.

Fraction of coastal areas

The fraction of coastal areas can have a considerable impact on the economy of a country. In several southern European countries, the tourism sector is one of the most important economic sectors. Large hotel constructions have been developed to accommodate tourists. In recent years, large areas have been taken up for the building of bungalows to enhance the prosperity of coastal areas. As a consequence, a higher fraction of coastal areas is likely to be associated with higher *DIS* (↗) and higher *UP* (↗). Because most hotels and secondary homes are only temporarily full, *LUP* is also high (↗). All of these factors suggest that regions with a higher fraction of coastal areas will have higher sprawl values, at least with regard to countries with warm climates.

2.4.4 Political variables

History of communism

In times of communism, countries with such a socialist political system also had a different system of urban development, which followed the principles of socialism (Suditu et al., 2010; Cirtautas, 2013; Roose et al., 2013). Factories and companies were kept inside cities and large housing constructions were established along city margins (Kotus, 2006; Cirtautas, 2013). It can be assumed that urban sprawl was lower at this time. However, after the collapse of communism in these countries, new capitalist development attracted companies that required additional space for their factories and outlets, and took advantage of employees that would work for relatively low wages. As a result, these cities and regions faced competition, and, in the struggle for economic survival, larger areas outside cities were designated for development. Thus, urban sprawl in general increased after the collapse of communism, but it is unclear to what extent the previously established structure has slowed down the spread of built-up areas. We expect that *DIS* (↘) and *UP* (↘) are lower in the former communist countries than in the other countries of Europe, and that *LUP* is also lower (↘), leading to lower levels of sprawl in general. However, the *rates* of increase in urban sprawl may actually be higher.

Governmental effectiveness

Governmental effectiveness can be viewed as a major driver of urban sprawl. This may seem counter-intuitive at first sight, because urban and regional planning are parts of this variable. Governmental effectiveness includes 'the quality of public services, the quality of the civil service, the independence from political pressure, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies' (Kaufmann et al., 2010) to measure how effectively national administrative institutions manage their tasks. Accordingly, it covers many aspects in addition to planning. These other aspects of governmental effectiveness will often contribute to a higher *GDPc*, higher road density, higher attractiveness and a larger population. Therefore, it will, in most cases, lead to higher levels of sprawl, for example through the encouragement of single-family houses and the development of suburbs, which increase *DIS* (↗) and *UP* (↗). Often politicians are interested in making their region economically more attractive to investors and wealthy people, which results in higher sprawl as a result of the space required for these people and factory sites. *LUP* will increase because fewer people will be working or living in each building (↗). Urban sprawl is therefore expected to increase in regions in which governmental effectiveness is higher (↗).

Natural Resource Protection Indicator

The Natural Resource Protection Indicator (*NRPI*) was developed as an attempt to quantify the comprehensiveness of a government's commitment to habitat preservation and to biodiversity protection. It assesses whether or not a country is protecting at least 17 % of all of its biomes (e.g. deserts, forests, grasslands, aquatic and tundra). The values are available for only countries. Higher values suggest that the government is more aware of environmental problems and is likely to make more effort to reduce environmental impacts. Consequently, a higher *NRPI* is associated with a higher probability of initiatives for reducing urban sprawl (↘), as well as *LUP* (↘), *DIS* (↘) and *UP* (↘).

3 Urban sprawl in Europe and its driving forces

This chapter presents the results regarding urban sprawl in 2009 (Section 3.1) and the changes between 2006 and 2009 (Section 3.2) on three scales, followed by the results regarding the likely driving forces (Section 3.3).

3.1 The degree of urban sprawl in Europe (2009)

The results are presented on three scales: the country level, the NUTS-2 region level and 1-km^2 cell level. It is important to consider that the sizes of these reporting units differ widely; the measurements of sprawl for the small reporting units will exhibit a larger range of values than the large reporting units. This is because the differences between small units are levelled out if they are combined to give values for larger units (e.g. if the five NUTS-2 regions of Denmark are combined to give a value for the entire country). The value of a group of small reporting units combined can never result in more extreme values than the individual values of the small reporting units. This is the case with every variable that is measured for spatial units, and this needs to be considered in the interpretation of the values. For example, a country that has high levels of sprawl in a few regions, but very low levels of sprawl in all other parts will have a low overall value for sprawl. For instance, in Spain, some regions are highly sprawled, but this is not apparent from the overall sprawl value for Spain because large parts of Spain have no or very little sprawl. Therefore, the results of sprawl analysis should always be considered on all three scales in parallel.

3.1.1 Urban sprawl at the country level

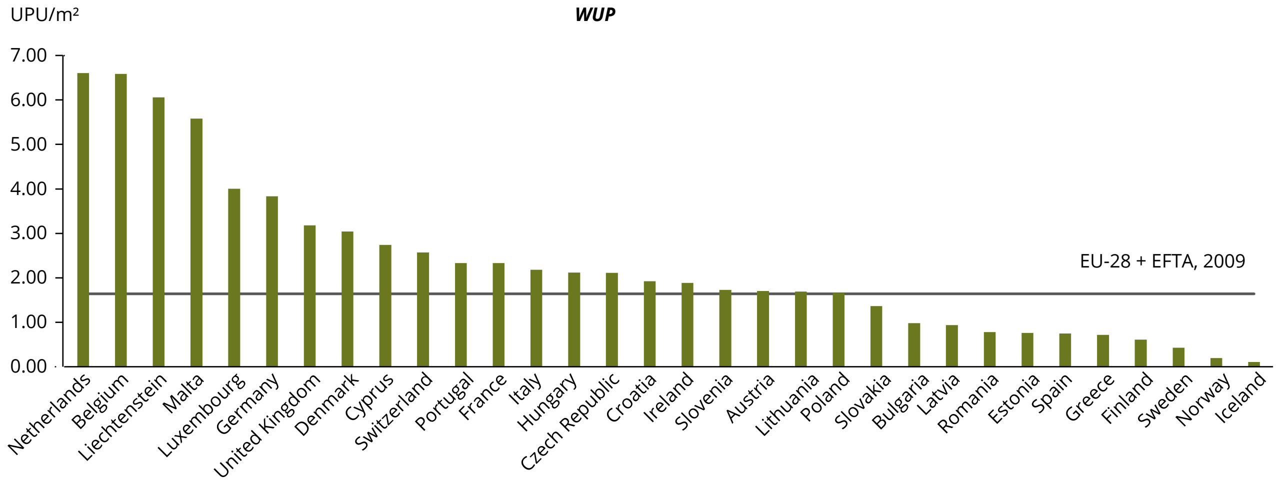
The results at the country level can give only a coarse overview of **overall** levels of sprawl in the countries. A country that exhibits a low overall *WUP* value could still have some regions in which sprawl is high (e.g. Spain and Finland), and, conversely, a country that has a high overall sprawl value may have some regions in which sprawl is low (e.g. Germany and the United Kingdom). Therefore, the results on the levels of NUTS-2 regions and 1-km^2 cells are more detailed, more informative and more useful than the country-level results, because they reveal the variation in sprawl within each country. Nonetheless, the country-level results can indicate some general trends and give a first overall impression. Accordingly, the discussion of the results at the country level is brief, and the discussion is more detailed for the other two scales.

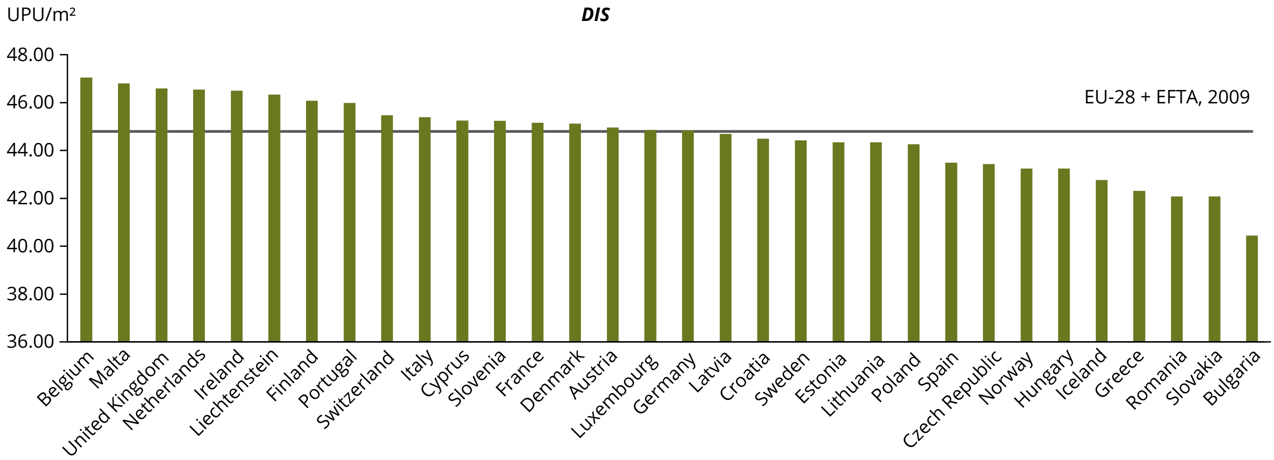
Large parts of Europe are affected by urban sprawl. The value of *WUP* for all of Europe (32 countries considered, i.e. EU-28 + 4) in 2009 was 1.64 UPU/m^2 (Figure 3.1). The urban sprawl values for Europe ranged from 0.1 to 6.6 UPU/m^2, with the lowest values for Iceland and the highest values for the Netherlands and Belgium. The other countries that were most affected by sprawl were Liechtenstein and Malta. Their sprawl values were > 5.5 UPU/m^2, that is more than threefold higher than the combined value for the 28 EU and four EFTA countries. The next most-affected group included Luxembourg and Germany, for which *WUP* was between 3.83 and 4.01 UPU/m^2, followed, more gradually according to *WUP* values, by the United Kingdom (3.18 UPU/m^2), then the other countries. The Balkan and Scandinavian countries were least affected by sprawl, along with other northern and south-eastern countries (excluding Malta and Cyprus).

Map 3.1 shows a hotspot of urban sprawl, formed by the Netherlands, Belgium, Germany and Luxembourg. In 2006, the level of sprawl in the Netherlands (6.40 UPU/m^2) was lower than in Belgium (6.48 UPU/m^2), as discussed in Section 3.2.1 below. In general, sprawl levels in Europe decline gradually from the central to the outer countries, with the exceptions of Portugal (2.33 UPU/m^2) and Malta (5.58 UPU/m^2), which have relatively high levels of sprawl. Only countries that are separated from the other European countries by the sea (i.e. Sweden, Norway, Cyprus and Malta) show abrupt differences in their sprawl values. Accordingly, the lowest sprawl values were found in Scandinavia (≤ 0.61 UPU/m^2) and the southern Balkan countries (< 1 UPU/m^2).

This pattern is, to some extent, reflected in the *PBA* values, which ranged from 0.29 % to 24.3 % (Figure 3.1). The highest *PBA* value of 24.3 % was found in Malta, and this is 64 % higher than the next highest value (14.8 % for the Netherlands) and more than sixfold

Figure 3.1 **Country-level values of weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*) in 2009**



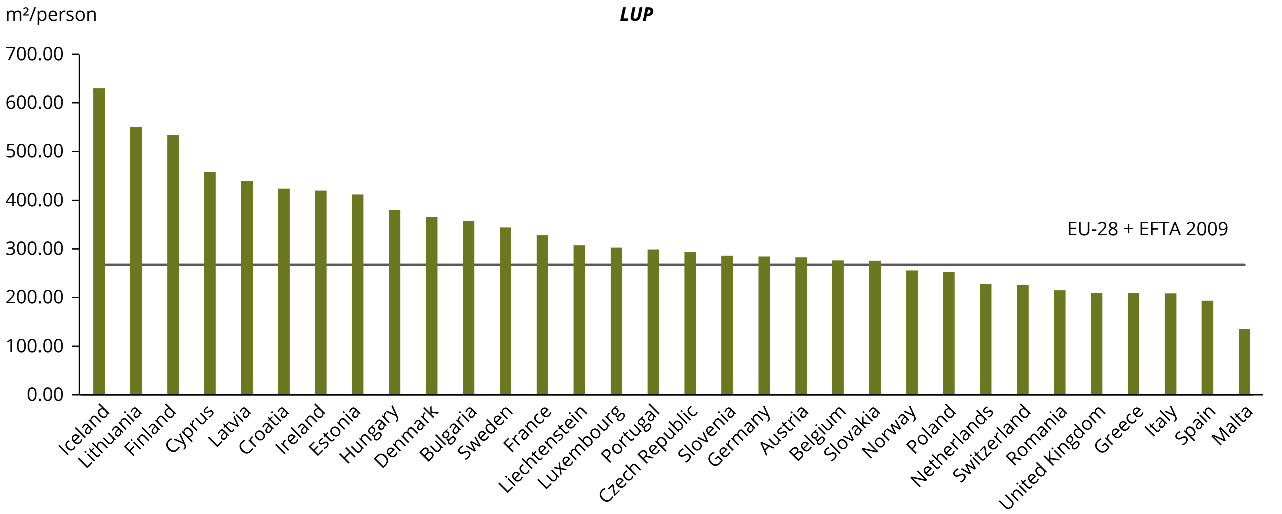


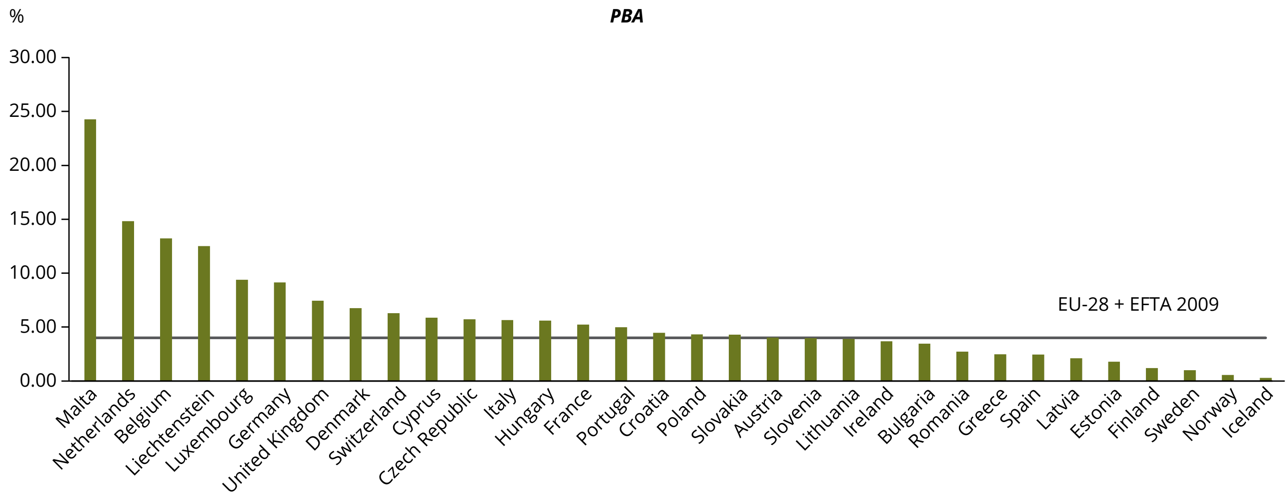
Note: The horizontal line indicates the overall value for Europe (EU-28 + 4). The countries are ordered (in all four parts) by decreasing values.

higher than for the 28 EU and four EFTA countries overall (4 %). As for *WUP*, Malta, the Netherlands, Belgium and Liechtenstein were the most highly built-up countries (*PBA* > 12 %), and, again, this group was followed by Luxembourg and Germany (*PBA* > 9%), for which the *PBA* value was 23 % larger than it was for the country with the next highest *PBA* value, namely the United Kingdom (7.45 %). The lowest value was observed for Iceland (0.29 %), for which the *PBA* was only 7 % of the overall European value. The similarities that are apparent from Figure 3.1 are also visible from Map 3.1: the region of high *PBA* values in the centre of Europe was, again, formed by the Netherlands, Belgium, Germany and Luxembourg. Towards the periphery, the *PBA* values decline. The Scandinavian countries, together with Estonia and Latvia, had the smallest *PBA* values. However, the most western and south-eastern parts of Europe also had relatively few built-up areas.

On the other hand, *DIS* and *LUP* show a different pattern (Figure 3.1). The variation in *DIS* (minimum of 40.44 UPU/m^2 in Bulgaria; maximum of 47.05 UPU/m^2 in Belgium) was much smaller than the variation in *WUP*. The value for the 28 EU and four EFTA countries combined was 44.8 UPU/m^2. Countries in eastern/

Figure 3.1 Country-level values of weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*) in 2009 (cont.)



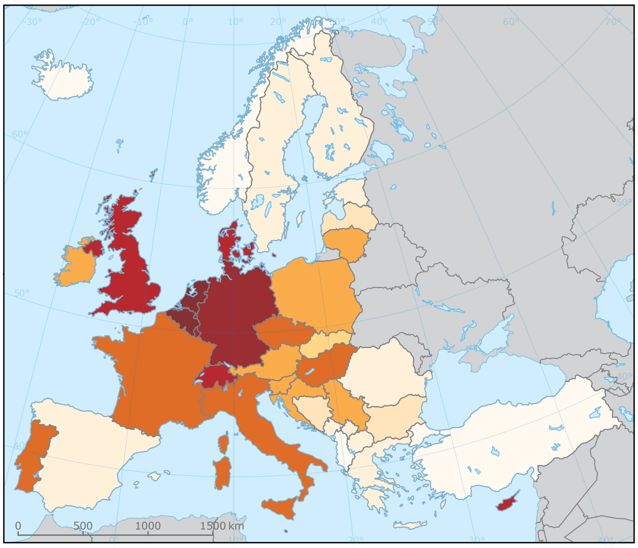


Note: The horizontal line indicates the overall value for Europe (EU-28 + 4). The countries are ordered (in all four parts) by decreasing values.

south-eastern parts of Europe, namely Slovakia, Romania, Bulgaria and Greece, have smaller *DIS* values than most of the rest of Europe, indicating that the built-up areas are more compact in these countries, which reflects the presence of many small and medium-sized towns. Some countries that neighbour each other had widely different *DIS* values (e.g. there is a much higher *DIS* in Portugal than in Spain).

The variation in *LUP* was large (Figure 3.1). For example, in Iceland (630 m² per inhabitant or job), 7.8-times more area was taken up per person than in Malta (136 m² per inhabitant or job). This variation mirrors cultural differences among the countries in Europe. Nonetheless, the overall value for the European countries (267.4 m² per inhabitant or job) can be explained by the fact that many people live alone or with a partner in individual apartments or houses. Although this may be related to ageing within the societies of Europe, the maps also suggest an additional explanation: most countries with larger *LUP* values are in northern Europe (e.g. Iceland, Finland, Estonia, Latvia, Lithuania and Ireland). All of these countries have a low population density and a cold climate with long and dark winters during which people

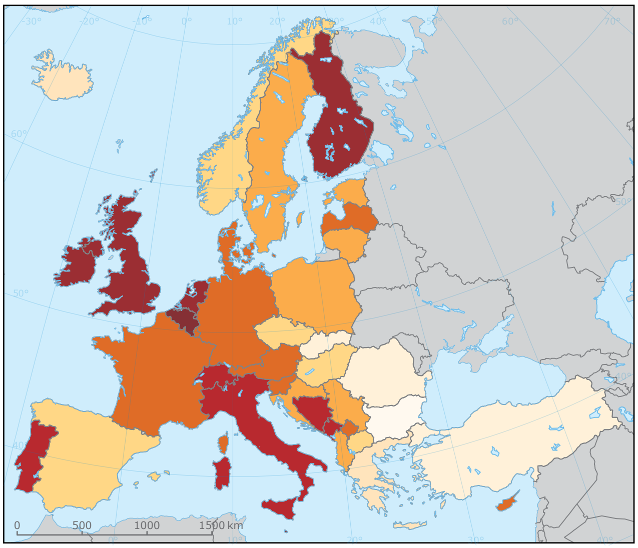
Map 3.1 **Maps of urban sprawl per country in 2009 for weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*)**



Weighted urban proliferation *(WUP)* per country, 2009

Urban permeation units per m²

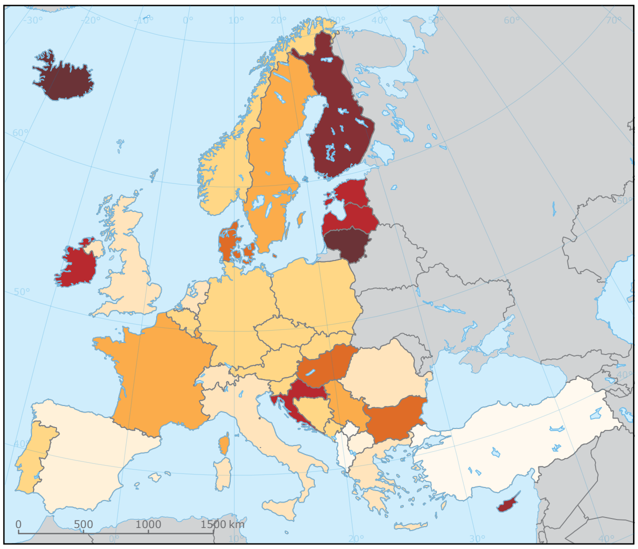
< 0.4; 0.4–0.8; 0.8–1.2; 1.2–1.6; 1.6–2.0; 2.0–2.4; 2.4–3.2; 3.2–4.3; 4.3–6.7; > 6.7; Outside coverage



Dispersion (*DIS*) of the built-up areas per country, 2009

Urban permeation units per m²

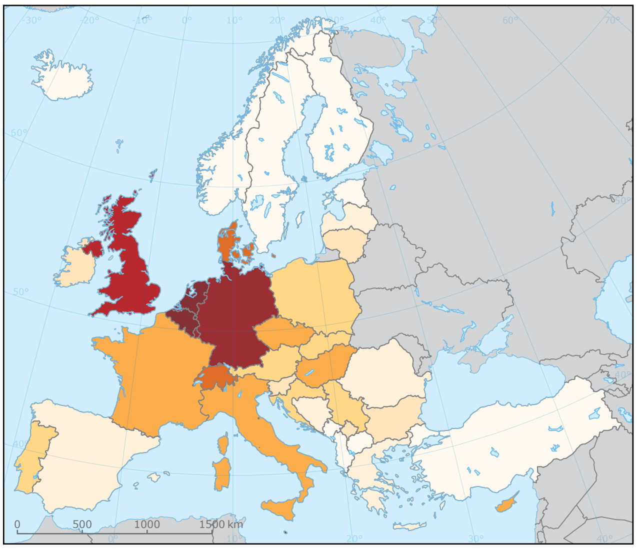
< 41.50; 41.50–42.25; 42.25–43.00; 43.00–43.75; 43.75–44.50; 44.50–45.25; 45.25–46.00; 46.00–46.75; 46.75–47.50; > 47.50; Outside coverage



Land uptake per person (*LUP*) per country, 2009

m² of built-up area per inhabitant or job

< 150; 150–200; 200–250; 250–300; 300–350; 350–400; 400–450; 450–500; 500–550; > 550; Outside coverage



Percentage of build-up areas (*PBA*) per country, 2009

Percentage

< 2; 2–3; 3–4; 4–5; 5–6; 6–7; 7–8; 8–11; 11–17; > 17; Outside coverage

spend a lot of time indoors. People may also wish to live further apart if space is abundant.

The following example illustrates how the three components of *WUP* interact. Belgium and the Netherlands are among the most densely populated countries in Europe, but they have different land property regimes and have followed different trajectories of urban development (Halleux et al., 2012). Both the level of *DIS* (47.05 UPU/m^2) and the *LUP* (276.3 m^2 per inhabitant or job) are higher in Belgium than in the Netherlands (46.54 UPU/m^2 and 227.6 m^2 per inhabitant or job, respectively). These significant differences are a result of differences in land-use planning, and are in good accordance with the higher degree of landscape fragmentation in Belgium (105.1 meshes per 1 000 km^2) than in the Netherlands (61.1 meshes per 1 000 km^2) (EEA and FOEN, 2011a). If the built-up areas in Belgium were as compact, or its *LUP* were as low, as in the Netherlands, the *WUP* value for Belgium would be significantly lower (i.e. 6.35 UPU/m^2 or 6.12 UPU/m^2, respectively) than its current value of 6.59 UPU/m^2. In the Netherlands, a considerable part of the land is owned by the state and the use of the land was planned in a more systematic way, based on a long tradition of planning, whereas Belgium is a federalist country and every municipality has planned its own land use in the absence of any regional planning tradition. The Netherlands has a polycentric urban structure in the Randstad region, which exhibits some concentration of the population in urban centres; in clear contrast, Belgium exhibits a disperse urbanisation pattern due to the continuous increase of relatively small urban centres in the countryside (Nijkamp and Goede, 2002). However, the *PBA* value for Belgium (13.2 %) is lower than for the Netherlands (14.8 %). Overall, this resulted in a slightly higher value of *WUP* for the Netherlands (6.61 UPU/m^2) than for Belgium (6.59 UPU/m^2) in 2009, while the inverse was true in 2006 (6.40 UPU/m^2 for the Netherlands and 6.48 UPU/m^2 for Belgium). Both countries have a heritage of urban sprawl, which illustrates the long-term consequences of a settlement structure: once such a structure has been established, the future continuation of sprawl is likely and there is a danger of a lock-in effect, that is the greater the extent of sprawl, the more difficult it becomes to reverse such trends.

3.1.2 Urban sprawl at the level of NUTS-2 regions

The patterns at the level of NUTS-2 regions are, to some degree, similar to those at the country level. However, they also show large variations *within* each country (Figure 3.2). In many countries, one or a few NUTS-2 regions exhibit very high values for the various metrics. In most cases, these regions are either regions that include the countries' capital cities (e.g. Helsinki in Finland, Lisbon in Portugal, Bucharest in Romania and Prague in the Czech Republic) or regions of particularly high economic importance (e.g. Upper Silesia in Poland, the Ruhr region in Germany, Zurich and Basel in Switzerland, and industrial regions around Merseyside and Cheshire in the United Kingdom) (Map 3.2). The large differences between the values for these regions and the other NUTS-2 regions of each country makes these regions stand out. Such regions contribute the most to a country's values, while the NUTS-2 regions that show only small variations contribute more or less equally.

For example, Finland, Hungary and Poland have a single NUTS-2 region that exhibits a high *WUP* value, while all other parts of these countries have much lower levels of sprawl. In contrast, Belgium, the Netherlands, France, Germany and the United Kingdom exhibit a more even distribution of *WUP* values and, accordingly, are considerably affected by urban sprawl throughout. The most highly sprawled NUTS-2 regions are located in the United Kingdom (Merseyside (UKD7), the West Midlands (UKG3), Greater Manchester (UKD3), Outer London (UKI2) and West Yorkshire (UKE4); all of which have values of > 10 UPU/m^2); and Germany (Bremen (DE50), Hamburg (DE60) and Düsseldorf (DEA1); all of which have values of > 10 UPU/m^2), which have very different planning systems. The next most highly sprawled regions are the Antwerp province (BE21), Lisbon (PT17) and Limburg (NL42), all of which also have values of > 10 UPU/m^2; there is a highly sprawled core region in the most central part of Europe, which is more clearly visible on the maps of NUTS-2 regions than on the maps of countries, while the most northern and south-eastern regions of Europe are the least sprawled (Map 3.2). The Scandinavian countries are affected by sprawl in only their most southern parts, while most parts of these countries are not affected. Similarly, many NUTS-2 regions in Spain exhibit little sprawl; however, the coastal regions are significantly more sprawled than the interior parts. Finally, Inner London (UKI1), Northern Norway (NO07), Pohjois-ja Itä-Suomi (FI1D), Brussels (BE10), Iceland (IS00) and Övre Norrland (SE33) and Mellersta Norrland (SE32) have the lowest sprawl values (< 0.2 UPU/m^2). Inner London and Brussels are densely built up (*PBA* > 66%) and have very low *LUP* values (*LUP* < 65 m^2 per inhabitant or job). This indicates that the built-up areas of these regions are very well used by their citizens and employees, and, consequently, there is no sprawl.

The NUTS-2 region of Madrid (ES30) has a high *DIS* value (46.4 UPU/m^2), but *LUP* is low (88.5 m^2 per inhabitant or job), and, therefore, *WUP* is low (0.33 UPU/m^2). Certain parts of Spain are sprawled, mostly along the coast, but the corresponding NUTS-2 regions also include large amounts of land that are further inland and have few built-up areas and, therefore, the *WUP* values for these NUTS-2 regions remain relatively low (all < 3.2 UPU/m^2). Therefore, smaller reporting units are needed to detect regions of high sprawl in Spain (see Section 3.1.3). Another example of this is given by the Midi-Pyrénées region (FR62) of France. Although there is a highly sprawled city (Toulouse) in this region, the value of *WUP* is only 1.47 UPU/m^2, because FR62 is a large NUTS-2 region (larger than Denmark) and includes many rural areas with low population densities. However, *LUP* (363.3 m^2 per inhabitant or job) and *DIS* (45.5 UPU/m^2) values are high throughout this NUTS-2 region.

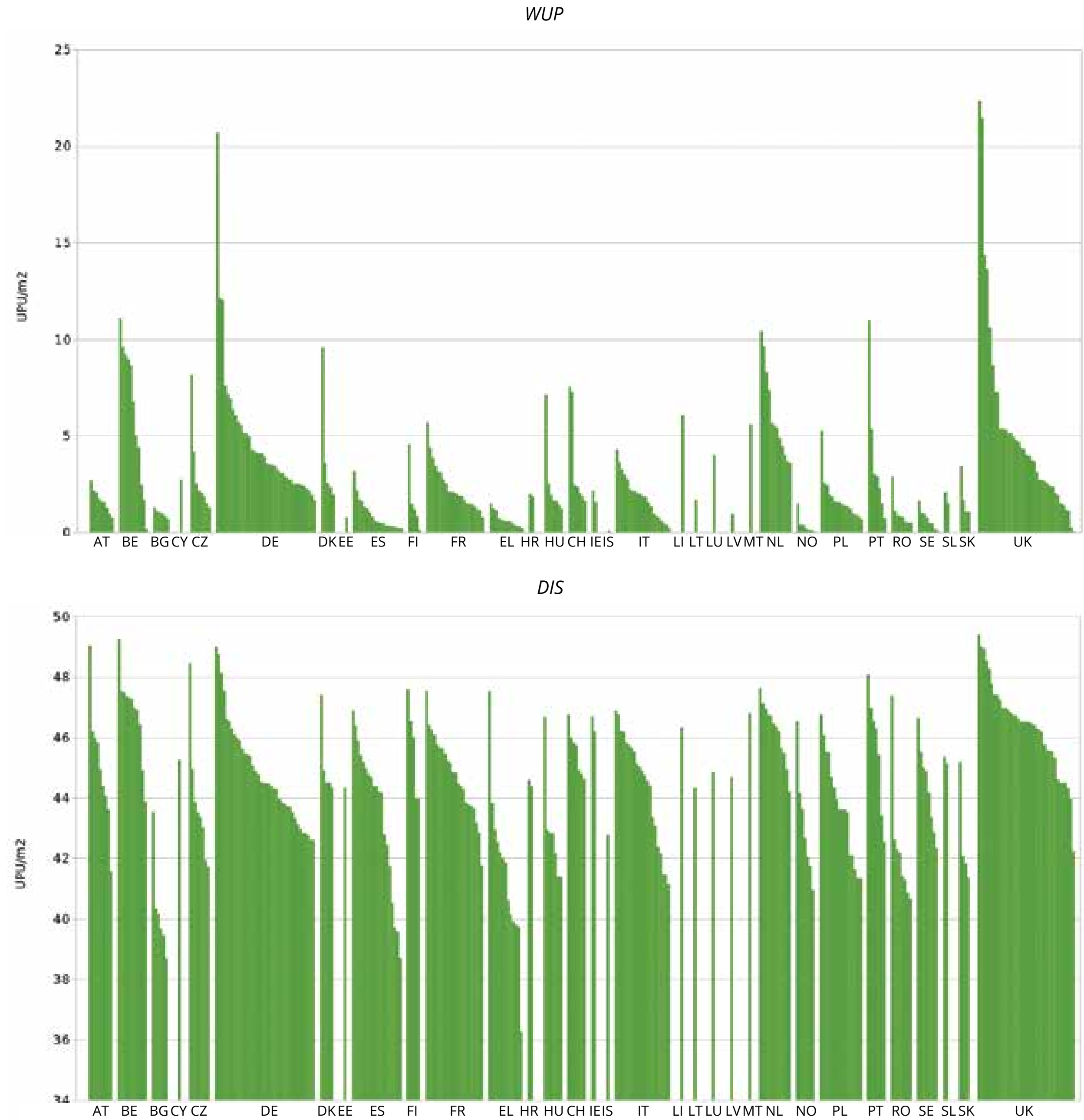
The results for the *PBA* values resemble those for *WUP* in some respects. However, the situation is different in the sense that the regions with the highest *PBA* values are found in the United Kingdom (several regions), followed by NUTS-2 regions in Belgium, Spain, Germany and Austria. In many countries, there are one or two NUTS-2 regions that are very heavily built up. These mostly include capital cities or economically important regions, for example Inner London (UKI1), Outer London (UKI2), Brussels (BE10), Melilla (ES64), the West Midlands (UKG3), Berlin (DE30), Vienna (AT13), Merseyside (UKD7), Prague (CZ01), Bremen (DE50) and Hamburg (DE60), all of which have *PBA* values of > 45 % (Map 3.2). In almost all countries, there are one or two prominent NUTS-2 regions with very high *PBA* values. Only in Bulgaria, the Netherlands and Italy are *PBA* values more evenly distributed among all regions. In particular, in Bulgaria, the NUTS-2 region that includes the capital city has a *PBA* value that is similar to the *PBA* values for all other Bulgarian NUTS-2 regions. By contrast, the Scandinavian NUTS-2 regions, particularly the northern regions, and the south-eastern parts of Europe have small *PBA* values. Only the southern regions of the Scandinavian countries are highly built up, while there are almost no built-up areas towards the northern parts. A similar gradient can be seen in Austria (in this case, a decline in built-up areas from east to west), in which the NUTS-2 region that includes the capital city has the largest built-up area. In Romania, the *PBA* values also decline with increasing distance from the capital city, as the cities become smaller and the population density decreases. An interesting pattern is apparent within Spain: the coastal regions and the NUTS-2 region in the centre of Spain (which includes Madrid) have high *PBA* values, while the regions in between have much lower *PBA* values.

In contrast to the patterns for *WUP* and *PBA*, *DIS* shows less extreme differences within the United Kingdom, Germany, France, Italy, Switzerland, the Netherlands, Poland, Portugal and Sweden (Figure 3.2). Among the countries with a large variation in *DIS* are Greece and Spain. The highest *DIS* values are always found in the capital cities (e.g. Lisbon, Helsinki, Bucharest, Paris and Berlin) and the economically important regions (e.g. Zurich, Upper Silesia in Poland, the Ruhr region of Germany and the Midlands in the United Kingdom; see Map 3.2). In Spain, higher *DIS* values are found along the Spanish coast and in the capital region than are found in the NUTS-2 regions surrounding the capital. This is in accordance with the economic importance of the coastal regions (related to tourism) and the capital region of Spain. In eastern Europe, the Romanian, Bulgarian and Greek NUTS-2 regions form an arc of low *DIS* values along the coast, even though these are also important coastal regions in terms of tourism and history. In the far north, the low *DIS* values for the NUTS-2 regions of the Scandinavian countries can be related to the harsh climatic conditions of the north; in such regions, built-up areas are more compact or there are more than 2 km between them.

Land uptake per person varies considerably within most countries (e.g. Germany, France, Austria, the United Kingdom and Belgium; see Figure 3.2). Only a few countries (e.g. Italy and Poland) present a relatively balanced per capita land uptake among their NUTS-2 regions. The Scandinavian NUTS-2 regions clearly have a leading position in *LUP*. Finland has the NUTS-2 regions with the highest values, followed by Sweden, Ireland, Iceland, Portugal and Lithuania. These observations are in line with the country-level observations. In France, almost all NUTS-2 regions have high *LUP* values (> 300 m^2 per inhabitant or job). Together with those in Hungary, these values are among the highest in Europe. The only exception is Paris (in the Île de France region), which has a much lower *LUP* value (124 m^2 per inhabitant or job). In the NUTS-2 regions of Switzerland, Italy and Romania, the highest *LUP* values are lower than they are in other countries, that is, these countries have consistently lower *LUP* values than the other European countries (excluding Malta). Spain has the steepest slope with regard to the distribution of its *LUP* values, that is Spain has a wide and continuous range of *LUP* values. Italy and the United Kingdom exhibit a similar S-shaped distribution of their *LUP* values, that is there is a more even distribution of *LUP* values in the middle of the range. In the main, the lowest *LUP* values are observed for capital cities (e.g. Inner London, Brussels, Madrid, Vienna, Berlin, Vienna, Prague, Bucharest, Paris and Stockholm, all of which have *LUP* values of < 126 m^2 per inhabitant or job) and other small NUTS-2 regions that are cities (e.g. Hamburg, which has a *LUP* value of 133 m^2 per inhabitant or job) (Figure 3.2).

The interpretations of differences in the *WUP* values and their components among different regions should take into account that areas in which it is impossible to construct buildings (i.e. irreclaimable areas) may have been included in the analyses. If a study area contains a large number of such areas, such as bodies of water, glaciers, cliffs or steep slopes, the *WUP* values will be relatively low. For a comparison of regions with few or no areas of this kind, it is useful to re-calculate the *WUP* values for only areas in which construction is possible. These re-calculated values are presented in Annex A3 for all countries and NUTS-2 regions.

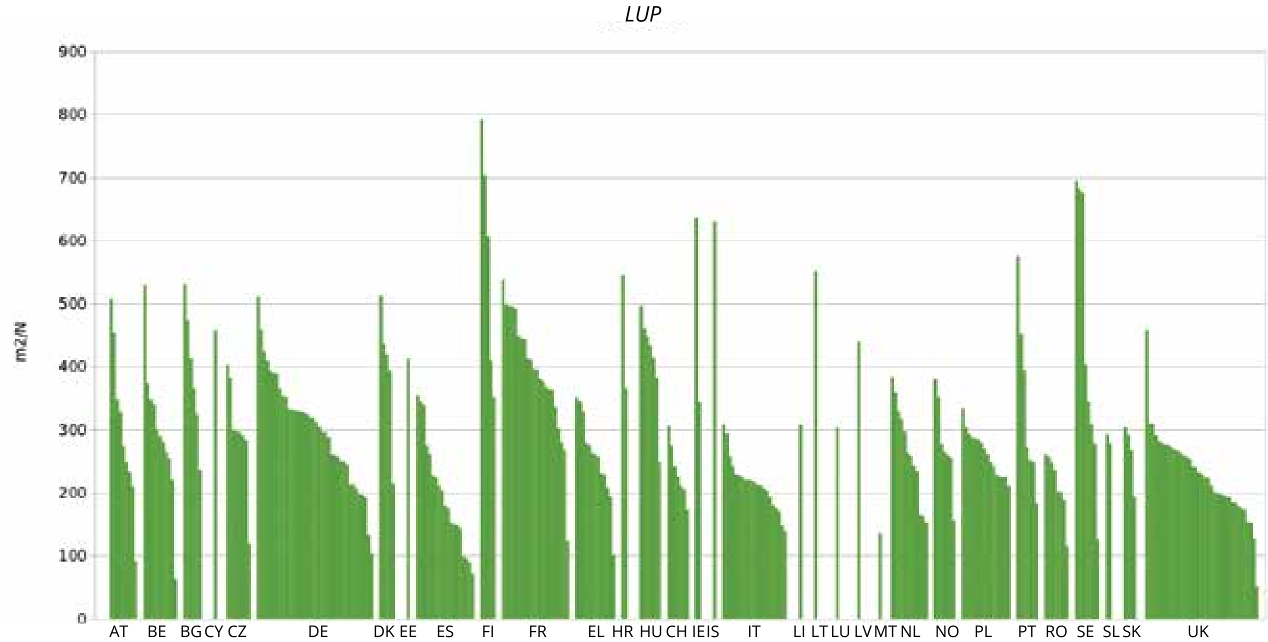
Figure 3.2 Values of weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*), and percentage of built-up area (*PBA*) in 2009 per NUTS-2 region

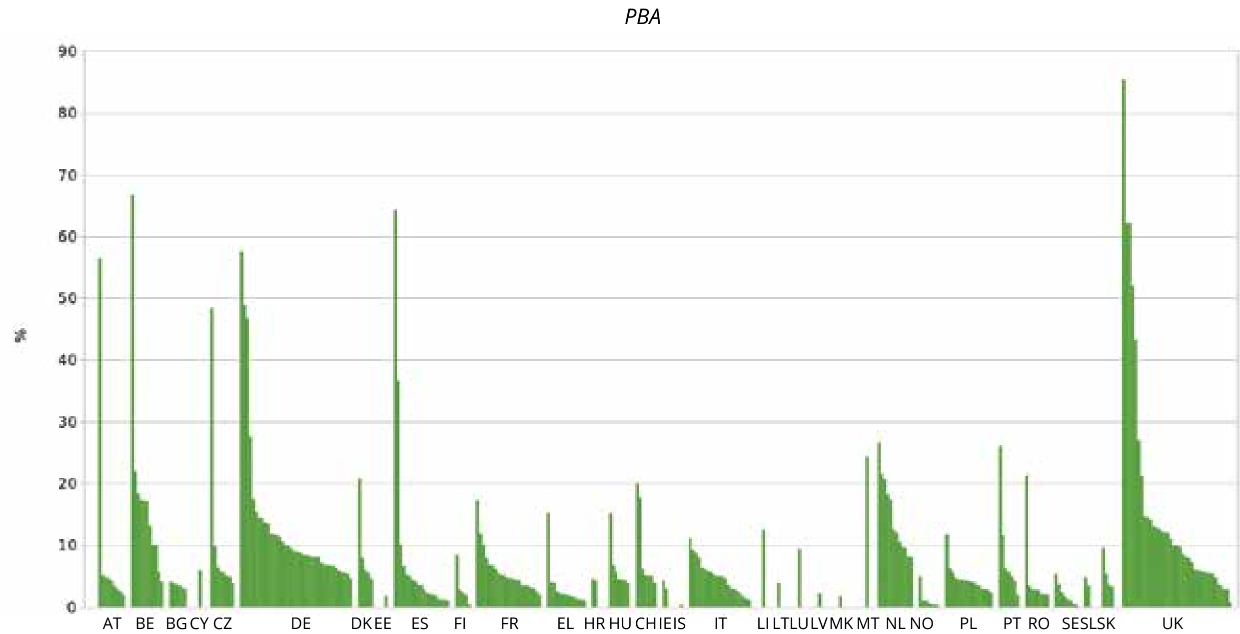


Note: The NUTS-2 regions are ordered by country and by decreasing value of the corresponding metric within each country.

AT, Austria; BE, Belgium; BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; FR, France; EL, Greece; HR, Croatia; CH, Switzerland; HU, Hungary; IE, Ireland; IS, Iceland; IT, Italy; LI, Liechtenstein; LT, Lithuania; LU, Luxembourg; LV, Latvia; MT, Malta; NL, Netherlands; NO, Norway; PL, Poland; PT, Portugal; RO, Romania; SE, Sweden; SI, Slovenia; SK, Slovakia; UK, United Kingdom.

Figure 3.2 Values of weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*), and percentage of built-up area (*PBA*) in 2009 per NUTS-2 region (cont.)

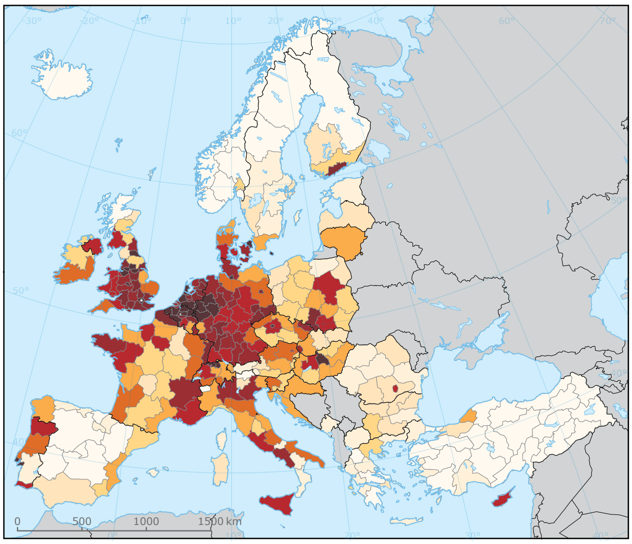




Note: The NUTS-2 regions are ordered by country and by decreasing value of the corresponding metric within each country.

AT, Austria; BE, Belgium; BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; FR, France; EL, Greece; HR, Croatia; CH, Switzerland; HU, Hungary; IE, Ireland; IS, Iceland; IT, Italy; LI, Liechtenstein; LT, Lithuania; LU, Luxembourg; LV, Latvia; MT, Malta; NL, Netherlands; NO, Norway; PL, Poland; PT, Portugal; RO, Romania; SE, Sweden; SI, Slovenia; SK, Slovakia; UK, United Kingdom.

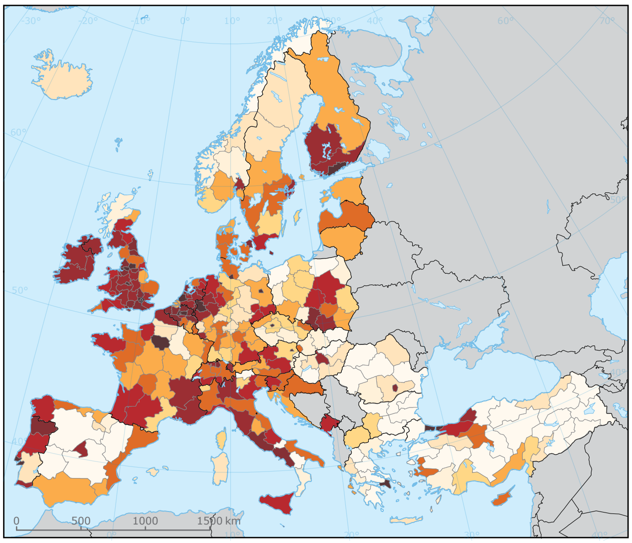
Map 3.2 **Maps of urban sprawl per NUTS-2 region in 2009 for weighted urban proliferation (*WUP*), dispersion of the built-up areas (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*)**



Weighted urban proliferation (*WUP*) per NUTS–2 region level, 2009

Urban permeation units per m²

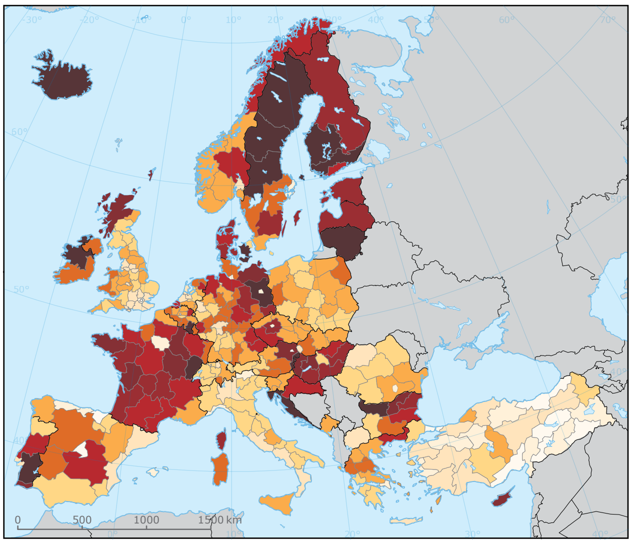
< 0.4, 0.4–0.8, 0.8–1.2, 1.2–1.6, 1.6–2.0, 2.0–2.4, 2.4–3.2, 3.2–4.3, 4.3–6.7, > 6.7, Outside coverage



Dispersion (*DIS*) of the built-up areas per NUTS–2 region level, 2009

Urban permeation units per m²

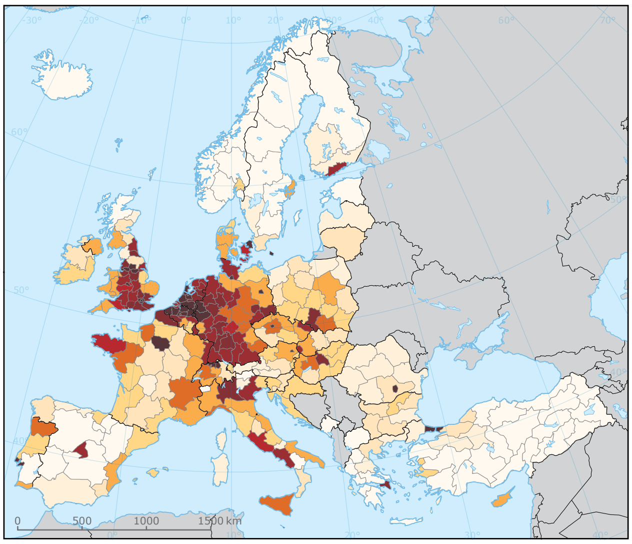
< 41.50, 41.50–42.25, 42.25–43.00, 43.00–43.75, 43.75–44.50, 44.50–45.25, 45.25–46.00, 46.00–46.75, 46.75–47.50, > 47.50, Outside coverage



Land uptake per person (*LUP*) per NUTS–2 region level, 2009

m² per number of inhabitant and jobs in built-up areas

< 100, 100–150, 150–200, 200–250, 250–300, 300–350, 350–400, 400–450, 450–500, > 500, Outside coverage



Percentage of built-up areas (*PBA*) per NUTS–2 region level, 2009

Percentage

< 2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–8, 8–11, 11–17, > 17, Outside coverage

3.1.3 Urban sprawl at the 1-km^2-grid level

Patterns related to the network of cities and large transport corridors are visible from the maps of the 1-km^2 grid (Map 3.3). Polycentric and monocentric parts of Europe are visible on these maps as well. Sprawl is mostly found around city centres, along large transport corridors and along many coastlines. It is much lower in most rural areas because of relatively low *PBA* and *DIS* values, and in city cores, such as the centre of Paris, because of low *LUP* values (Map 3.4b). Sprawl along coasts is observed in many places, for example along the Côte d'Azur (the French Riviera). Such places are often important centres of tourism. Many fluvial corridors are visible as being highly affected by sprawl, such as the corridors along the river Rhine (north of Basel and all the way to Mannheim, Cologne, Düsseldorf and the Netherlands) and the river Rhône (south of Lyon and all the way to Arles). In northern Italy, sprawl is highly prevalent in the Po Plain, whereas in the Alps, sprawl is observed along valley floors (Map 3.3). The highly sprawled cities are clearly visible at this scale. For example, Toulouse in the south of France, not far from the border with Spain, can be clearly observed as an area of high sprawl. The area of low sprawl in the city core of Toulouse is much smaller than the area of low sprawl in Paris. Along the most southern coast of Spain, the area between Almeria and Adra is a large continuous area of high sprawl. Significant parts of this area are covered by greenhouses (however, see Annex A3 on some data limitations regarding the detection of changes in areas covered by greenhouses). Further examples are shown in Maps 3.4a–f. Annex 4 provides the maps of *DIS*, *LUP* and *PBA* for all of Europe.

Barcelona has a relatively large core in which there is no sprawl; however, the coastlines to the south-west and the east of central Barcelona are highly sprawled (Map 3.4a), as is the region north of the centre between Sabadell and Granollers, and along the Autopista de la Mediterrània (E15). A large area of low sprawl is also found in the centre of Paris (Map 3.4b), but it is surrounded by a wide ring of sprawl that extends far into the countryside along several important transport corridors.

Map 3.4c clearly shows the polycentric structure of urban sprawl in the Benelux countries and western Germany. Both Amsterdam (centre north) and Brussels (centre south) have rather large cores of low sprawl. The largest area of continuously high urban sprawl is the Ruhr region in Germany (on the right-hand side of the centre).

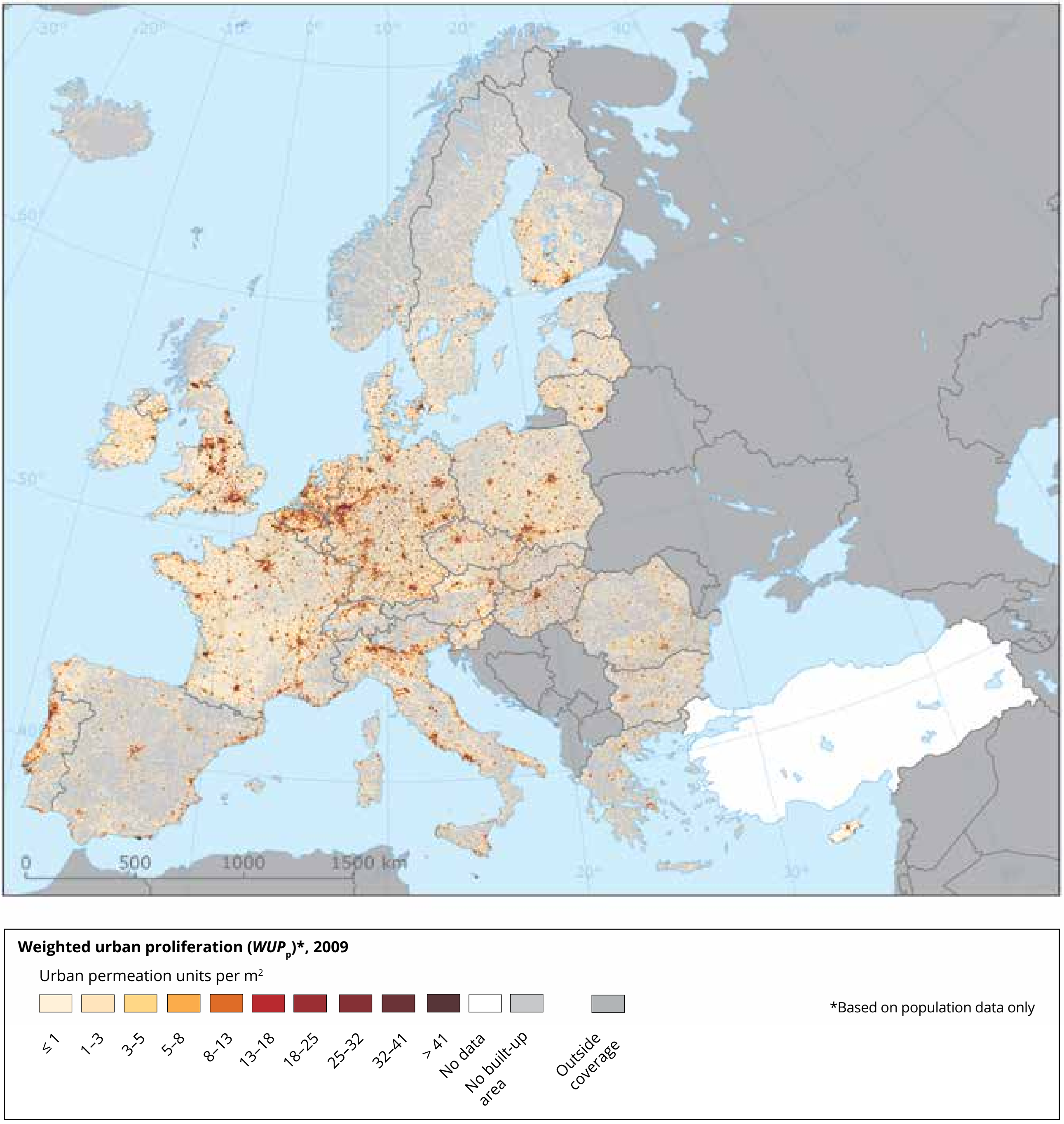
In contrast to many other large cities, there are few cells of low sprawl in Dublin (Map 3.4d). Two transport corridors (routes M4 and E20) around Dublin stand out as being accompanied by high levels of urban sprawl (Map 3.4d). Helsinki also exhibits only a few cells of low sprawl in the city centre (Map 3.4e); land uptake is relatively high throughout the city. One major axis of high sprawl values extends to the north of Helsinki along motorway E12 to Hyvinkää and Hämeenlinna (Map 3.4e). In Poland, Warsaw shows several bands, rather than a ring, of high urban sprawl, which project outwards from the city centre, and many scattered cells of low WUP_p (*WUP* based on population data only (not job data), that is, per inhabitant only) values in the city core (Map 3.4f).

In London, the built-up areas form an ellipse (with a diameter of approximately 30–50 km), and various towns with high *PBA* values are found in the vicinity (Map 3.5b). In the central parts of London, which are densely built up, *DIS* values are high (48–51 UPU/m^2) and do not vary much. In contrast, there is a large variability in *DIS* in the areas surrounding London, with intermediate values in town centres, surrounded by rings of very high values along town peripheries. Low values of *DIS* (< 33 UPU/m^2) are found only in the countryside. Land uptake per inhabitant is low in the core of London, and it increases with increasing distance from the city centre (Map 3.5d). Together, these variables explain the WUP_p values (Map 3.5a), that is there is an area of no sprawl in the city centre, which is surrounded by a ring of high urban sprawl. However, some areas within the city core do have high WUP_p values because there are few inhabitants and the places of work that are located in such areas were not taken into account in the calculations of WUP_p and LUP_p (because these data were not available). Most of these locations in the city core would exhibit very low *WUP* values if the number of jobs in these locations were included. Urban sprawl gradually declines as the distance from the city centre increases, but remains high along the transport corridors that connect London with other towns and with regions along the southern coast, in which sprawl values are also very high. Further similar examples are provided in Annex 4.

One of the advantages of using the 1-km^2 scale is that it corresponds much better than NUTS-2 regions to people's everyday perception of their environment, and their ability to identify problematic areas of urban sprawl. It also corresponds more closely with the scale used for policymaking for urban areas. Accordingly, this scale is useful for neighbourhood planning and for the placement of new designated building zones. Temporal changes are also identified more easily from the 1-km^2 grid, because even a few new buildings or changes in the numbers of inhabitants or jobs can have a measurable effect at this scale (which may not always be the case for the NUTS-2 region scale).

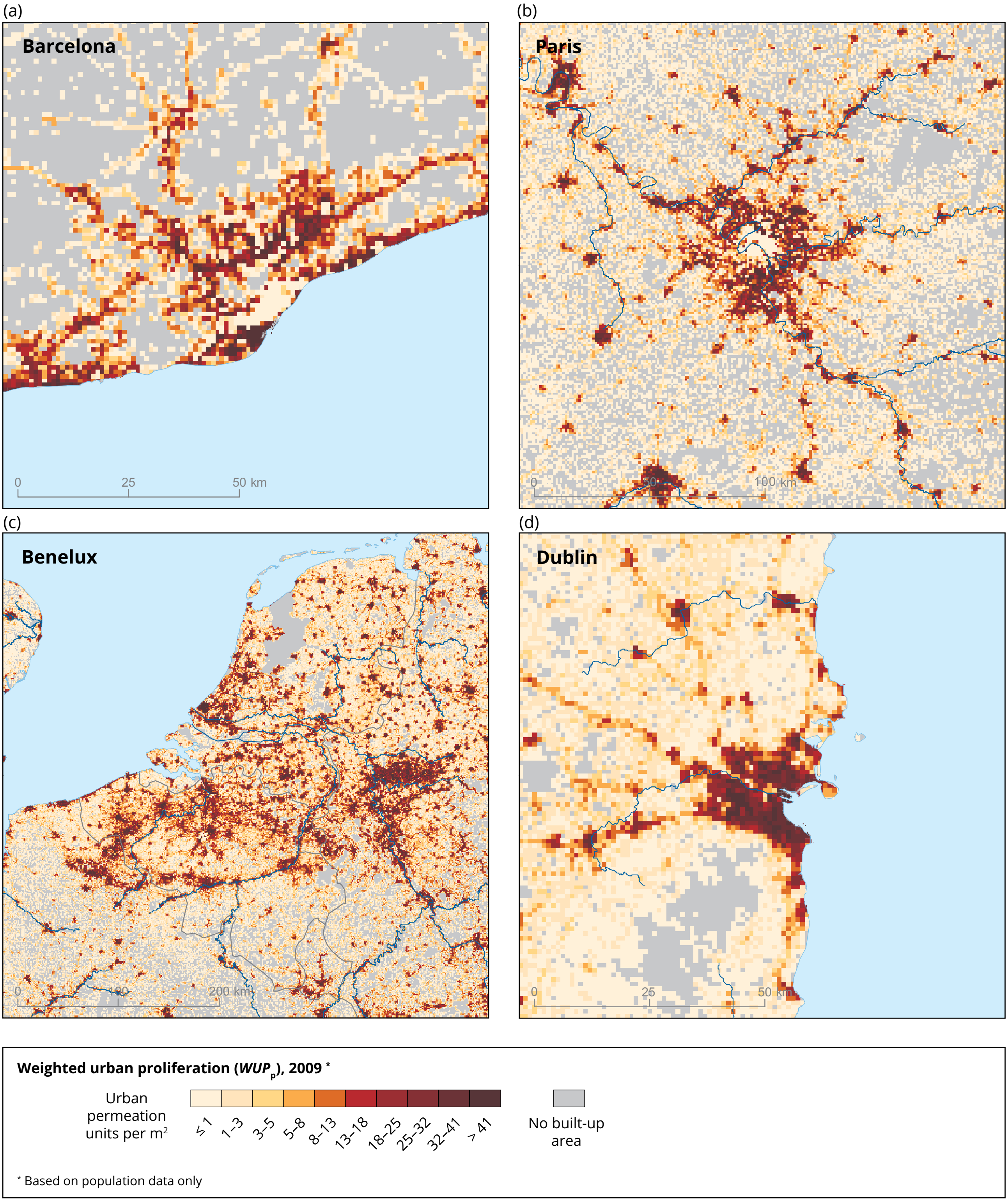
However, a disadvantage of using the 1-km²-grid scale is that job data may not be available, which is the case for Europe as a whole on this scale (WUP_p and LUP_p are based on only inhabitant data). There are two possible ways of solving this problem: (1) job data on a scale that is between the NUTS-2 and the 1-km²-grid scales (e.g. for municipalities) could be used, if such job data are available; or (2) the jobs from the NUTS-2 regions could be distributed into the 1-km²-grid cells based on remote sensing data (e.g. light emissions) and information from regional planning maps (e.g. zoning information). Even for cases in which data regarding the number of jobs are unavailable, the *WUP* method is still highly informative because the largest contribution to sprawl comes from residential areas in most cases, in which there are almost no jobs (e.g. in Switzerland, 51.2 % of sprawl is residential, 15.4 % is commercial/industrial, 32.8 % is mixed zone sprawl

Map 3.3 Urban sprawl in Europe on the 1-km² scale in 2009 (based on WUP_p values)

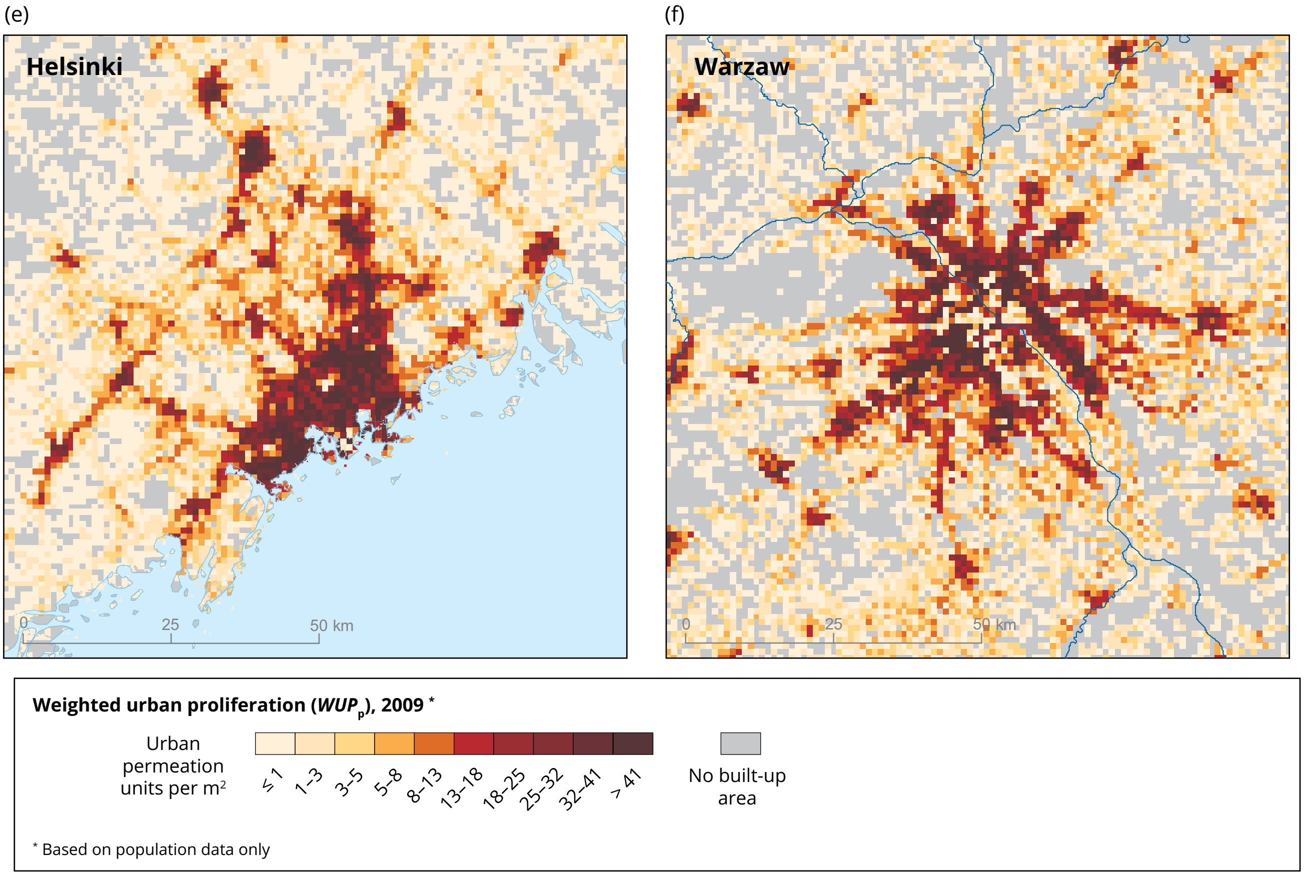


Note: WUP_p, weighted urban proliferation based on population data only (not job data), that is, per inhabitant only.

Map 3.4 **Six examples of urban sprawl at the 1-km² scale in 2009 (*WUP*$_p$): (a) Barcelona and the surrounding coasts, (b) Paris, (c) the Benelux countries, (d) Dublin, (e) Helsinki and (f) Warsaw**



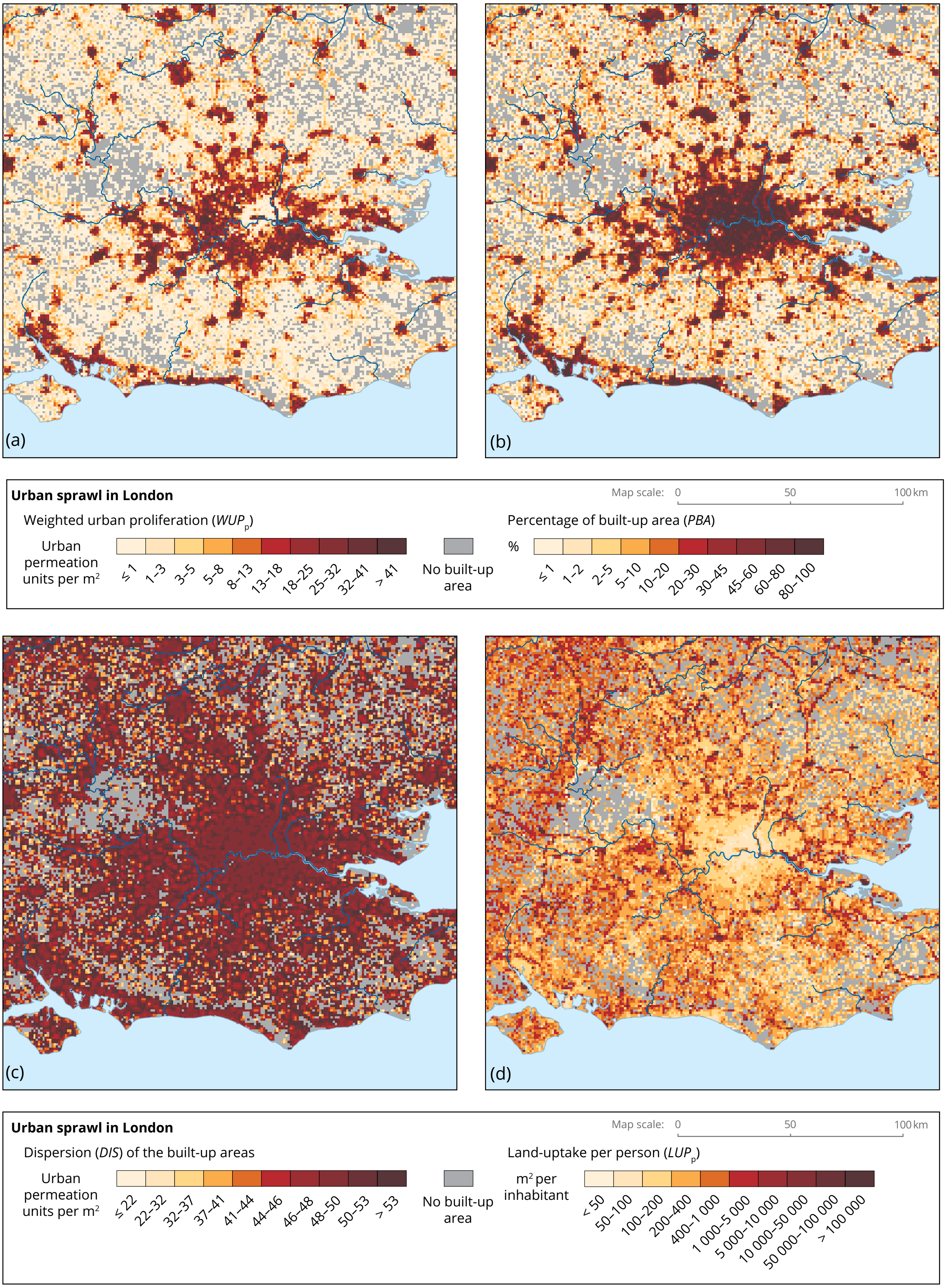
Map 3.4 **Six examples of urban sprawl at the 1-km² scale in 2009 (*WUP*$_p$): (a) Barcelona and the surrounding coasts, (b) Paris, (c) the Benelux countries, (d) Dublin, (e) Helsinki and (f) Warsaw (cont.)**



and 0.7 % results from recreation/tourism). Therefore, larger regions are comparable even without job data because the ratio between inhabitants and jobs exhibits less variability in larger regions, and issues due to the lack of job data become relevant at only a higher resolution (e.g. for the 1-km² grid and in town centres).

These results are in general agreement with studies published by the EEA (2006b) and Siedentop and Fina (2012), as well as with the results from regional studies, which show that there are low levels of sprawl in the Scandinavian countries and in the hinterlands of Spain, and high levels of sprawl in the Benelux countries, western Germany, the central and southern regions of England, and along the coast of the western Mediterranean sea. However, there are also some substantial differences in the results for some countries, because of the differences in the data layers used for the identification of built-up areas. Siedentop and Fina (2012) used CLC data for 1990, 2000 and 2006 with a resolution of 25 ha, while the HRL IMD layer has a resolution of 0.04 ha. These differences are most pronounced in regions that have a dispersed settlement structure (see Annex 4 for more detailed information).

Map 3.5 **Urban sprawl in London on the 1-km² scale in 2009: WUP_p and its three components *PBA*, *DIS* and LUP_p**



3.2 Change in urban sprawl between 2006 and 2009

We compared the results for *WUP* and its components between 2006 and 2009 in order to estimate how fast urban sprawl changed during this period at all three scales (i.e. at the country level, the NUTS-2 region level and the 1-km^2-grid level). Since this period was only 3 years, the estimated rates of change may not be representative of any changes before 2006 or after 2009 in all cases, but they still provide a useful first indication of the overall magnitude of the rates of increase or decrease in sprawl in Europe.

The larger the reporting units used, the less variability is observed in *WUP* values because the values of a group of smaller reporting units combined can never be more extreme than the individual values of the smaller reporting units. This is also true for the changes; e.g. there is less variability in the changes in *WUP* values among the countries than among the NUTS-2 regions, and the interpretation of the *WUP* values should take this into account.

3.2.1 Changes in urban sprawl at the country level

Urban sprawl increased in all countries (Figure 3.3) between 2006 and 2009. The overall increase was 0.08 UPU/m^2 (i.e. 5 %), from 1.56 to 1.64 UPU/m^2, or 1.65 % per year. The largest absolute increases were observed for Malta (+ 1.44 UPU/m^2), Liechtenstein (+ 0.59 UPU/m^2) and Cyprus (+ 0.25 UPU/m^2), while Malta (+ 35 %), Sweden (+ 23 %) and Spain (+ 16 %) showed the largest relative increases. The smallest absolute increases occurred in Iceland, Finland, Norway and Latvia (< 0.04 UPU/m^2). Even in Belgium and the Netherlands, the two most sprawled countries in Europe, urban sprawl still increased by more than 0.1 and 0.2 UPU/m^2, respectively (i.e. more than 1.6 % and 3.2 %, respectively) from 2006 to 2009. Considering the relative increases in northern, southern, eastern and western Europe separately, the largest increases in sprawl in northern Europe occurred in Norway and Sweden (> 17 %), the largest increase in south-eastern Europe occurred in Slovenia (+ 13 %) and, in the west, the largest increase in sprawl occurred in Spain (+ 16 %).

Among the largest countries, namely Germany (+ 0.09 UPU/m^2, + 2.4 %), France (+ 0.07 UPU/m^2, + 2.9 %), the United Kingdom (+ 0.11 UPU/m^2, + 3.6 %) and Poland (+ 0.07 UPU/m^2, + 4.6 %), the value of *WUP* increased most in the United Kingdom in absolute terms and most in Poland in relative terms. The increases in sprawl in Italy (+ 0.14 UPU/m^2, + 7 %), Austria (+ 0.09 UPU/m^2, + 5.6 %), Croatia (+ 0.12 UPU/m^2, + 6.6 %), Serbia (+ 0.11 UPU/m^2, + 7.2 %), Slovakia (+ 0.12 UPU/m^2, + 9.4 %) and Portugal (+ 0.13 UPU/m^2, + 5.8 %) were higher than the European average in both absolute and relative terms.

In terms of absolute changes in *PBA*, the largest increase occurred in Malta (+ 2.14 percentage points), followed by Liechtenstein (+ 0.88 percentage points) and Cyprus (+ 0.53 percentage points); the European average (EU-28 + 4) is + 0.14 percentage points. The situation is quite different in terms of relative changes: the largest relative changes in *PBA* occurred in Sweden (+ 18.9 %) and Norway (+ 12.3 %), followed by Cyprus (+ 9.9 %), Malta (+ 9.7 %) and Slovenia (+9.6 %). Relative changes in *PBA* above the European average of + 3.7 % also occurred in Spain (+ 7.4 %), Slovakia (+ 5.7 %), Croatia (+ 5.7 %), Estonia (+ 5.1 %), Greece (+ 4.9 %), Portugal (+ 4.6 %), Austria (+ 4.6), Ireland (+ 4.6 %), Italy (+ 4.6 %), Luxembourg (+ 4.2 %), Bulgaria (+ 4 %) and Switzerland (+ 3.8 %).

For *DIS* and *LUP*, the patterns of absolute and relative changes are similar. The largest increases in *DIS*, from 2006 to 2009, occurred in Liechtenstein, Spain and Slovakia (absolute change: > 0.2 UPU/m^2; relative change: > 0.5 %); significant increases were also observed in Norway, Greece, the Czech Republic, Ireland, Poland, Romania, Sweden and Slovenia (absolute change: > 0.08 UPU/m^2; relative change: ≥ 0.19 %). A decrease in *DIS* occurred in only four countries (Iceland, Finland, Portugal and Cyprus), that is, in these countries, newly built-up areas were constructed in a way that resulted in a slightly more compact spatial arrangement overall (at the scale of analysis of 2 km). The *DIS* value for Iceland (42.8 UPU/m^2 in 2009) was considerably below the European average (44.8 UPU/m^2) in 2009, and among all the countries below the average value, Iceland was the only country in which *DIS* decreased. The *DIS* values for Finland, Portugal and Cyprus were clearly above the European average.

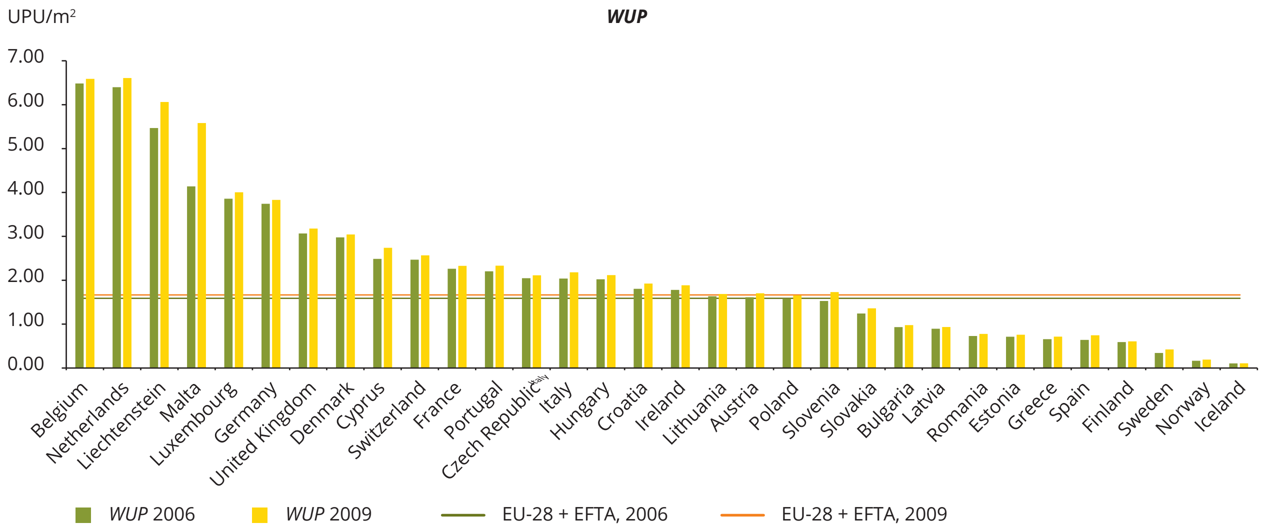
Similarly, *LUP* declined in only three countries, namely Luxembourg (– 14 m^2 per person), Belgium (– 2.4 m^2 per person) and Switzerland (– 0.2 m^2 per person), which indicates that densification occurred in these countries between 2006 and 2009. In relative terms, the largest increases in *LUP* were observed in Sweden, Latvia, Slovenia and Estonia (> 9 %), while, in absolute terms, the largest increases occurred also in Lithuania and Croatia (> 24 m^2 per person). High increases were also observed for Spain, Ireland, Hungary, Portugal, Norway, Cyprus, Liechtenstein and Slovakia (> 10 m^2 per person).

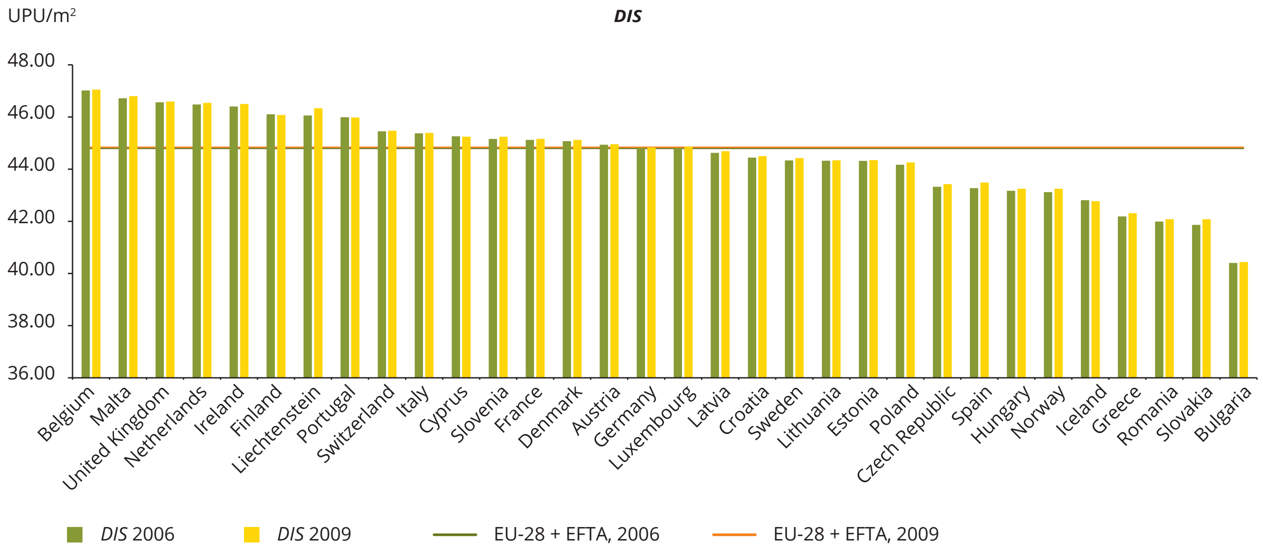
Given that *WUP* is a combination of *DIS*, *PBA* and *LUP*, an analysis of the relative contributions of these three components to *WUP*, and the potential reasons for the observed changes, is interesting for each country (also at the scales of NUTS-2 regions and 1-km^2 grid).

We give some examples from the most affected countries.

In Spain, the increase in *WUP* (+ 16.3 %) between 2006 and 2009 was mostly caused by increases in *PBA* (7.4 %) and *LUP* (6 % increase in $w_2(LUP)$), and to a lesser degree by the increase in *DIS* (+ 2.2 % increase in $DIS \times w_1(DIS)$). In contrast, the dominant contributions to the increases in *WUP* that occurred in France, Germany, the United Kingdom and Ireland

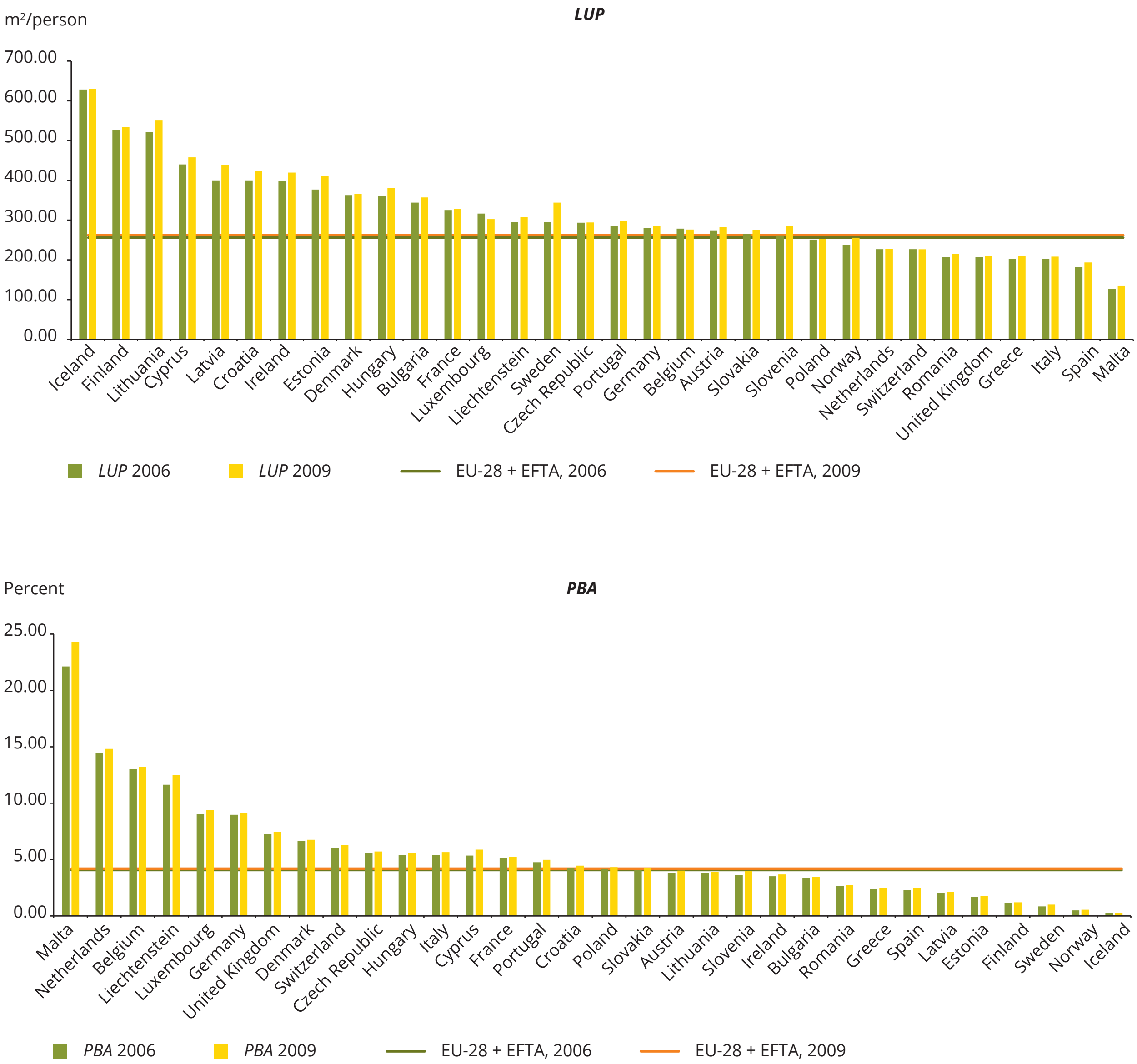
Figure 3.3 Comparison of the values of weighted urban proliferation (*WUP*), dispersion (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*) on the country level for 2006 and 2009





Note: The horizontal lines indicate the overall values for Europe (EU-28 + 4). The countries are ordered according to their 2006 values.

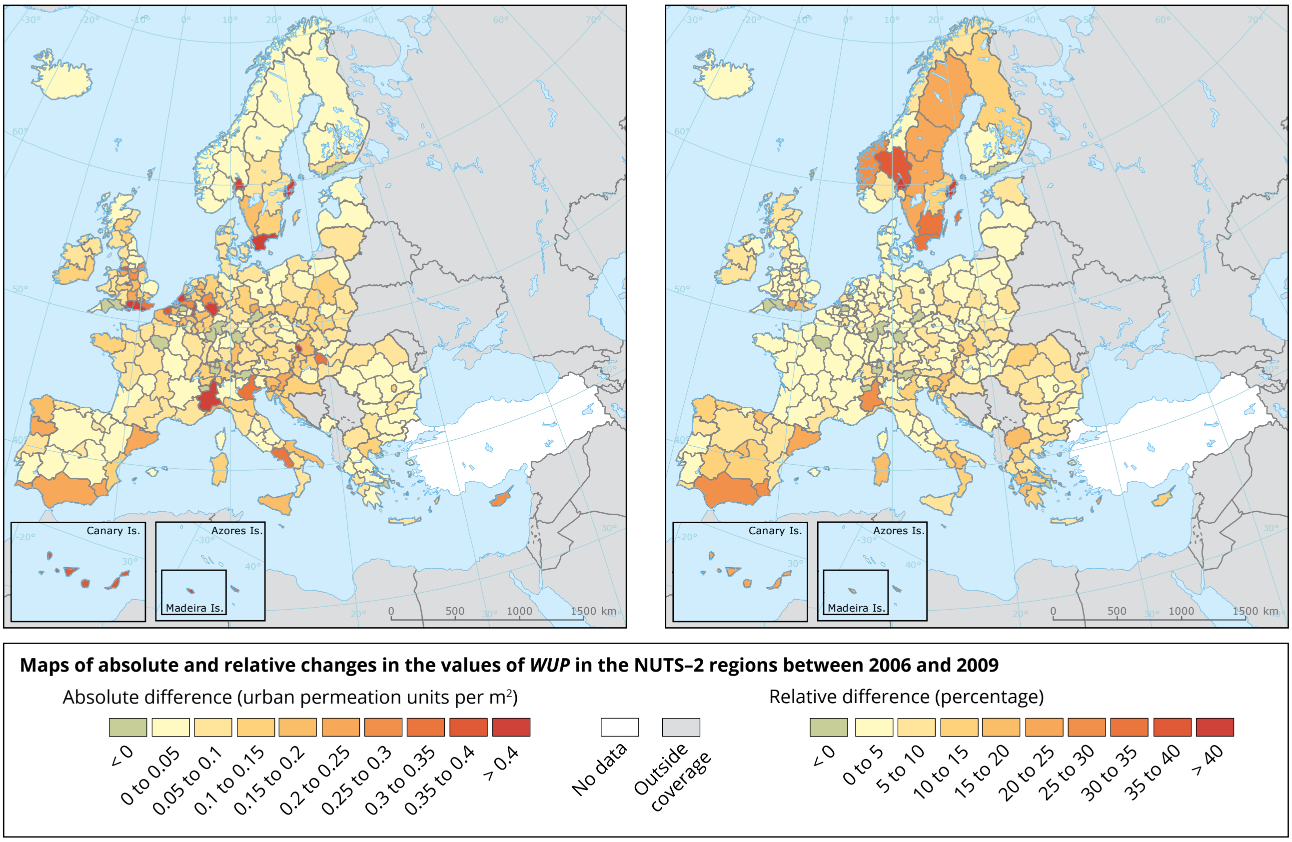
Figure 3.3 Comparison of the values of weighted urban proliferation (*WUP*), dispersion (*DIS*), land uptake per person (*LUP*) and percentage of built-up area (*PBA*) on the country level for 2006 and 2009 (cont.)



Note: The horizontal lines indicate the overall values for Europe (EU-28 + 4). The countries are ordered according to their 2006 values.

were the increases in *PBA* values, which contributed to between 69 % and 83 % of the increases in *WUP*. In France (+ 2.9 % increase in *WUP*), the next most important contribution was the increase in *DIS* (0.34 % increase in *DIS* × w_1(*DIS*)), while the contribution from the increase in *LUP* was only half as important. However, in Germany, the contribution from increased *LUP* (0.38 % increase in w_2(*LUP*)) was twice as important as the contribution from increased *DIS* (0.19 % increase in *DIS* × w_1(*DIS*)). Similarly, in the United Kingdom (3.6 % increase in *WUP*), the increase in *LUP* contributed more (0.9 % increase in w_2(*LUP*)) than the increase in *DIS* (0.24 % increase in *DIS* × w_1(*DIS*)). In 2009, the *DIS* value for Germany was very similar to the European average (44.8 UPU/m^2), while it was much higher in the United Kingdom (46.6 UPU/m^2). If the built-up areas in Germany were as dispersed as those in the United Kingdom, Germany's *WUP* value would have been 4.43 UPU/m^2 (instead of 3.83 UPU/m^2) in 2009. Conversely, the *WUP* value for the United Kingdom would have been 2.74 UPU/m^2 (instead of 3.18 UPU/m^2), if its built-up areas were spatially dispersed at the same level as those in Germany.

Map 3.6 **Changes in *WUP* values at the NUTS-2 region level between 2006 and 2009 (both absolute (left) and relative (right) changes are shown)**



The contributions to the increase in *WUP* in Ireland (5.9 % increase) differed from the contributions for the countries discussed above, in that the contributions from an increase in *DIS* and *LUP* were very similar (both about + 0.54 %).

The high relative increases in sprawl values observed for Norway (+ 17 %) and Sweden (+ 23.5 %) mostly resulted from increases in *PBA* values (> 70 %), followed by similar contributions from the increases in the *LUP* values (almost 3 % increase in w_2(*LUP*)), for both countries. *DIS* contributed a bit more to *WUP* in Norway (+ 1.3 % increase in *DIS* × w_1(*DIS*)) than in Sweden (+ 0.9 % increase in *DIS* × w_1(*DIS*)).

In south-eastern Europe, the largest increase in sprawl occurred in Slovenia (+ 13.2 %); this can be attributed to more than 72 % to the increase in the *PBA* between 2006 and 2009, followed by the increase in *LUP* (2.6 % increase in w_2(*LUP*)) and, to a smaller extent, the increase in *DIS* (+ 0.7 % increase in *DIS* × w_1(*DIS*)).

3.2.2 Changes in urban sprawl at the NUTS-2 region level

Out of a total of 284 NUTS-2 regions (in EU-28 + 4), the value of *WUP* increased in 260 (i.e. 92 %) between 2006 and 2009, and decreased in only 24 (i.e. 8 %) (Map 3.6). The relative changes in *WUP* ranged from – 39 % (in Inner London (UKI1), United Kingdom) to + 82 % (in Oslo og Akershus (NO01), Norway), while the absolute changes ranged from – 1.55 UPU/m^2 (in Berlin (DE30), Germany) to + 1.44 UPU/m^2 (in Malta (MT00)). The *DIS* values increased in 237 NUTS-2 regions (i.e. 83 %). The changes in *DIS* ranged from – 0.53 UPU/m^2 or – 1.2 % (in Åland (FI20), Finland) to + 0.47 UPU/m^2 or + 1.1 % (in Hedmark og Oppland (NO02), Norway) in absolute and relative terms, respectively. The number of NUTS-2 regions that exhibited an increase in *LUP* was slightly lower, at 219 (i.e. 77 %). The changes ranged from – 249.9 m^2 per person (in Åland (FI20), Finland) to + 135.7 m^2 per person (in Mellersta Norrland (SE32), Sweden) in absolute terms. The relative changes ranged from – 26.2 % (in Åland (FI20), Finland) to + 24.9 % (in Småland med öarna (SE21), Sweden).

In general, the largest contributions to the increases in *WUP* at the NUTS-2 level were made by the increases in *PBA* values. However, there are various cases in which other components contributed to *WUP* more than *PBA*. In 28 cases, *WUP* even increased **less** than *PBA* (in relative terms). This was caused either by a concomitant decrease in *LUP* (in Puglia (ITF6), Calabria (ITG2), Gelderland (NL22), Flevoland (NL23), Prov. Oost-Vlaanderen (BE23), Prov. Limburg (BE22), Prov. Vlaams-Brabant (BE24), Prov. Brabant Wallon (BE31), Agder og Rogaland (NO04), Luxembourg (LU00), Nordwestschweiz (CH03), Outer London (UKI2), West Yorkshire (UKE4), North Yorkshire (UKE2), Hovedstaden (DK01) and Oberbayern (DE21)), by a decrease in *DIS* (in Campania (ITF5), Trøndelag (NO06), Brandenburg (DE40), Northumberland and Tyne and Wear (UKC2), and Island (IS00)) or by both (in Sardegna (ITI3), Abruzzo (ITF3), Sicilia (ITH5), Lombardia (ITC4), Cornwall and Isles of Scilly (UKK3), Rhône-Alpes (FR71) and Lisbon (PT17)). For example, the 0.8 % increase in *WUP* that occurred in Lombardy, Italy, was the result of 1.5 % increase in *PBA*, a decrease in *LUP* from 193.2 to 192.3 m^2 per person and a decrease in *DIS* from 46.22 to 46.19 UPU/m^2. In contrast, the value of *WUP* in Zurich (CH04) **decreased** by 1.05 %, even though *PBA* increased by 2.2 %. This is because the *LUP* decreased from 178.3 to 173.44 m^2 per person, and *DIS* decreased slightly, from 46.768 to 46.765 UPU/m^2.

The largest relative increases in *WUP* occurred in Scandinavia, particularly Sweden and southern Norway. Most affected were the capital cities (Oslo (NO01) and Stockholm (SE11), in which *WUP* increased by > 75 %), the northern neighbouring region of Oslo (Hedmark og Oppland (NO02)) and the southern Swedish NUTS-2 regions (Småland and the islands (SE21) and South Sweden (SE22)) that are closest to Denmark. There was also a considerable increase in sprawl in Spain's southern coastal NUTS-2 regions (Andalusia (ES61) and the region of Murcia (ES62), in which *WUP* increased by > 25 %) and the most eastern coastal region (Catalonia (ES51), in which *WUP* increased by 22 %).

Several European capital regions exhibited a decline in sprawl between 2006 and 2009: Helsinki (FI1B), Paris (FR10), Brussels (BE10), Berlin (DE30), Prague (CZ01), Vienna (AT13), Athens (GR30) and Inner London (UKI1). Sprawl also declined in some other NUTS-2 regions in the United Kingdom (Devon (UKK4) and Dorset and Somerset (UKK2)), the Netherlands (Utrecht (NL31)), Belgium (Prov. Antwerpen (BE21)), Germany (Hamburg (DE60), Rhine-Hesse-Palatinate (DEB3), Darmstadt (DE71), Chemnitz (DED1) and Mittelfranken (DE25)) and Switzerland (Zurich (CH04) and Central Switzerland (CH06)). In addition, 2 of the 21 Italian NUTS-2 regions showed slightly lower urban sprawl values for 2009 than they did for 2006, as a result of decreases in *LUP* and *DIS*. These regions are located in the northern part of Italy (Aosta Valley (ITC2)) and along the western coast (Lazio (ITF2)). In France and Greece, all regions other than the capital regions exhibited an increase in sprawl.

Several of the regions that are most affected by sprawl in terms of absolute values were not greatly affected in relative terms because they already had high or very high levels of urban sprawl in 2006. In parts of the United Kingdom (mostly in the midlands and along the southern coast: Merseyside (UKD7); Greater Manchester (UKD3); West Midlands (UKG3); Surrey, East and West Sussex (UKJ2); Hampshire and Isle of Wight (UKJ3); and Kent (UKJ4)), urban sprawl increased conspicuously (> + 0.3 UPU/m^2) between 2006 and 2009. The same applies to some NUTS-2 regions in the Netherlands (Limburg (NL42), South Holland (NL33) and North Brabant (NL41)), Belgium (West Flanders (BE25)), western Germany (Bremen (DE50), Muenster (DEA3) and Arnsberg (DEA5)), Portugal (Madeira (PT30) and Açores (PT20)) and Italy (Piemonte (ITC1), Molise (ITF4) and Veneto (ITH3)), in which *WUP* increased by more than 0.25 UPU/m^2 between 2006 and 2009. High absolute increases in sprawl also occurred in the Bratislava region of Slovakia (SK01) and Central Hungary (including Budapest; HU10).

A more detailed analysis of the contributions of the three components of *WUP* is possible for each NUTS-2 region. However, we present only a few examples below.

In France, one region in which there was a large increase in *WUP* was Bretagne (FR52), in which *WUP* increased from 3.72 to 3.85 UPU/m^2. This increase was, in the main (more than 90 %), caused by an increase in *PBA*, with the rest mostly due to an increase in *DIS*. Land uptake is very high (almost 500 m^2 per person) in this region and *LUP* increased only slightly (by 0.1 %) during this period.

The region that exhibited the highest relative increase in *WUP* (+ 26.4 %) in Spain was Andalucia (ES61) (in which *WUP* increased from 0.81 to 1.02 UPU/m^2). More than half of this increase was as a result of an increase in *PBA*, followed by an increase in *LUP* (from 201 to 226 m^2 per person, which made a 30 % contribution) and an increase in *DIS* (which made an approximately 13 % contribution). However, the increase in *WUP* in absolute terms was even higher in the Canary Islands (ES70) (from 1.80 to 2.18 UPU/m^2). This increase was caused mostly by an increase in *LUP* (from 163 to 175 m^2 per person), followed by an increase in *PBA* (which contributed to approximately one-third of the increase in *WUP*) and an increase in *DIS* (which contributed to about 10 %).

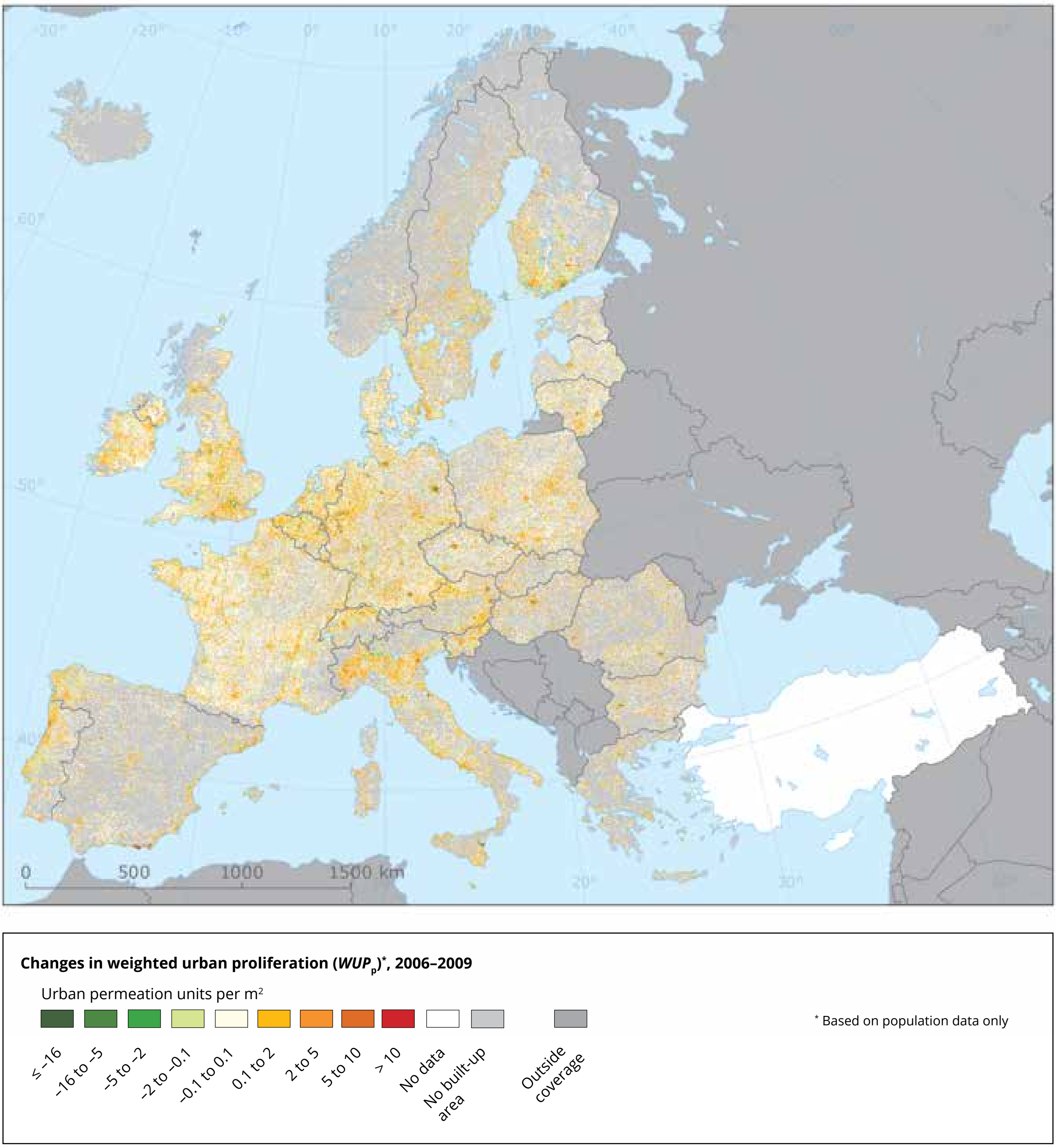
The NUTS-2 regions of Vienna (AT13) and Prague (CZ01) are illustrative examples of regions in which there was a decrease in *WUP* that resulted from a noticeable reduction in *LUP*. In Vienna, the *LUP* decreased from

94 to 91.7 m² per person, while *PBA* increased by 0.7 % and *DIS* increased only very slightly (0.002 % increase in *DIS* × w_1(*DIS*)). In contrast, there was a larger increase in *PBA* in Prague (by 2 %) and *DIS* also increased more (0.26 % increase in *DIS* × w_1(*DIS*)), whereas *LUP* decreased by a similar amount, from 121.4 m² per person to 119 m² per person; however, in absolute terms, *LUP* is significantly higher in Prague than it is in Vienna.

3.2.3 Changes in urban sprawl at the 1-km²-grid level

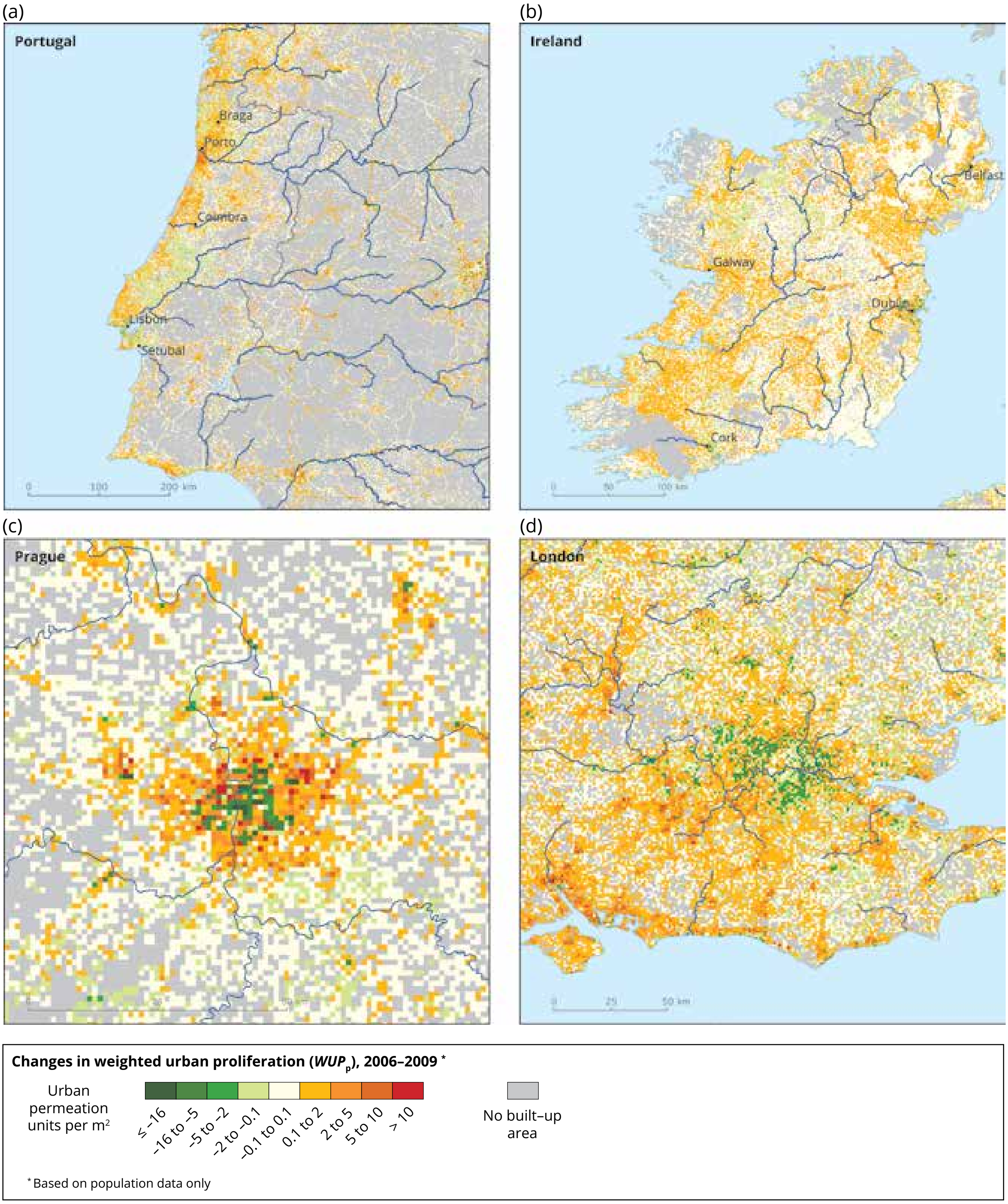
Overall, increases in *WUP* were, by far, more prevalent than decreases in *WUP* between 2006 and 2009 (Map 3.7), but there were some locations in which *WUP* decreased during this period. Very large increases in *WUP* occurred along the southern coasts of Spain and the United Kingdom, at the northern

Map 3.7 Changes in *WUP* in Europe between 2006 and 2009 on the 1-km²-grid scale



fringe of Oslo and in various other locations. Large increases in urban sprawl occurred along many transport corridors, around many large cities (e.g. in Toulouse in southern France or the region from Malmö to Helsingborg in southern Sweden), along the coast of Portugal, most parts of the coast of Spain, most parts of the coast of Italy, some parts of the coast of Greece, many parts of the coast of France,

Map 3.8 Changes in WUP_p between 2006 and 2009 on the 1-km²-grid scale in (a) Portugal, (b) Ireland, (c) Prague and (d) London



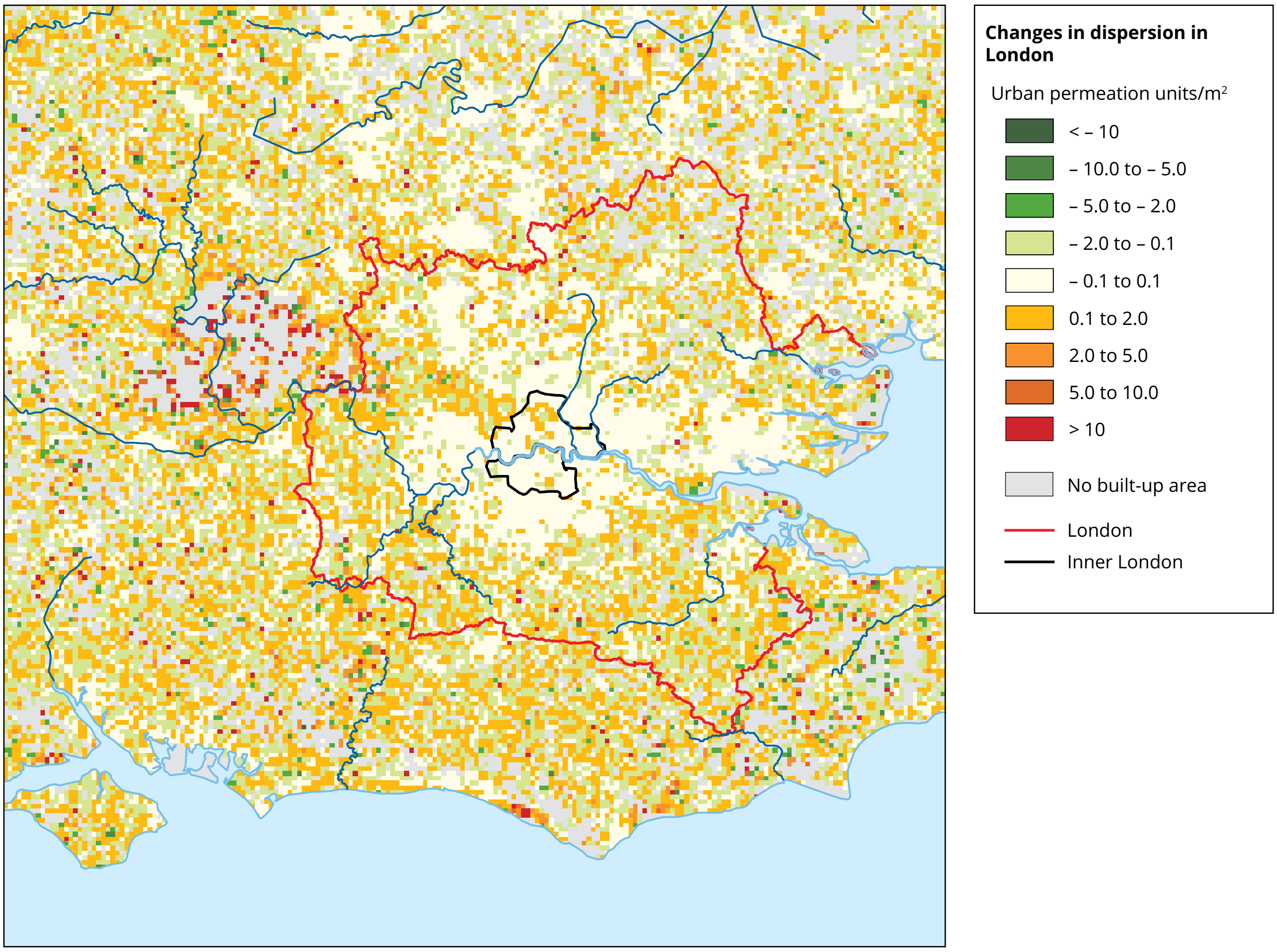
in the south-east of the United Kingdom, particularly along the coast south of London, and along most of the coast of Sweden.

There are interesting differences between the patterns observed for Portugal and Spain. In Spain, built-up areas are more concentrated in villages and towns that are clearly separated from each other by open landscape (grey areas on the map in Map 3.3). In Portugal, the *PBA* (4.98 %) is higher than it is in Spain (2.44 %), and accordingly, many NUTS-2 regions in Portugal have higher *PBA* values than those in Spain (Figure 3.2). The settlements are spread more evenly across larger parts of the landscape in Portugal (*DIS* of 45.98 UPU/m^2 in Portugal and 43.5 UPU/m^2 in Spain), and, therefore, there are higher levels of sprawl (*WUP* of 2.33 UPU/m^2 in Portugal and 0.75 UPU/m^2 in Spain). This difference is also reflected in the changes observed between 2006 and 2009: the cells in Portugal in which an increase in sprawl was detected stretch from the coast far inland over larger distances than in Spain (Map 3.7). However, there are also some areas farther inland in Portugal in which sprawl decreased during this period (Map 3.8a). The largest increases in urban sprawl occurred in Porto, but sprawl also increased significantly along the coast.

In Ireland, large parts of the south-west and the north-east were affected by increases in urban sprawl between 2006 and 2009 (Map 3.8b), particularly locations along the major roads, such as north of Dublin, and between Dublin and Galway. Prague is a typical example of a city in which urban sprawl decreased in the city centre between 2006 and 2009, while it strongly increased in a larger ring-shaped area around the city centre (Map 3.8c). Large parts of the city centre of London also exhibited a reduction in urban sprawl during this period, while sprawl increased in a large ring around London, particularly to the south and south-west of London and along the southern coast (e.g. in Southampton) (Map 3.8d).

As an example of how one of the components of *WUP* changed between 2006 and 2009, we show how *DIS* changed in London during this period (Map 3.9). In

Map 3.9 Changes in *DIS* in London between 2006 and 2009 on the 1-km^2-grid scale



the centre of London, *DIS* values changed very little because the area was already heavily built up and, therefore, no further significant changes were possible (white cells in Map 3.9). West of London, in the areas of Chiltern Hills and the Colne Valley, the *UP* values were relatively low in 2006. By 2009, additional buildings had been constructed in these areas, which strongly influenced the observed increase in *DIS*. Built-up areas on the outskirts of London have expanded, which has, in many cases, resulted in increases in *DIS* at the edges of these built-up areas and decreases in *DIS* in the centres of these areas. The other changes in *DIS* were distributed relatively homogeneously across the rest of the landscape, with moderate increases and decreases found almost everywhere.

More examples of maps of the 1-km^2-grid scale are provided in Annex 4. Explanations about data quality with regard to detecting changes in built-up areas are given in Annex A3.1. Many negative change signals in the IMD data may actually be false, given that the reversal of sealing rarely happens in reality. Therefore, any decreases in *PBA* should be interpreted with caution.

3.3 Predictive socio-economic models

3.3.1 Countries in 2009

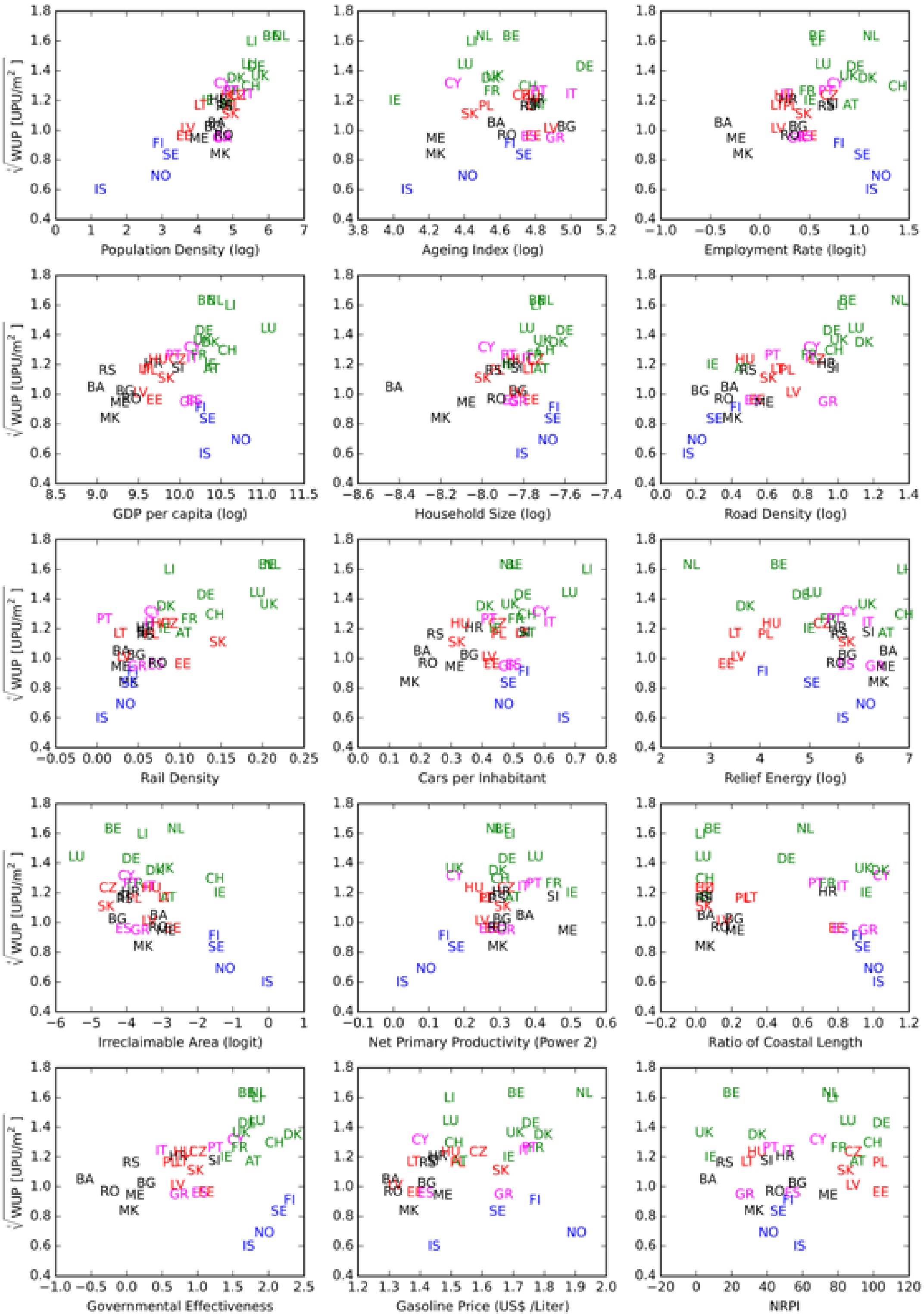
The pairwise scatterplots in Figure 3.4 provide an overview of the relationships between the metric *WUP* and the explanatory variables used in the statistical analysis. The *WUP* metric exhibits a linear relationship with the five variables population density, road density, rail density, relief energy and irreclaimable area (Figure 3.4). Since almost the entire EU and the four EFTA countries are included, this effect can be considered representative of all of Europe (EU-28 + 4). For the other variables, a linear relationship with *WUP* is less evident, which suggests that there may not be a significant linear effect of these variables on urban sprawl. The lack of a significant effect, in many cases, appears to be related to groups of countries that exhibit a different relationship between *WUP* and these explanatory variables. For example, if only the three Scandinavian countries and Iceland are considered, urban sprawl appears to decline with increasing employment rate. Therefore, these four countries cancel out the positive effect of employment rate on *WUP* in the other countries, because they pull the regression line downwards at its right-hand side.

This pattern is even more apparent in situations in which different groups of countries show different directions of the slopes of the relationship. For example, urban sprawl increases with increasing *NPP* in the Scandinavian countries and Iceland, as well as in the eastern European countries, while the opposite was observed for western Europe, and for countries located along the Mediterranean Sea coast and in the Balkans, there appears to be no effect of *NPP* on urban sprawl. These differing relationships between groups of countries are also found for the ageing index, the number of cars per inhabitant, household size, *GDP*c (in PPS), relief energy, governmental effectiveness and *NRPI*. The identification of such subgroups of countries can be based on spatial, historical or governmental characteristics. The differences in their relationships with the response variable *WUP* indicate the complexity of these relationships. However, the slopes are consistent for all countries for variables such as population density and irreclaimable area.

With regard to the statistical results, several variables play an important role in driving urban sprawl in the European countries (Map 3.10 and Tables 3.1 and 3.2). The strongest relationships were observed between *WUP* (and all its components) and population density (for 2006 and 2009). A larger population requires more space for living and working, resulting in higher *PBA* and higher *DIS* values. On the other hand, less land is taken up per person in countries with a higher population density (Table 3.1).

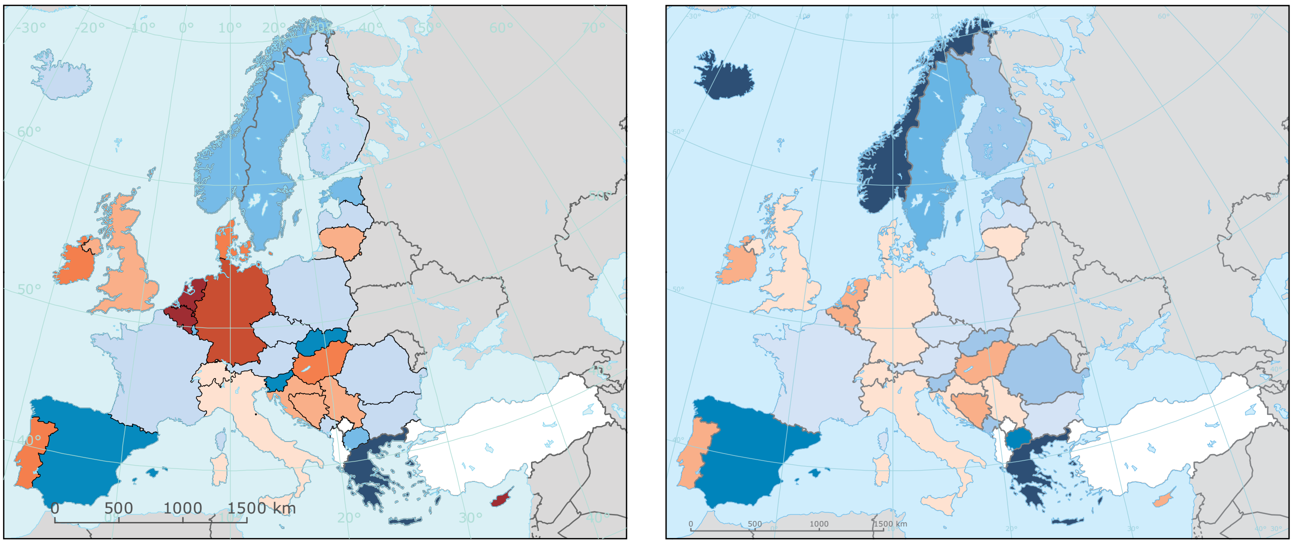
Road and rail density followed by the number of automobiles, which are among the socio-economic variables, are the next most important drivers of urban sprawl and its components (Tables 3.1 and 3.2). A well-developed road and railway network is required to transport people and goods, and, accordingly, these factors are significantly related to *DIS*, *UP* and *WUP*. The infrastructure is also closely linked to the number of cars per inhabitant. Cars are likely to be more common in countries that have more dispersed settlement areas, and, in fact, this relationship was statistically significant in our results for 2006. People living on the outskirts of agglomerations or in rural areas almost always use cars to commute, go shopping and use health services. Accordingly, the relationships between cars per inhabitant and several of the sprawl metrics are significant. Since income is related to *GDP*c, a higher *GDP*c is likely to foster the development of residential areas with single-family houses in suburban areas, which is one of the reasons many people move to the outskirts of cities. Although there is a positive relationship between *GDP*c and *WUP* for most countries (Figure 3.4), the impact of *GDP*c on most sprawl metrics is not statistically significant. As expected, *UP* and *DIS* increase with increasing *GDP*c, but this relationship was only significant for *DIS* in 2006. The relationship between *GDP*c and *LUP* was negative, contrary to our expectations (but not statistically significant). This pattern can, at least partly, be attributed to the atypical situation in

Figure 3.4 Bivariate scatterplots of the (transformed) *WUP* values and each explanatory variable used in the statistical model for the countries in 2009



Note: The colours indicate groups of countries (as in Figure 3.5). If the explanatory variable has been transformed, the transformation used is indicated in parentheses. Blue represents Scandinavia (DK: Denmark, FI: Finland, IS: Iceland, NO: Norway and SE: Sweden); red represents the north-eastern European countries (CZ: the Czech Republic, EE: Estonia, HU: Hungary, LT: Lithuania, LV: Latvia, PL: Poland and SK: Slovakia); black represents the south-eastern European countries (BA: Boznia and Herzegovina, BG: Bulgaria, HR: Croatia, ME: Montenegro, MKD: the former Yugoslav Republic of Macedonia, RO: Romania, RS: Serbia and SI: Slovania); pink represents five of the countries along the Mediterranean Sea (CY: Cyprus, ES: Spain, EL: Greece and IT: Italy) and PT: Portugal; and green represents other countries in western and central Europe (AT: Austria, BE: Belgium, CH: Switzerlan, DE: Germany, FR: France, IE: Ireland, LI: Liechtenstein, LU: Luxembourg, NL: the Netherlands and UK: United Kingdom).

Map 3.10 Residuals for *WUP* at the country level for 2009



Differences between observed and fitted (predicted) values from the ridge regression model for Weighted Urban Proliferation (*WUP*) in absolute terms and percentages for the year 2009 at the country level.

Absolute difference (urban permeation units per m²): < –0.75; –0.75 to –0.50; –0.50 to –0.25; –0.25 to 0; 0 to 0.25; 0.25 to 0.50; 0.50 to 0.75; 0.75 to 1; > 1

No data; Outside coverage

Relative difference (percentage): < –100; –100 to –75; –75 to –50; –50 to –25; –25 to 0; 0 to 25; 25 to 50; > 50

Note: Absolute values (a) show the differences between the observed *WUP* values and the back-transformed fitted values from the statistical model, while relative values (b) indicate the ratios of these differences and the observed *WUP* values. Blue colours reflect lower sprawl values than expected, while red colours indicate higher sprawl values than expected.

Table 3.1 Standardised regression coefficients of the relationships between the explanatory variables and *WUP*, and its components, at the country level for 2006 (06) and 2009 (09)

Variable	*WUP06*	*WUP09*	*UP06*	*UP09*	*DIS06*	*DIS09*	*LUP06*	*LUP09*	*PBA06*	*PBA09*
Population density (log)	**0.189**	**0.244**	**0.293**	**0.298**	***0.058***	***0.078***	**– 0.081**	**– 0.153**	**0.279**	**0.287**
Ageing index (log)	– 0.003	– 0.001	– 0.013	0.002	– 0.028	– 0.043	– 0.026	– 0.031	– 0.007	0.009
Employment rate (logit)	0.008	0.028	0.013	0.031	– 0.001	– 0.004	0.029	0.015	0.014	0.032
GDPc (log)	0.037	0.035	0.025	0.029	*0.039*	0.042	– 0.001	– 0.026	0.026	0.029
Household size (log)	– 0.034	– 0.022	– 0.034	– 0.019	– 0.018	– 0.002	– 0.008	– 0.043	– 0.035	– 0.022
Road density	**0.158**	**0.188**	**0.196**	**0.194**	***0.073***	***0.098***	– 0.022	– 0.036	**0.188**	**0.187**
Rail density	**0.126**	**0.142**	**0.159**	**0.159**	*0.051*	0.065	– 0.043	*– 0.085*	**0.158**	**0.157**
Governmental effectiveness	*0.046*	*0.053*	0.041	0.033	***0.053***	***0.075***	0.031	*0.063*	0.036	0.026
NRPI	– 0.001	– 0.034	– 0.016	– 0.038	– 0.034	– 0.055	0.009	0.002	– 0.009	– 0.030
Cars per inhabitant	*0.055*	*0.077*	0.059	0.070	*0.052*	0.062	0.034	*0.083*	0.051	0.062
Fuel price	0.017	0.031	0.014	0.029	*0.059*	0.058	– 0.002	– 0.083	0.006	0.028
Relief energy (log)	– 0.052	– 0.066	– 0.057	– 0.056	– 0.020	– 0.026	*– 0.068*	***– 0.149***	– 0.053	– 0.052
Irreclaimable area (logit)	***– 0.087***	***– 0.097***	**– 0.119**	***– 0.119***	0.026	0.048	0.036	0.050	**– 0.125**	**– 0.127**
NPP (power 2)	***0.080***	*0.095*	*0.079*	0.080	*0.055*	*0.080*	– 0.029	– 0.035	*0.076*	0.076
Length of coast	– 0.054	– 0.072	*– 0.076*	*– 0.085*	0.011	0.011	0.033	0.055	*– 0.076*	*– 0.085*
Lambda	1.861	0.983	0.778	0.703	4.067	2.448	4.643	1.701	0.887	0.789
Pseudo-R^2	0.722	0.800	0.852	0.860	0.306	0.362	0.247	0.438	0.842	0.853

Note: The results are based on a ridge regression with $n = 35$ observations. A pseudo-R^2 and the penalised value (lambda) are shown at the bottom of the table for each statistical model. All explanatory variables were standardised (i.e. centred on the mean and divided by the standard deviation). Statistically significant results are underlined. Underlined and bold: $p < 0.001$; underlined, bold and italic: $p < 0.01$; underlined and italic: $p < 0.05$; not underlined: $p > 0.05$.

the Scandinavian countries (Figure 3.4), in which most people tend to live in cities along the coast and a large proportion of new residential areas are constructed along the coast, close to the largest settlement areas (e.g. in Iceland and Norway); consequently, large areas remain open despite the high levels of wealth. This explanation also correlates with the lower level of infrastructure, the low population densities and the large inland areas that are unsuitable for construction, which hamper the spread of built-up areas, in the Scandinavian countries (Figure 3.4).

Many socio-economic variables are also closely linked to political variables. For example, governmental effectiveness reflects a country's citizens' satisfaction with their government. High income, subsidies and well-developed public services contribute substantially to the well being of people and hence to a higher satisfaction with governments. Governments make efforts to attract investors and new places of business are likely to be located within agglomerations or along city margins. The net effect of this is often the spread of settlement areas into the landscape; therefore, the relationships with *WUP* and its components are positive and most are statistically significant (Table 3.1).

Among the geo-environmental factors, irreclaimable area was statistically significantly associated with lower levels of urban sprawl, while *NPP* was significantly associated with the spread of urban areas in the landscape (Table 3.1). The higher the proportion of irreclaimable areas, the lower the possibility that settlement areas will extend into the landscape. For example, in countries with many lakes (e.g. Finland) or rocky regions (e.g. Austria and Switzerland), there are fewer areas available that can be built on. Consequently, settlement areas grow less in these countries than in countries with lower proportions of irreclaimable areas; therefore, irreclaimable areas have a negative effect on urban sprawl. Larger *NPP* values are related to higher agricultural productivity. Areas with large *NPP* are also more attractive for construction, because they are often located close to existing settlements and have a flat surface. Accordingly, our hypothesis that *NPP* correlates with *WUP* and its components (Section 2.4.3) is confirmed by the results.

The differences between the results for 2006 and 2009 are small (Tables 3.1 and 3.2), that is the statistical models are very similar, indicating that the results are quite robust.

The data for the EU and the four EFTA countries (and NUTS-2 regions) are almost complete. This means that the analysis was performed on the entire population rather than on only a sample. Accordingly, the *p*-values would only be relevant if we wanted to make conclusions about some larger population, that is if there were other regions that follow similar driving forces as the regions covered in our analysis (or for regions at different points in time). Therefore, the sizes of the coefficients, presented in Tables 3.1 and 3.3, accurately reflect the strengths of the relationships in the EU and EFTA countries in 2006 and 2009 regardless of the *p*-values.

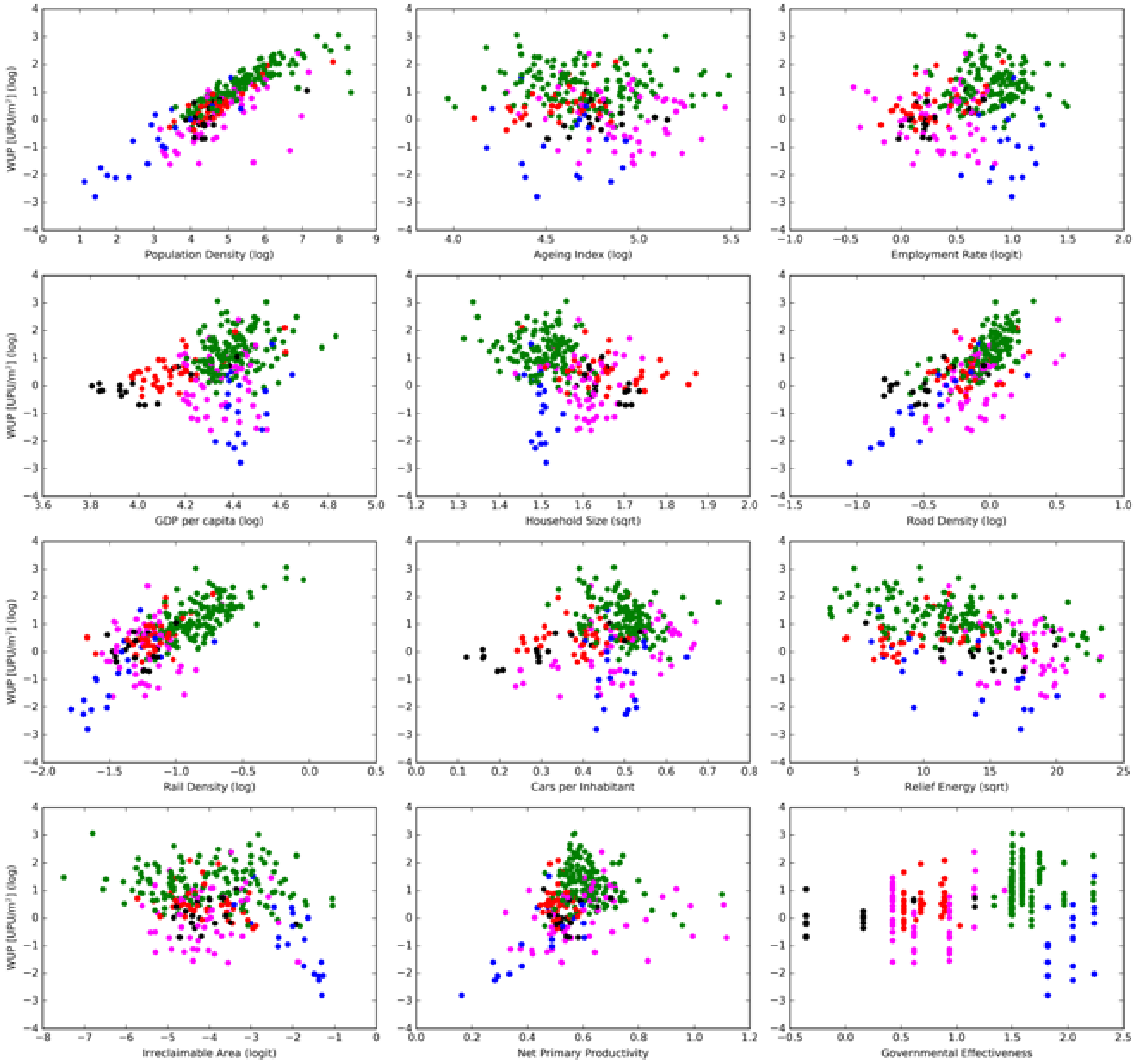
Table 3.2 Relative importance of the variables, ranked according to their importance based on the size of the standardised regression coefficients, at the country level for 2006 (06) and 2009 (09)

Variable	*WUP06*	*WUP09*	*UP06*	*UP09*	*DIS06*	*DIS09*	*LUP06*	*LUP09*	*PBA06*	*PBA09*
Population density	1	1	1	1	3	3	1	1	1	1
Ageing index	14	15	14	15	10	10	10	12	14	15
Employment rate	13	13	15	11	15	14	9	14	12	9
*GDP*c	10	10	11	13	8	11	15	13	11	11
Household size	11	14	10	14	13	15	13	9	10	14
Road density	2	2	2	2	1	1	11	10	2	2
Rail density	3	3	3	3	7	5	3	3	3	3
Governmental effectiveness	9	9	9	10	5	4	7	6	9	13
NRPI	15	11	12	9	9	8	12	15	13	10
Cars per inhabitant	6	6	7	7	6	6	5	4	8	7
Fuel price	12	12	13	12	2	7	14	5	15	12
Relief energy	8	8	8	8	12	12	2	2	7	8
Irreclaimable area	4	4	4	4	11	9	4	8	4	4
NPP	5	5	5	6	4	2	8	11	6	6
Length of coast	7	7	6	5	14	13	6	7	5	5

3.3.2 NUTS-2 regions in 2009

The NUTS-2 region level provides a more detailed picture of the relationships between *WUP* and its components and the explanatory variables. Although the general patterns are the same as they were for the country level (Figure 3.5), NUTS-2 regions allow the variability within countries to be observed and the most extreme cases to be identified. For example, the NUTS-2 regions that contain the capital cities of the Scandinavian countries are fundamentally different, in terms of urban sprawl, from the adjacent NUTS-2 regions (see Annex A1). On the other hand, the Spanish NUTS-2 region that includes the capital Madrid is similar to its adjacent regions; this is also the case for several other NUTS-2 regions that include capital cities,

Figure 3.5 Bivariate scatterplots of the (transformed) *WUP* values and the explanatory variables used in the statistical model for the NUTS-2 regions in 2009



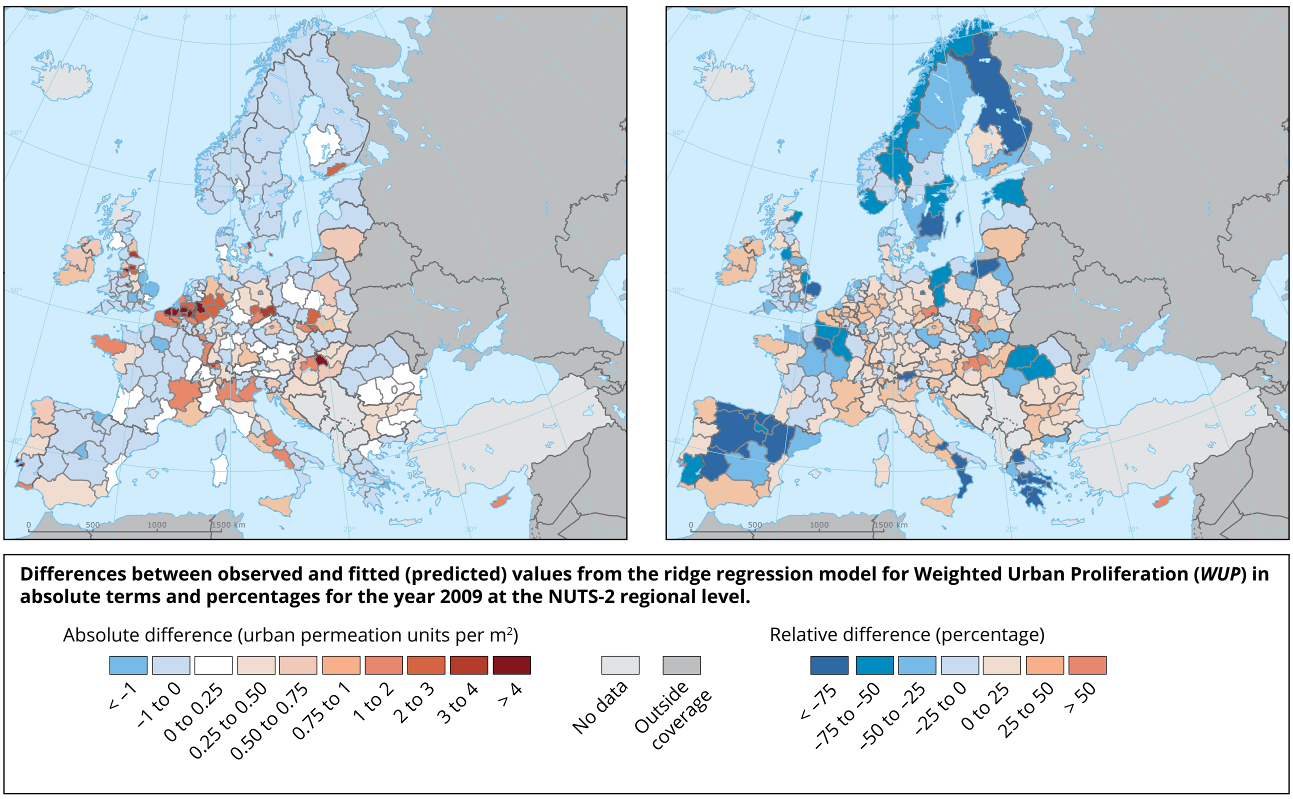
Note: The colours indicate groups of countries (as in Figure 3.4). Blue represents Scandinavia (DK: Denmark, FI: Finland, IS: Iceland, NO: Norway and SE: Sweden); red represents the north-eastern European countries (CZ: the Czech Republic, EE: Estonia, HU: Hungary, LT: Lithuania, LV: Latvia, PL: Poland and SK: Slovakia); black represents the south-eastern European countries (BA: Boznia and Herzegovina, BG: Bulgaria, HR: Croatia, ME: Montenegro, MKD: the former Yugoslav Republic of Macedonia, RO: Romania, RS: Serbia and SI: Slovania); pink represents five of the countries along the Mediterranean Sea (CY: Cyprus, ES: Spain, EL: Greece and IT: Italy) and PT: Portugal; and green represents other countries in western and central Europe (AT: Austria, BE: Belgium, CH: Switzerlan, DE: Germany, FR: France, IE: Ireland, LI: Liechtenstein, LU: Luxembourg, NL: the Netherlands and UK: United Kingdom).

such as Dublin (in Ireland), Rome (in Italy) and Sofia (in Bulgaria). If only the country values were considered, it would not be possible to distinguish effects that are due to the capital cities (or other regions that behave differently than the rest of the country) from effects related to other parts of the country. Such distinct sprawl situations in capital cities and industrial regions increase the variation in *WUP* in the NUTS-2 regions within a group of countries, and cause a larger overlap of the point clouds in Figure 3.5 of NUTS-2 regions with those of other groups of countries. For example, Helsinki-Uusimaa (FI1B) has the highest urban sprawl value (4.57 UPU/m^2) in Scandinavia. The point for this region does not cluster with the points for the remaining Scandinavian NUTS-2 regions and is located in the centre of the green cloud, which, in general, represents the NUTS-2 regions of western and central Europe. This indicates that the urban development processes in the Finnish capital are more closely related to those found in western and central Europe than those in the rest of Scandinavia. Similar conclusions can be drawn for Bucharest (RO32), which has the highest *WUP* value among the Balkan country NUTS-2 regions (1.05 UPU/m^2).

Overlaps between entire groups of NUTS-2 regions suggest some similarity between them. For example, in terms of *GDP*c (in units of PPS), the number of cars per inhabitant and urban sprawl, the Scandinavian regions (blue points) do not behave much differently from NUTS-2 regions located along the Mediterranean sea (pink points). However, these numerical proximities do not necessarily correlate with the same effect on urban sprawl. In Scandinavian NUTS-2 regions, urban sprawl increases with increasing *GDP*c, while in Mediterranean NUTS-2 regions, such a positive effect of *GDP*c on sprawl is not present.

Spatial proximity does not necessarily coincide with similarities in the relationship with sprawl, either. For example, the Scandinavian and west-central European NUTS-2 regions are next to each other geographically and are considered closely related in terms of their economies and societies, but the number of cars per inhabitant exhibits a much stronger positive relationship with sprawl in Scandinavia than it does in west-central Europe (Figure 3.5). On the other hand, the slopes show the same direction for north-eastern and south-eastern Europe with regard to the number

Map 3.11 Residuals for *WUP* at the NUTS-2 region level in 2009



Note: Absolute values (a) show the differences between the observed *WUP* values and the back-transformed fitted values from the statistical model, while relative values (b) indicate the ratios of these differences and the observed *WUP* values. Blue colours reflect lower sprawl values than expected, while red colours indicate higher sprawl values than expected.

of cars per inhabitant and several other predictor variables, suggesting that these NUTS-2 regions have socio-economic and demographic processes in common that are important for urban sprawl.

Finally, the additional information provided by the analysis of NUTS-2 regions leads, for some groups of regions, to different slopes than those derived from using information at only the country level. For instance, at the country level, irreclaimable area has a negative effect on urban sprawl (i.e. a negative slope) for all groups (Figure 3.4). However, if information obtained at the NUTS-2 region level is used, there is no strong evidence for such a negative relationship between sprawl and irreclaimable area for eastern Europe, the Balkan countries or the Mediterranean countries (Figure 3.5). Another example for which the relationship with sprawl varies depending on whether information at the country level or the NUTS-2 region level is used is *NPP*: for the NUTS-2 regions along the Mediterranean sea, the relationship between *WUP* and *NPP* produces a slope with a gradient of zero or even a negative gradient, while at the country level, urban sprawl clearly increases with increasing *NPP* (Figure 3.4). Since the analysis at the country level does not reveal some of the most interesting information about urban sprawl and its drivers, the credibility of the results obtained from using the NUTS-2 region information is higher.

In order to determine the relative importance of the drivers of sprawl, a statistical analysis was performed (Tables 3.3 and 3.4). The number of variables investigated at the NUTS-2 level is slightly lower (12 + 2) than was investigated at the country level (15; see Section 3.1.1), but there were 7.6 times more observations (267 observations) at the level of NUTS-2 regions than there were at the country level (35 observations). Urban sprawl is driven by nine variables at this scale; population density is the strongest among them (Table 3.3). The positive effect of population density can be explained by the fact that an increase in population density will cause an increase in the *PBA* and *DIS*, as hypothesised (Section 2.4.1). This

Table 3.3 Standardised regression coefficients of the relationships between the explanatory variables and *WUP*, and its components, at the NUTS-2 level for 2006 (06) and 2009 (09)

	WUP06	*WUP09*	*UP06*	*UP09*	*DIS06*	*DIS09*	*LUP06*	*LUP09*	*PBA06*	*PBA09*
Population density (log)	**0.342**	**0.359**	**0.61**	**0.626**	**0.431**	**0.433**	**– 0.528**	**– 0.493**	**0.618**	**0.631**
Population density (log, 2)					0.087	0.085				
Ageing index (log)	*– 0.04*	– 0.031	– 0.008	0.002	**– 0.107**	**– 0.122**	0.03	*0.056*	– 0.009	0.004
Employment rate (logit)	– 0.032	– 0.006	***– 0.048***	*– 0.035*	– 0.007	– 0.042	*– 0.075*	– 0.028	***– 0.05***	– 0.032
GDPc (log)	– 0.022	– 0.021	0.003	0.003	**0.11**	**0.095**	**– 0.267**	**– 0.267**	– 0.002	0.003
GDPc (log, 2)			0.035	0.038						
Governmental effectiveness	**0.059**	***0.059***	0.034	*0.04*	0.05	***0.074***	**0.299**	**0.284**	0.016	0.02
Household size (sqrt)	**– 0.068**	**– 0.067**	**– 0.059**	**– 0.061**	– 0.034	*– 0.053*	– 0.062	*– 0.065*	**– 0.058**	***– 0.057***
Household size (sqrt, 2)							– 0.039	– 0.043		
Road density (log)	**0.156**	**0.153**	**0.12**	**0.115**	**0.13**	**0.132**	0.032	0.004	**0.105**	**0.1**
Rail density (log)	**0.141**	**0.138**	**0.11**	**0.107**	*0.066*	***0.079***	***– 0.105***	**– 0.105**	**0.11**	**0.105**
Relief energy (sqrt)	**– 0.156**	**– 0.151**	**– 0.125**	**– 0.12**	***– 0.076***	***– 0.068***	**– 0.261**	**– 0.225**	**– 0.127**	**– 0.123**
Irreclaimable area (logit)	– 0.016	– 0.019	– 0.008	– 0.013	**0.121**	**0.12**	– 0.046	– 0.045	– 0.018	– 0.022
NPP					**0.104**	**0.092**	0.049	0.03		
NPP ($x < 0$)	**0.329**	**0.334**	**0.192**	**0.189**					**0.206**	**0.204**
NPP ($x > 0$)	*– 0.066*	*– 0.067*	*– 0.048*	*– 0.052*					***– 0.066***	**– 0.069**
Cars per inhabitant	***0.058***	0.04	*0.039*	0.023	***0.084***	**0.099**	**0.11**	*0.071*	0.017	– 0.001
Lambda	0.411	0.379	0.143	0.136	0.252	0.262	0.225	0.26	0.142	0.139
Pseudo-R^2	0.808	0.804	0.938	0.94	0.734	0.746	0.668	0.687	0.936	0.936

Note: The results are based on a ridge regression with n = 267 observations. A pseudo-R^2 and the penalised value (lambda) are shown at the bottom of the table for each statistical model. All explanatory variables were standardised (i.e. centred on the mean and divided by the standard deviation). Statistically significant results are underlined. Underlined and bold: $p < 0.001$; underlined, bold and italic: $p < 0.01$; underlined and italic: $p < 0.05$; not underlined: $p > 0.05$. *WUP*, *LUP*, and *PBA* response variables were log-transformed (to base e), while *DIS* was taken to the power of 7 to get an approximately normal distribution of errors and homoscedasticity. The 'sqrt' indicates that the square root transformation was applied; the '2' indicates that the quadradic term was used in the statistical model.

effect is stronger than the negative effect of population density on *LUP*: a low *LUP* value will be outcompeted by the positive effect of population density on *DIS* and *PBA* in most cases. At high levels of population density, a low *LUP* value will result in lower *WUP* values, but this usually occurs for only reporting units that are smaller than NUTS-2 regions (e.g. municipalities) (see examples shown in Annex A2).

The *NPP* is the second most important variable related to urban sprawl. The NUTS-2 regions can be split into two groups, based on relationships between *NPP* and the response variables *WUP* and its components. In NUTS-2 regions with lower than average *NPP*, urban sprawl and *PBA* values increase with increasing *NPP*, while, in NUTS-2 regions with above average *NPP* levels, sprawl gradually decreases with increasing *NPP* (Figure 3.5). This is partly in contrast to our original expectations. Indeed, in the northern Scandinavian regions, *NPP* is lower than in the regions along the Baltic Sea coast, while urban sprawl follows the same pattern. A similar gradient is apparent for the areas from south-eastern Europe to the central part of Europe for *NPP*, *WUP* and *PBA*. *NPP* correlates with climatic conditions, from the coldest regions in the north and the warmest regions in the south-east to the more favourable climates of western Europe. Milder conditions are better suited to the cultivation of crops and are also more attractive to people, which contributes to higher levels of sprawl in these areas. The gradual decline of sprawl with increasing *NPP* in NUTS-2 regions with higher than average *NPP* can be partly explained by the fact that many highly productive regions are found along the northern and north-western coasts of such countries (e.g. Spain, Portugal, France and Ireland). The lower sprawl values in these regions could be related to their relatively high humidity, which may negatively affect crop production and is also less favourable for the settlement of large human populations. Furthermore, the small negative effect of *NPP* on sprawl in areas with relatively high *NPP* values could reflect some protection of agricultural areas from urban sprawl because of their high productivity.

Relief energy (discussed further below), road density and rail density are the next most influential variables (Tables 3.3 and 3.4). With the exception of *LUP*, all metrics are positively affected by a higher availability of road and rail infrastructure, because they provide accessibility to areas that are farther from urban centres. These areas often exhibit better air quality, lower noise pollution and closer proximity to recreational areas such as forests (Jetzkowitz et al., 2007). Industrial and commercial development also requires a well-established infrastructure (Verburg et al., 2004; Müller et al., 2010). Often these developments cover large areas and have a relatively low density of employees, which contributes to the significant positive relationship between *WUP* and road density. Examples of this relationship can found throughout Europe in sprawled regions, for example in CentrO (Oberhausen/Germany — Düsseldorf, DEA1), Commercial Area Spreitenbach (Zürich/Switzerland —

Table 3.4 Relative importance of the variables, ranked according to their importance based on the size of the standardised regression coefficients, at the level of NUTS-2 regions for 2006 (06) and 2009 (09)

Variable	*WUP06*	*WUP09*	*UP06*	*UP09*	*DIS06*	*DIS09*	*LUP06*	*LUP09*	*PBA06*	*PBA09*
Population density	1	1	1	1	1	1	1	1	1	1
Ageing index	9	9	11	12	5	3	12	8	11	10
Employment rate	10	12	7	9	12	12	7	11	7	7
*GDP*c	11	10	9	8	4	6	3	3	12	11
Governmental effectiveness	7	7	10	7	10	9	2	2	10	9
Household size	6	6	6	6	11	11	8	7	6	6
Road density	4	3	4	4	2	2	11	12	5	5
Rail density	5	5	5	5	9	8	6	5	4	4
Relief energy	3	4	3	3	8	10	4	4	3	3
Irreclaimable area	12	11	12	11	3	4	10	9	8	8
NPP	2	2	2	2	6	7	9	10	2	2
Cars per inhabitant	8	8	8	10	7	5	5	6	9	12

Note: In cases of higher order terms, only the highest coefficient was considered.

Zurich, CH04), Bielany Park Handlowy (Wrocław/Poland — Dolnośląskie, PL51) and Belle Epine (Thiais/France — Île de France, FR10).

The number of cars per inhabitant also correlates positively with most sprawl metrics and drives *DIS*, *LUP* and sprawl (Table 3.3). Cars facilitate travel over considerable distances and are related to owning a single-family house in a suburban area. Families that have moved to such regions need access to shops and services, such as health services and schools, which makes car use necessary. In accordance with our hypothesis (Section 2.4.2), this explains the significant positive effect of the number of cars per inhabitant on urban sprawl and its components.

The next most important variable is household size, as hypothesised (Section 2.4.2). Accordingly, all sprawl metrics are negatively related to household size. A decrease in household size increases the demand for dwellings, and, consequently, suitable construction land, and leads to more urban sprawl, not only in regions with growing populations, but also in regions in which the population is stable or declining, land prices are low and the prosperity of the society is high enough to afford separate dwellings. In general, families tend to purchase construction land or houses in the outskirts of urban areas, in order to benefit from the surrounding green space. Wealthier families often have fewer family members living in the same house, which requires more space for construction per family. Therefore, regions with high proportions of wealthy families will often exhibit larger and more dispersed built-up areas than areas with higher proportions of less wealthy families.

Relief energy is among the three environmental variables and it negatively affects urban sprawl and its components (Table 3.3). Higher relief energy is associated with more mountainous regions, in which built-up areas are more restricted (Nemes, 2011). Therefore, the higher the relief energy, more sparingly the land is used. The effect on *DIS* is not as strong as it is on the other variables; this is likely to be because of the spatial distribution of hill farms, mountain resorts, ski resorts, etc. in these regions (which are more than 2 km apart).

Governmental effectiveness is also among the important drivers of urban sprawl and its components (Tables 3.3 and 3.4). Good governance is closely linked with a thriving economy, a high quality of public services and other factors that contribute to citizen satisfaction. These aspects, however, are usually related to a lifestyle (e.g. living in a single-family house in a suburban area) that entails a high consumption of resources, high *LUP* and high *DIS*. Although good planning (as part of good governance) may restrict the extent of resource use, including land use, the positive relationship between governmental effectiveness and the urban sprawl metrics suggest that resource-efficient planning, so far, has had relatively little influence, clearly less than the other factors.

Given the increasing number of elderly people in Europe, we hypothesised that, because many elderly people will remain in their family homes after their children have moved out, urban sprawl would increase (see Section 2.4.1). However, our results contradict this hypothesis and show that a higher ageing index is related to a lower *DIS* (Table 3.3). Social and spatial restructuring may explain this negative effect of ageing index on *DIS*. For example, previously industrial regions, such as the Ruhr area of Germany and Upper Silesia in Poland, had prospering economies based on the charcoal and automobile industries; this caused the immigration of many people and a large extension of urban areas (Runge et al., 2003). In the 1990s, the charcoal industry collapsed, while the automobile industry moved many production factories to China and India. The resulting high unemployment rates forced some of the younger generation to leave these regions. Conversely, older people were less able to afford to move to other regions or were too strongly connected to the regions to leave (Dye et al., 2010). Similarly, in many eastern European regions, many young people from rural areas and relatively small cities moved away because of high unemployment rates (Grossmann et al., 2008; Becker and Heller, 2009; Grigorescu et al., 2012). The increase in the proportion of elderly people in these small, rural regions, caused by the migration of the younger generation, may explain the negative relationship between *DIS* and the ageing index.

Finally, three variables exhibited no or only a small, non-statistically significant effect on urban sprawl, even though some components of *WUP* were affected significantly by these variables (Table 3.3). Since owning a family home is related to income, we hypothesised that a higher *GDP*c would be related to a higher level of urban sprawl, which is supported by findings from several studies (e.g. Bai et al., 2012; Barbero-Sierra et al., 2013). The statistical models do not provide any evidence to support a direct effect of *GDP*c on *WUP*; however, there is evidence to indicate that *GDP*c promotes *DIS,* while reducing *LUP*. Economically strong districts, such as central banking districts or industrial centres with a high *GDP*c, are often characterised by tall office buildings which accommodate many employees and, therefore, *LUP* in these areas is relatively low. On the other hand, most people only work in these areas, while they tend to live in suburban areas. This may explain why *DIS* increases with increasing *GDP*c. Since these two effects compensate for each other, their combined effect on

WUP is too small to be detected by this scale of analysis. Indirect effects of *GDP*c (through other explanatory variables) would require a more sophisticated statistical method (e.g. SEM).

Employment rate had only a weak negative effect on *WUP* and *LUP* in 2006 and 2009, but had a slightly more significant negative effect on *UP* and *PBA*. This negative relationship with *UP* and *PBA* can be explained, to some degree, by the number of working places. In NUTS-2 regions with relatively high *UP*, there are also fewer job opportunities than there are in cities that are characterised by relatively low *UP*. Similarly, a large *PBA* value is usually associated with a wider spread of built-up areas. Working places (and residential areas) may be located further away in regions with fewer job opportunities. For example, more dispersed rural areas may be characterised by a higher unemployment rate (although they have the same population density) than less dispersed rural areas.

The relationship between higher levels of *DIS* and a higher proportion of irreclaimable areas is related to the amount of space available for construction. Irreclaimable areas are more scattered across the landscape than areas of high relief energy and, therefore, exhibit a positive relationship with *DIS*, whereas the relationship with relief energy is negative. For example, several NUTS-2 regions in Switzerland, Norway and the northern part of the United Kingdom have a relatively small area available for construction, and single houses are often scattered throughout the landscape; however, these houses are unlikely to have a significant effect on *LUP*. On the other hand, the lack of planning schemes to tackle urban sprawl in countries with considerable irreclaimable areas contributes to the development of scattered settlement areas. For example, the importance of cantonal competition and attractiveness for wealthy people dominated the interests of the canton Nidwalden, Switzerland, in 2009; this led to discussions related to the introduction of special construction zones for wealthy people (Merki, 2009). Switzerland is not an exception, and in all countries in which only small areas are available for construction, competition between administrative units for taxes and the lack of strong planning schemes can easily result in a contradiction with the goal of the sustainable development of settlement areas; this lack of cohesion between these priorities contributes to *DIS* and urban sprawl.

The influence of a history of communism and the presence of coastal areas

To determine whether or not the sprawl metrics differ between regions with a history of communism and other regions, we compared post-communist regions and regions that were not communist (Table 3.5). We also compared regions that have a coast with regions without a coast (see below).

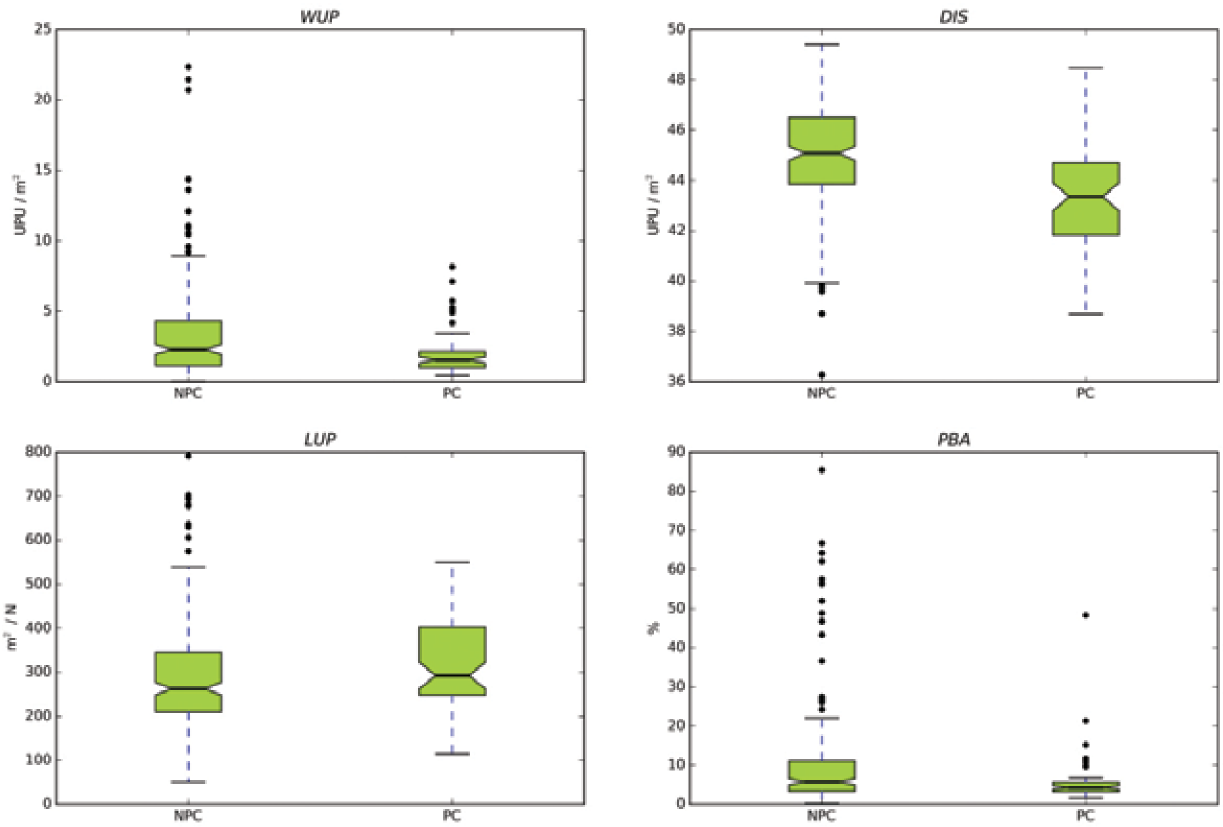
After the Second World War, Europe was divided into western and eastern parts. The border ran along the western edge of Poland, the former Czechoslovakia (now the Czech Republic and Slovakia), Hungary and the former Yugoslavia (now Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia, and Slovenia). The political systems of these two parts of Europe differed until the breakdown of communism in eastern Europe at the end of the 1980s. Since then, the countries of the eastern part have adopted the same political

Table 3.5 Means and standard deviations (in parentheses) of the sprawl metrics for NUTS-2 regions in 2009 in relation to two factorial variables that represent political history (with regard to communism) and the presence or absence of coastal areas

Variable	Post-communistic (PC)	Not post-cummunistic (NPC)	PC vs NPC *p*-values	Coastal (C)	Not coastal (NC)	C vs NC *p*-values
WUP (UPU/m²)	1.94 (1.55)	3.33 (3.51)	< 0.001	2.64, (3.2)	3.37 (3.2)	0.003
DIS (UPU/m²)	43.27 (2.00)	44.97 (2.12)	< 0.001	44.67 (2.1)	44.5 (2.4)	0.22
LUP (m² per inhabitant or job)	317.99 (102.28)	287.51 (123.96)	0.0046	305.23 (137.9)	284.51 (99.98)	0.35
PBA (%)	5.76 (6.34)	9.98 (12.92)	0.0019	7.38 (9.8)	10.54 (13.4)	< 0.001
n	65	208	–	125	148	–

Note: The *p*-values for the differences are based on randomisation tests (using 9 999 permutations). The number of NUTS-2 regions (*n*) is given in the bottom row. C, regions with coastal areas; NC, regions without coastal areas; NPC, regions that were not communist; PC, regions that were communist.

Figure 3.6 **Comparison of weighted urban proliferation (*WUP*) and its components, dispersion (*DIS*), land-uptake per person (*LUP*), and percentage of built-up area (*PBA*), at the level of NUTS-2 regions for 2009, between regions that were and those that were not communist**



Note: The box-and-whisker plots show the median, and the first and third quartiles. All differences between the means (not shown) are statistically significant (see Table 3.5). NPC, regions that were not communist; PC, regions that were communist.

system as western Europe, and their economies have joined the global economy. However, not all of the eastern NUTS-2 regions have adapted well to the conditions in western Europe. Therefore, we expected significantly smaller mean values for *WUP*, *DIS* and *PBA* in eastern than in western European NUTS-2 regions, while *LUP* was expected to be similar or higher in the eastern NUTS-2 regions.

We expected that the post-communist regions would have a lower level of sprawl than other regions because, historically, the planning systems differed in these different types of region. During the communist period, the planning system in eastern European countries tended to follow the compact-city approach (Sailer-Fliege, 1999). Large complexes of buildings made of precast concrete slabs were common in eastern European cities and housed major parts of the populations. While the living conditions in these large complexes were not necessarily desirable, they considerably reduced the spread of built-up areas and, thus, urban sprawl. It is very likely that, because of the prevalence of such buildings, *WUP* and *PBA* will be lower, even today, in these regions than they are in western European regions (see Table 3.5 and Figure 3.6).

Another common characteristic of eastern European landscapes were large rural populations and the presence of many small villages. While each farm in such a landscape would have been inhabited by relatively few people, the relatively low *LUP* in cities is likely to have counterbalanced this relatively high *LUP* in rural areas to some degree. However, the spatial configuration of settlements in rural areas was predominantly clustered, which explains the lower *DIS* values for the eastern European countries (Figure 3.8).

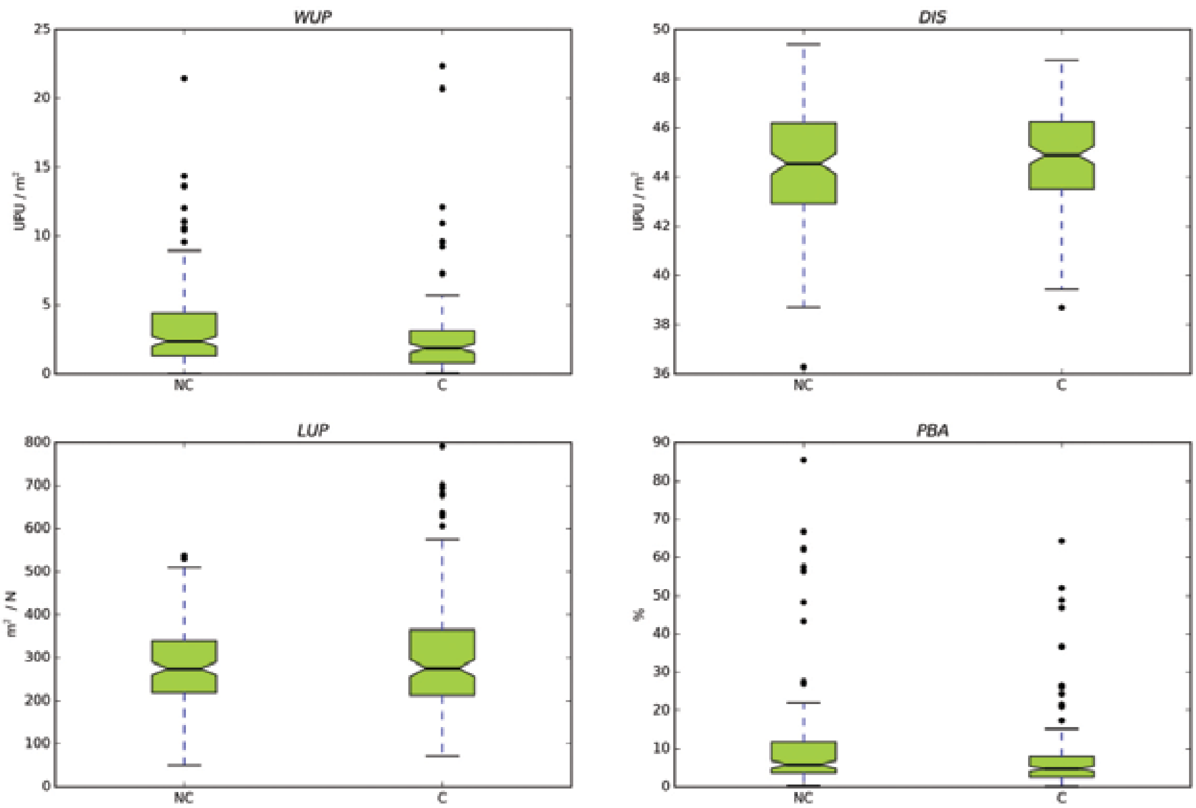
Overall, there has been less urban sprawl in eastern European countries than in western European countries. The remaining differences between western and eastern European countries reflect the rate of adaptation and development of the latter (Pichler-Milanovič et al., 2007). The results for the NUTS-2 region level support our hypothesis (Figure 3.6). However, in order to analyse the consequences of the political changes in the previously communist countries in more detail, historical data on urban sprawl for more points in time between 1945 and today are desirable.

Coastal areas play an important role in tourism and often contribute substantially to local economies (Dharmaratne and Brathwaite, 1998; Klein et al., 2004; Yepes and Medina, 2005). While coastal regions have undergone drastic construction development, in order to accommodate large numbers of tourists, the call for a more sustainable path of development has received more attention in recent years (Bramwell, 2004). This promotion of more sustainable development has, to some extent, been driven by the migration of retired wealthy people, who want to spend their remaining years in beautiful and uncrowded areas (Warnes, 1993; Williams et al., 1997), and by the preference of the general public for clean beach areas that are not highly built up (Tudor and Williams, 2006). Therefore, in some countries, tourist accommodation has been established in the hinterlands near beaches (Jordan, 2000; Andriotis, 2006). The spread of accommodation into hinterlands is expected to increase *DIS*, while *LUP* is likely to remain at the same level or increase, as a result of the establishment of relatively small hotels and more single-family houses. Therefore, urban sprawl was expected to be higher in NUTS-2 regions with coastal areas than in inland NUTS-2 regions.

However, the results are not in accordance with this hypothesis at the scale of NUTS-2 regions. In 2009, urban sprawl was, in fact, lower in coastal NUTS-2 regions (by 22 %) on average than in non-coastal regions, while 6.8 % more land was taken up per person in coastal NUTS-2 regions than in non-coastal NUTS-2 regions (Figure 3.7). The data on *DIS*, on the other hand, do support our hypothesis: higher average values of *DIS* were observed in coastal NUTS-2 regions than in non-coastal regions.

The lower level of urban sprawl in coastal NUTS-2 regions could be related to the fact that, although most of the expected characteristics of coastal tourist

Figure 3.7 **Comparison of weighted urban proliferation (*WUP*) and its components, dispersion (*DIS*), land-uptake per person (*LUP*), and percentage of built-up area (*PBA*) between non-coastal (NC) and coastal (C) NUTS-2 regions for 2009**



Note: The box-and-whisker plots show the median, and the first and third quartiles. The differences between the means (not shown) for *WUP* and *PBA* are statistically significant (see Table 3.5).

regions apply to southern Europe, these characteristics do not apply to many of the NUTS-2 regions in northern Europe. In particular, the northern NUTS-2 regions in Norway, Sweden and Finland, as well as the Baltic states, do not have many built-up tourist areas along their coasts. Furthermore, and perhaps surprisingly, the NUTS-2 regions of Greece are not highly sprawled (although the islands and coastlines are). This may also explain the differences in the *PBA* values. Therefore, although these results reveal general trends, it is difficult to generalise across all coastal NUTS-2 regions and, furthermore, suitable strategies for controlling urban sprawl in these regions may differ.

3.3.3 Changes at the country level between 2006 and 2009

The statistical models show almost no differences in terms of the direction and significance of the regression coefficients between 2006 and 2009 (Table 3.1). The few exceptions include minor changes with regard to rail density, governmental effectiveness and cars per inhabitant, which are related to *LUP*; and *GDP*c, rail density, gasoline price and cars per inhabitant, which are related to *DIS*. Some changes may be related to the economic impacts of the financial crisis in Europe in the 2006–2009 period.

The change in the significance of the relationship between rail density and *DIS* between 2006 and 2009 could be explained by two scenarios. Firstly, the lengths of the railway systems in Bosnia and Herzegovina and Serbia changed between 2006 and 2009. The length of Bosnia and Herzegovina's railway system declined (– 1 %), while the length of the railways in Serbia increased (+ 0.3 %). On the other hand, there was a small increase in *DIS* in both Bosnia and Herzegovina (+ 0.2 %) and Serbia (+ 0.1 %). The opposite directions of the changes in rail density in these countries contribute to the small change in the significance of the relationship between rail density and *DIS* between 2006 and 2009. Secondly, three countries with relatively high rail densities (Spain (0.063 km/km^2), Liechtenstein (0.082 km/km^2) and Slovakia (0.137 km/km^2)) experienced the largest increases in *DIS* between 2006 and 2009 (+ 0.5 % for Spain, + 0.6 % for Liechtenstein and + 0.5 % for Slovakia); these changes will have contributed to the increase in the slope indicating the more positive relationship between rail density and *DIS* in 2009, compared with 2006.

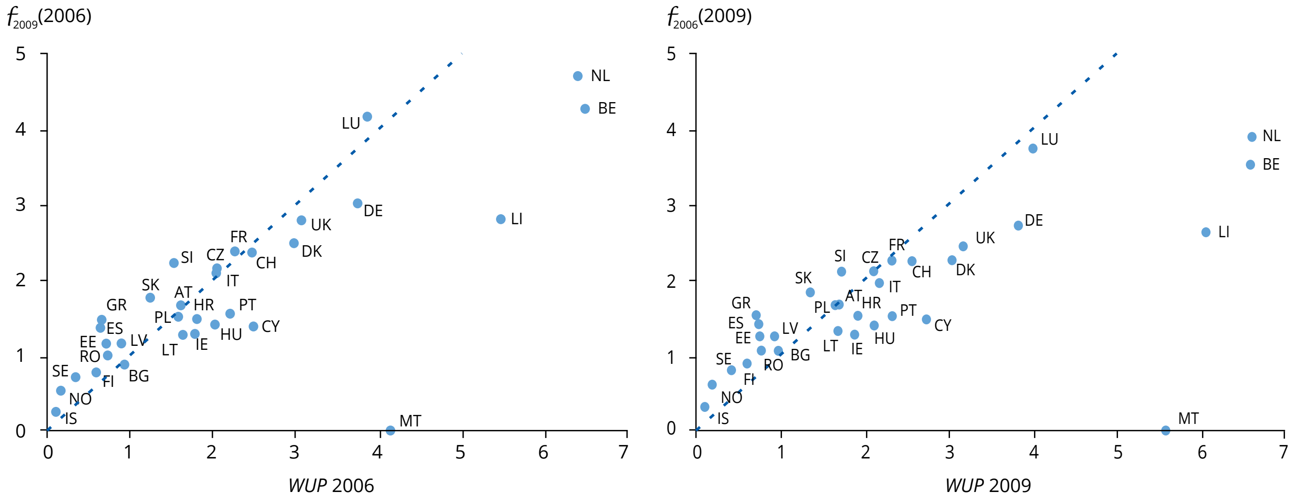
The relationship between rail density and *LUP* was also affected. In both 2006 and 2009, a higher railway density was associated with a lower *LUP*, but this was statistically significant in only 2009. The reason for this change is the considerable increase in *LUP* that occurred in countries with little railway infrastructure (particularly Lithuania, Latvia, Estonia, Sweden, Malta and Serbia) between 2006 and 2009. The Baltic countries may serve as an example of other eastern European countries that have small railway systems and are expected to experience an increase in *LUP* as a result of improved economic conditions and a higher demand for houses.

The statistical significance of the positive relationship between cars per inhabitant and *LUP* increased between 2006 and 2009. Again, Lithuania (cars: + 7.6 %; *LUP*: + 5.6 %) and Latvia (cars: + 10.4 %; *LUP*: + 9.8 %) contributed substantially to this effect. Although Estonia showed a small decline in the number of cars per inhabitant (– 1.3 %), the change in *LUP* was among the highest (+ 9.2 %). There were large increases in *LUP* and the number of cars per inhabitant in Finland, Cyprus, Croatia and Ireland, and the number of cars per inhabitant declined, combined with relatively low *LUP* values, in Switzerland and Norway. Three processes may explain these changes: (1) the economic stabilisation of Ireland after the European banking crisis; (2) the preparation of Croatia for EU membership; and (3) the increasing prosperity of the Baltic countries.

The higher number of cars per inhabitant in 2009 in Romania (+ 24.5 %), Bulgaria (+ 30.4 %) and Slovakia (+ 15.6 %) were the main reason for the change in the statistical significance of the relationship between the number of cars per inhabitant and *DIS* between 2006 and 2009; these changes were the three largest among all countries. The increase in prosperity in these countries is associated with the development of construction ground outside city boundaries and, therefore, an increase in the number of cars per inhabitant for commuting and shopping, etc. In contrast to expectations, Bulgaria did not reduce fuel prices between 2006 and 2009, but, instead, increased (+ 32.9 %) them more than any other Europe country other than Greece (+ 41.4 %), while the drastic decline in fuel prices in Iceland (– 23.1 %) contributed to the less significant relationship between fuel price and *DIS*.

Both *WUP* and *PBA* increased in countries without any coastal areas (i.e. Austria, the Czech Republic, the former Yugoslav Republic of Macedonia, Hungary, Liechtenstein, Luxembourg, Serbia, Slovakia and Switzerland) between 2006 and 2009 by, on average, 7.2 % and 4.9 %, respectively. By contrast, countries for which more than 70 % of their outer boundaries are coastal exhibited an increase of 8.7 % in *WUP* and 6.4 % in the *PBA*. These differences are not large, but they resulted in more pronounced slopes for the

Figure 3.8 Comparison of the predicted values of *WUP* at the country level



Note: The predictions for 2009 were based on the statistical model from 2006 using information about the explanatory variables from 2009, and were compared with the observed *WUP* data for 2009 (right). For comparison, the diagram on the left shows the predictions for 2006 based on the statistical model for 2009. These results correspond well with Map 3.10 (in which the residuals are shown for 2009).

corresponding relationships in 2009 (Table 3.1); thus, countries with longer coastlines have relatively lower values of *WUP* and *PBA*.

Model predictions

There are almost no differences in the predictions for *WUP* between the statistical models for 2006 and 2009 at the country level (Figure 3.8). Therefore, the following discussion does not distinguish between these years. In most countries, including Austria, the Czech Republic and France, the predicted values are close to the observed values (i.e. close to the diagonal line in Figure 3.8). Considerable deviations are apparent for Belgium, Cyprus, Denmark, Germany, Hungary, Liechtenstein, the Netherlands and Portugal (for both years). These countries have larger than predicted values, given the information regarding the explanatory variables that would account for any changes in the conditions in each country during that period. The reason for these differences is the relatively large values for *WUP* and its components for these countries, compared with the other countries (see Figure 3.1). In order to achieve a similar level of sprawl to other parts of Europe, these countries would have to reduce sprawl by 20 to 40 %. Greece and Spain are examples of countries that were less sprawled than predicted. Other factors that are not considered in the statistical model may have caused the differences, or some factors may have had a stronger influence in some countries than in others.

The results of the statistical model point to population size, road and rail density, and the number of automobiles per inhabitant as the most important variables (Tables 3.1 and 3.2). These variables have the largest coefficients and, hence, altering these variables will have the most dramatic effects on the predictions.

3.3.4 Changes at the level of NUTS-2 regions between 2006 and 2009

The overall pattern of the relative importance of the explanatory variables was very similar in 2006 and 2009. Population density, *NPP*, relief energy, road density, rail density and household size were the most important variables in both years, while the amount of irreclaimable area, employment rate and *GDP*c were the least influential. However, the coefficients of several variables changed in size in ways that affected their importance for *WUP* and its components, namely ageing index, employment rate, governmental effectiveness, household size and the number of cars per inhabitant (Tables 3.3 and 3.4). For illustration, some examples are discussed below.

With regard to ageing index, the decrease in the coefficient that describes its relationship with *WUP* can be related to inner migration. Several NUTS-2 regions with low ageing indices showed a decrease in *WUP* between 2006 and 2009, including capital regions, such as Helsinki-Uusimaa (ageing index = 78.8; $\Delta WUP_{2006–2009}$ = – 4.6 %), Paris (ageing index = 64.3; $\Delta WUP_{2006–2009}$ = – 1.3 %), Vienna (ageing index = 118.4; $\Delta WUP_{2006–2009}$ = – 13.2 %), Prague (ageing index = 131.2; $\Delta WUP_{2006–2009}$ = – 4.7 %) and Central

Switzerland, including Bern (ageing index = 97.5; $\Delta WUP_{2006–2009}$ = – 2.9 %), and economically or touristically active regions, such as Zurich (ageing index = 111.3; $\Delta WUP_{2006–2009}$ = – 1.1 %) and Åland (ageing index = 106.5; $\Delta WUP_{2006–2009}$ = – 30.8 %). Conversely, several NUTS-2 regions that include a large proportion of rural areas exhibited a high ageing index and an increase in urban sprawl, including some Italian and Spanish regions, such as Liguria (ageing index = 236.8; $\Delta WUP_{2006–2009}$ = + 12.3 %), Piemonte (ageing index = 179.8; $\Delta WUP_{2006–2009}$ = + 27.5 %), Principado de Asturias (ageing index = 208.6; $\Delta WUP_{2006–2009}$ = + 11.5 %) and Galicia (ageing index = 190.3; $\Delta WUP_{2006–2009}$ = + 11.9 %). The ageing index declined in rural regions (e.g. Principado de Asturias (ES12): – 3.5 %; Liguria (ITC3): – 1.8 %), while it increased in capital regions, and in touristically and economically active regions (e.g. Helsinki-Uusimaa (FI1B): + 8.9 %, Zentralschweiz (CH06): + 9.3 %, Åland (FI20): + 8.3 %) indicating a slight shift in the regional population structure between 2006 and 2009 as a result of the movement of younger couples or families from cities towards the open areas on the outskirts of urban agglomerations.

The reduced gradient of the slope for the relationship between *LUP* and employment rate resulted from an increase in the employment rates, in its lower range, and an increase in *LUP*, in its upper range. As employment rate declined in its upper range, *LUP* declined in its lower range.

Dispersion declined with increasing household size, and this relationship was stronger in 2009 than it was in 2006. *DIS* increased in many NUTS-2 regions, in which additional development took place. At the other end of the range of *DIS*, the increase was very small in most cases.

There was a considerable reduction in the statistical significance of the relationship between employment rate and *PBA* between 2006 and 2009 (i.e. this relationship was significant in 2006, but not in 2009), but this did not change the importance of employment rate relative to other variables. The three Baltic countries, Iceland and the Irish NUTS-2 region Border, Midland and Western (IE01) experienced a large decline in their employment rates. Unemployment rates also increased in several eastern European countries and more people moved away from these countries or stayed with their parents for longer than in 2006. In the three Baltic states, *LUP* and *PBA* increased in the same period; this was likely because part of the population benefitted from the economic development and used their new-found prosperity to build single-family houses, while other parts of the population lost their employment. This situation would have led to a pattern of declining employment rates, but increasing *PBA* and *LUP*. While this seems to apply to the Baltic countries, it is more difficult to explain the changes in Iceland and Ireland. The financial crisis led to the loss of employment in Iceland and Ireland. The importance of the relationships between employment rate and *PBA* and *LUP* were also affected in the Norwegian and Swedish NUTS-2 regions, in which *PBA* and *LUP* increased most noticeably (in Norway, *LUP*, in five out of the seven regions, increased by 3–24.2 % and *PBA* increased by 4.1–25.7 %; in Sweden, *LUP* increased by 9.99–24.9 % and *PBA* increased by 12–24.3 %), while employment rates remained among the highest in the data set (> 74.9 % in Norway and > 70.1 % in Sweden). The northern Polish NUTS-2 regions (Zachodniopomorskie (PL42), Pormorskie (PL63), Kujawo-Pormorskie (PL61) and Warminsko-Mazurskie (PL62)) also contributed to the changes in these two relationships; these regions have low employment rates, experienced a decline in *LUP* and experienced a relatively small increase in *PBA*. More investigation is required with regard to the NUTS-2 regions that have high employment rates and low *LUP* values, as no clear patterns with regard to the changes among these NUTS-2 regions were found.

Changes in *DIS* and *LUP* in Polish and Slovakian NUTS2 regions contributed to the alteration of their relationships with household size. Both *DIS* and household size increased in many Polish (in 9 out of 16 regions for *LUP* and in all regions for *DIS*) and all Slovakian NUTS-2 regions. Although these relationships may appear contradictory, they can be explained by the migration of many young Polish and Slovakian citizens from rural areas to larger cities, and the construction of new built-up areas in the vicinity of these cities. This is also supported by changes in *LUP* in many capital regions and economically thriving NUTS-2 regions, which have relatively large household sizes, but in which *LUP* declined as a result of immigration (of citizens and people from other countries): *LUP* declined by 2.4 % in Vienna, 1.5 % in Copenhagen (DK01), 1.9 % in Prague (CZ01), 6.8 % in Helsinki (FI1B) and 2.7 % in Zurich (CH04). In addition, NUTS-2 regions in Greece, Hungary, Italy, Portugal, Romania and Spain that have low household sizes showed increases in *LUP*, which contributed to strengthening the relationship between these two variables. In many cases, the increases in *LUP* were driven by the completion of construction projects that had started before the effects of the financial crisis manifested, since there were time lags between the onset of this crisis and its effects on different parts of the economy.

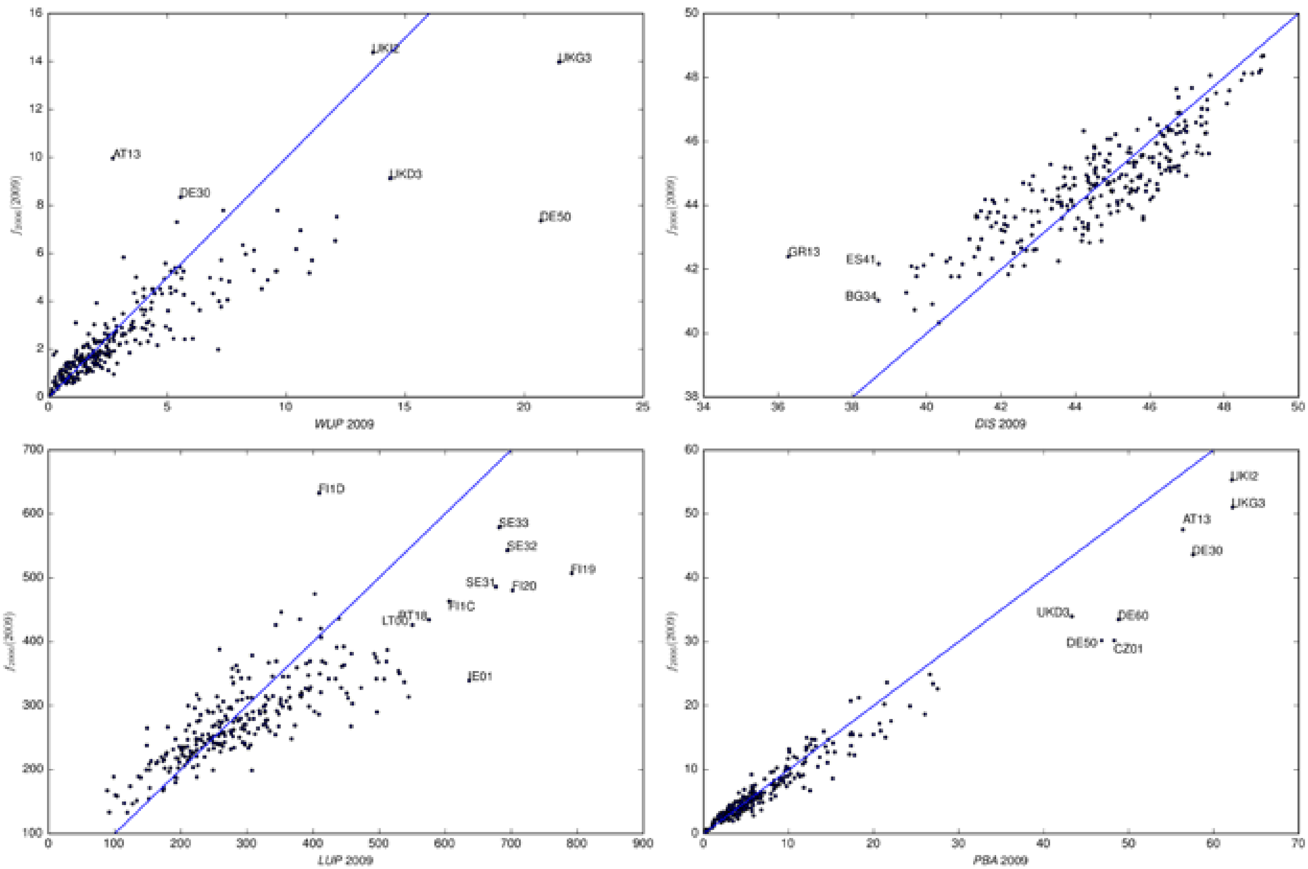
The number of cars per inhabitant was a slightly weaker driver of urban sprawl in 2009 than it was in 2006. The number of cars increased considerably in many Scandinavian, Spanish and Greek NUTS-2 regions, while it declined in several German NUTS-2 regions. While the dispersion of settlement areas is larger in the NUTS-2 regions of the Scandinavian countries, public transport services are less developed than in Germany. The possession of a car is thus of more importance in Scandinavia than in Germany. Although *DIS* is much lower in the NUTS-2 regions of Spain and Greece than it is in the Scandinavian countries, similar limitations with regard to public transport exist and more people are able to afford a car.

The increase in the gradient of the slope related to the relationship between governmental effectiveness and *DIS* can mostly be explained by the increase in *DIS* in NUTS-2 regions with the decline in governmental effectiveness. This was observed in capital regions, such as Outer London (UKI2; *DIS*: + 0.06 %; governmental effectiveness: – 12.6 %), Prague (CZ01; *DIS*: + 0.1 %; governmental effectiveness: – 17.3 %), Athens (GR30; *DIS*: + 0.03 %; governmental effectiveness: – 10 %), Copenhagen (DK01; *DIS*: + 0.1 %; governmental effectiveness: – 1 %), Paris (FR10; *DIS*: + 0.1 %; governmental effectiveness: – 5.8 %) and Vienna (AT13; *DIS*: 0 %; governmental effectiveness: – 8 %), as well as in most NUTS-2 regions in Belgium and the United Kingdom. The increase in *DIS* in European capital regions can, at least partly, be related to the increase in the number of gated communities in European cities (Cassiers and Kesteloot, 2012) and the increase in the demand for space in order to accommodate the lifestyle of wealthy people. At the same time, increased social tensions due to inequality reduce governmental effectiveness.

Model predictions

By comparing the predicted and real values for the four metrics, it is apparent that the actual *DIS* and *PBA* values deviate less dramatically from the predicted values than the *WUP* and *LUP* values do (Figure 3.9). Built-up areas in regions with low *DIS* values were less

Figure 3.9 Comparison of the predicted values of *WUP* and its components for the NUTS-2 regions



Note: Predictions for 2009 were based on the statistical model for 2006, using information on explanatory variables for 2009, and were compared with the observed data for 2009. The results for 2006 based on the 2009 models look similar and therefore are not shown here. These results correspond well with Map 3.11 (in which the residuals are shown for 2009).

dispersed than was predicted for 2009 by the changes in the explanatory variables in 2009, based on the statistical model for 2006 (e.g. Dytiki Makedonia (EL13), Castilla y León (ES41) and Yugoiztochen (BG34)). On the other hand, several large European capital regions (e.g. Prague (CZ01) and Berlin (DE340)) and closely located regions have a much higher *PBA* values than was predicted by variables such as ageing index, employment rate and household size. Similarly, the value of *WUP* for most large cities was higher in 2009 than predicted.

Knowledge about the most important variables can help explain which variables have contributed most to the differences between predictions and observations. With regard to *DIS*, the most important contributing variables are population and ageing index, which are related to demographic change, and road density and number of cars per inhabitant, which are related to mobility. In fact, the population in Europe is changing rapidly in terms of population structure (i.e. the population is becoming older) and density (i.e. the population is declining in some regions), while mobility is increasing considerably. The situation for *PBA* is similar, that is changes in population and road and rail mobility have a great influence. Changes in household size also contribute to changes in *PBA*. These changes are linked to financial situations and socio-cultural changes. There have been particularly substantial socio-cultural changes in the eastern European countries, towards individualistic, career-orientated lifestyles, and the loss of the traditional family-related lifestyle; these lifestyle changes are perceived to be accompanied by a reduction in social cohesion in European societies (Power, 2001; Cassiers and Kesteloot, 2012).

The largest deviation in expected and predicted values is observed for *LUP*. In many NUTS-2 regions (i.e. those with relatively high *LUP* values), the actual *LUP* value was much higher in 2009 than was predicted by the 2006 model, whereas the opposite is true for NUTS-2 regions with relatively low *LUP* values. Many Swedish and Finnish NUTS-2 regions are among those that exhibit the largest deviations. These substantial deviations indicate that some processes have changed. Missing variables (e.g. differences in planning legislation) and changes in the importance of the driving forces contribute to these differences. In fact, the largest changes in regression coefficients were observed for the relationship between *LUP* and the explanatory variables (Tables 3.3 and 3.4). The most remarkable shifts among the socio-economic variables were observed for ageing index, employment rate and household size. If the conditions had remained as they were in 2006, the differences would be the same as the residuals in Map 3.11.

3.3.5 *Discussion of the relative importance of the drivers and the lessons learned*

Which drivers are more important than others?

At the country scale, population density was the most important variable for all sprawl metrics (for both years) except *DIS*, for which road density was most important (population density was the third most important variable for *DIS*) (Tables 3.1 and 3.2). Road and rail density were the second and third, respectively, most important variables for *WUP*, *PBA* and *UP*; while for *LUP*, the second and third most important variables were relief energy and rail density (both of which had a negative relationship with *LUP*), respectively. For *DIS*, road density was followed by fuel price in 2006 and *NPP* in 2009. Ageing index, employment rate and *NRPI* were the least important in most cases. The most substantial variation between 2006 and 2009 was for *DIS*, for which rail density, *GDP*c, household size and the price of gasoline changed in terms of their importance. Such changes were less often observed for *LUP* and *WUP*, and there were almost no changes for *PBA*. The results suggest that *DIS* was the most sensitive variable, but the drivers varied little during the 3-year period investigated.

At the level of NUTS-2 regions, population density also played the most important role for all sprawl metrics in both years (Table 3.4). It was most commonly followed by the two environmental variables *NPP* and relief energy, and by road density. The least important drivers were irreclaimable area, employment rate, *GDP*c and ageing index. However, in some cases, the importance varied between 2006 and 2009. The largest change between the two years was observed for *LUP*, for which ageing index gained importance, while employment rate decreased in importance. A comparison of the importance of the explanatory variables across all sprawl metrics, revealed that employment rate and irreclaimable area are the least important variables.

What can we expect for the future?

Future changes in urban sprawl will mainly depend on four variables: (1) the development of the population; (2) road density and rail density; (3) politics; and (4) the number of cars per inhabitant (lifestyle). Interestingly, a recent study contradicts the general assumption that the population will stop increasing in Europe (Gerland et al., 2014); however, even if the population declines, there is strong evidence to suggest that sprawl will continue to increase in many cases (Hoymann, 2011). Although perforation through the removal of unused buildings may reduce the number and size of built-up areas, more families are likely to be living in detached houses, and the dispersion of the remaining, more perforated built-up areas are likely to be higher. Increases in population density, road and rail infrastructure, and the number of cars per inhabitant are likely to drive settlement areas to spread further and to take up land at a lower *UD*. Similar effects are expected to result from the efforts of many governments to increase income, quality of life and general well being on a short-term basis, because these measures often focus on certain subsidies, a rather liberal market and activities that enhance attractiveness to investors, and hence are linked to *GDP*c (even though *GDP*c did not exhibit a strong relationship with urban sprawl in our analysis). Although the effects of such measures were not investigated in this report, they will probably contribute substantially to further increases in land consumption and the sprawling of residential, commercial and industrial areas, unless urban and regional planning are strengthened considerably (see Chapter 4).

In some countries (e.g. Germany and Poland), rail density, or the number of railway connections, has declined, while the road network has been extended. In particular, the road networks of the new eastern European Member States are being developed at a fast pace, in order to improve trade connections. This has the potential to increase the regional *GDP*c, attract new investors and increase the demand for construction land. Accordingly, it is expected that urban sprawl will greatly increase in the eastern European countries in the coming years.

A well-developed road network promotes automobile dependence and is made even more attractive by subsidies, such as the commuter tax relief. Local governments often sell construction ground at low prices in order to encourage people, particularly wealthy people, to build and to enhance the amount of incoming taxes. The consequences of this can be observed in many towns in Europe, in which residential areas of single-family dwellings are growing close to the towns and nearby villages. This competition between municipalities is likely to continue.

3.3.6 A brief discussion of the statistical limitations

The explanatory variables were standardised (i.e. centred and scaled) to overcome issues of largely differing ranges and unequal units, and to avoid coefficients of greatly dissimilar magnitudes that could not be directly compared. If the response variables are also standardised, the standardised regression coefficients (b_i) indicate that a change (increase or decrease) in the explanatory variable *i* by a standard deviation of 1 changes the response variable by b_i times the standard deviation of the response variable.

We used standardised variables so that we could compare the importance of the effects of the different explanatory variables (Thayer, 1991; Bring, 1994).

Outliers

A few observations were located far outside the main point cloud and appeared to follow a different direction (e.g. Monaco, Kosovo (under UNSCR 1244/99) and the NUTS-2 regions Ceuta and Melilla). Such values can render effects of the large majority of points (countries or NUTS-2 regions) invisible and violate the assumptions of parametric models. Therefore, we removed such unusual observations after visual inspection of the scatterplot.

Alternatively, resistant regression approaches or quantile regression could have been used. However, those do not overcome the problem of multicollinearity between explanatory variables (and ways of correcting for this problem have not yet been implemented in commonly used software). The countries or NUTS-2 regions that constitute outliers can be analysed separately. Since there are only relatively few countries, the power of the statistical analysis at the country level is limited, and the results need to be interpreted with caution.

Missing variables

The pseudo coefficients of determination in Tables 3.1 and 3.3 showed that some models (e.g. for *UP*, $R^2 > 0.8$) explain a large amount of variation in the response variables. Other models (e.g. for *DIS*) had a smaller coefficient of determination, which indicated a lack of important explanatory variables. The greatest challenge in data collection is to gather complete information for all potentially relevant variables; this is necessary for the generation of a coherent picture of the drivers of urban sprawl in Europe. Therefore, we considered the trade-off between the number of explanatory variables and the completeness of information for these variables and decided to use fewer, but complete explanatory variables. Future research should include the missing variables, once more complete information about them becomes available.

Advantages and disadvantages of the statistical models

Multicollinearity is common in models with several explanatory variables because of the shared information between two or more variables. Typical consequences of this problem are large standard errors and incorrect estimations of regression coefficients. Moreover, the power of estimation declines with the number of explanatory variables, because fewer observations per variable are available for estimating the coefficients. We applied ridge regression to account for the effect of shared information between explanatory variables. Ridge regression and related approaches (least absolute shrinkage and selection operator (LASSO) and Elasticnet), which are called regularisation techniques, rely on the introduction of a bias into the calculation of parameters in order to reduce the variance of coefficients (Hoerl and Kennard, 1970). This bias, usually termed lambda, serves to constrain the variation of the coefficients, which is why these techniques effectively reduce multicollinearity (e.g. Kidwell and Brown, 1982; Charnes et al., 1986). However, the various possibilities in which to obtain lambda render the method less attractive (Duzan and Shariff, 2015). Although there is some superiority of cross-validation using train and test data sets over other methods to determine lambda, it still leaves open the question of the sizes of the corresponding data sets and the number of folds used in cross-validation. General recommendations suggest that 5- or 10-fold cross-validation should be performed (Hastie et al., 2009). Krstajic et al. (2014) showed that cross-validation should be applied several times, because lambda can vary because of the choice of observations in folds. This is even more important when sample size is small and some outliers are present, as is the case in the country model. Outliers can accumulate in one fold accidentally and distort the estimation of lambda. This can be ameliorated when larger sample sizes are available, because it allows the generation of larger sub-samples. In our analysis of the countries, we decided to use 30 out of the 35 available observations as the training data set and applied threefold iterative cross-validation to find the best lambda. For the model of the NUTS-2 regions, we chose 60 % of the observations for the training data and a fivefold iterative cross-validation to generate a range of lambda values. The lambda value chosen most often in the iterative approach was used in the ridge regression analysis.

Spatial autocorrelation

Both *WUP* models inherit a spatial process that can be described by a spherical model that ranges up to 3 500 km (Annex A5). Spatial autocorrelation violates the assumption of independence, which is fundamental in statistical testing, and affects the significance and sometimes the coefficient estimates. However, our data for the EU and the four EFTA countries are almost complete. Therefore, no statistical testing is required because we analysed the entire population rather than only a sample. Since we understand the relationships in the population, we do not need to do statistical tests (which are used to draw conclusions about the population based on a sample). Nonetheless, we have calculated the *p*-values because readers are familiar with *p*-values, and they can be used to justify confidence in the importance of the variables. In our case, it was sufficient to use the sizes of the coefficients. The larger the coefficients, the stronger the influence of the variables. The fact that the sizes of the coefficients perfectly mirror the observations made in the scatterplots (Figures 3.4 and 3.5) further supports the fact that *p*-values are not necessarily required. As a consequence, the presence of spatial autocorrelation does not have any substantial impact on our results and conclusions.

4 Policy relevance and implications

The findings of this study have important implications for policymaking, urban and regional planning, transport planning and several other policy areas that are related to the driving forces or the consequences of urban sprawl. As an important example, the 7EAP, which entered into force in January 2014, calls for indicators of resource efficiency to be established in order to guide public and private decision-makers. Priority objective 8 of the 7EAP addresses the sustainability of cities. It states that the 7EAP aims to help cities become more sustainable, and to promote and expand initiatives that support innovation and best-practice sharing in cities. Soil protection and the sustainable use of land were identified as topics that need further action at EU and national levels: 'The aim is to ensure that by 2020, most cities in the EU are implementing policies for sustainable urban planning and design, and are using the EU funding available for this purpose' (EC 2013a, 2013b).

Accordingly, this chapter discusses the need to monitor urban sprawl (Section 4.1) and examines the implications for urban and regional planning and nature conservation (Section 4.2). Chapter 4 also provides guidelines and best-practice examples of controlling urban sprawl, and identifies future research needs (Section 4.3) and highlights the most immediate priorities (Section 4.4).

4.1 Monitoring urban sprawl

Effective policymaking requires a reliable understanding of the state of the environment and the present rates of environmental change. The objectives of environmental monitoring are to document the state of the environment and to detect and better understand changes. The results presented in this report are relevant for planning — urban and regional planning, land-use planning, and planning of transport and other infrastructure — and various other areas of policymaking, such as health services, ecosystem services and biodiversity conservation. The 7EAP emphasises the importance of resource efficiency, that land is a finite resource and the consideration of the urban context. The results of this report also portray the character and appearance of the landscape (Photo 4.1).

Accordingly, the results are applicable for several types of monitoring: environmental monitoring, sustainability monitoring, landscape-quality monitoring and biodiversity monitoring. Therefore, the findings of this study could be adopted by European and national monitoring systems (such as the EEA's core set of indicators (CSI)), and for the land ecosystem accounting efforts of the EEA (EEA 2006a; Romanowicz et al., 2007; Weber, 2007).

Photo 4.1 Váh river valley, Považská Bystrica town and surroundings (Slovakia)

© Rastislav Staník

Some results have already been included as pressure indicators in *The European environment — state and outlook 2015* report (State of the environment report (SOER) 2015) (EEA 2015b). The SOER provides a comprehensive assessment of the state of the environment, and the environmental trends and prospects, based on information from the EEA and the European Environment Information and Observation Network (Eionet). Ideally, urban sprawl values should be updated every 3 years, but this depends on data availability (the Copernicus HRLs, for example, have a 3-year update cycle).

Changes in the strength of the driving forces can serve as an early warning system of future increases in sprawl. Potential driving forces that are not yet monitored, such as an index about the strength of spatial planning legislation and practice across Europe (Reimer et al., 2014), land prices and mortgage interest levels, would be useful to observe and include in future statistical analysis. The models that predict the degree of sprawl are no substitute for monitoring sprawl trends directly. Rather, they can be used to identify regions in which the actual sprawl levels have increased faster or more slowly than the models had predicted (as an indication of the presence of additional factors), and to determine at which point economic development becomes successfully decoupled from further degradation of the environment.

A consistent definition of a built-up area and information with regard to the number of inhabitants and jobs are important for time series. Information about built-up areas has been gathered from the HRL IMD data set provided by the European Copernicus programme. It provides a high-resolution imperviousness data set of all artificially sealed areas (Section 2.3). Data regarding jobs are important for the calculation of *LUP* and *WUP*, mainly in industrial areas that often have low numbers of inhabitants but high numbers of jobs (Section 2.3). The quality of the data sources and consistent definitions and corrections are important for reliable monitoring data at the European level. If future monitoring is based on exactly the same definition and delineation of built-up areas as listed in Chapter 2, it will be possible to compare the results between countries and between different points in time. The Copernicus land monitoring service is a long-term EU initiative and provides a very good foundation for this.

Data regarding inhabitants and jobs can sometimes be difficult to obtain. If such data are available for only larger spatial units, they need to be broken down into smaller units. There are two solutions to this problem: (1) the use of inhabitant and job data at a resolution between the NUTS-2 scale and the scale of the 1-km^2 grid (e.g. at the scale of municipalities), if such job data are available; or (2) the distribution of inhabitants and jobs from NUTS-2 regions into grid cells based on remote sensing data (e.g. using light emissions or sealing levels as indicators of the densities of inhabitants and jobs) and information from regional planning maps (e.g. zoning information). However, there are some initiatives aimed at providing global gridded population data (e.g. WorldPop, Landscan, the Global Rural–Urban Mapping Project (GRUMP) and the Gridded Population of the World (GPW) data product) that may improve data availability. Even if data regarding the number of jobs are unavailable, the *WUP* method can still be applied because the biggest contribution to sprawl comes from residential areas, in which there are almost no jobs (e.g. in Switzerland, 51.2 % of sprawl is residential, 15.4 % is commercial/industrial sprawl, 32.8 % is mixed zone sprawl and 0.7 % results from recreation/tourism) (Schwick et al., in revision. Therefore, larger regions can be compared even without job data because the ratio of the number of inhabitants to the number of jobs exhibits less variability on relatively large scales; issues due to a lack of job data become relevant at only a higher resolution (e.g. at the scale of the 1-km^2 grid and for census tracts in central urban areas).

The urban sprawl analysis presented in this report is appropriate for all countries in Europe (EU-28 + 4) and it will be possible to apply this analysis to more countries as soon as the relevant data are available. The three components of sprawl can be considered separately, which is also helpful towards understanding and interpreting sprawl as a whole. The *WUP* method has important advantages (Section 2.2), which are outlined below.

1. The *WUP* method measures urban sprawl in accordance with the definition of 'urban sprawl' given in Section 1.2.1 of this report. The *WUP* method was constructed with this objective in mind. For example, *WUP* captures the influence of the density of inhabitants and jobs on sprawl if the density of inhabitants and jobs is declining, because the *LUP* then increases, and, accordingly, sprawl also increases.

2. The *DIS* metric is a new component that is not captured by earlier methods, since the compactness of built-up areas needs to be assessed **at a certain scale**, which is specified by the value of *HP*. Metrics of compactness that do not include a specification of *HP*, such as simple metrics based on the perimeter-to-area ratio, are not suitable because they are scale-independent and therefore favour compactness at the largest scale (i.e. corresponding to the size of the reporting unit). For example, on

the country level, the most compact configuration would correspond to one large city in the shape of a circle, while the rest of the country would be empty. However, this configuration does not correspond to sustainability and was never used in human history. A configuration in which people live in several locations in a country, far enough away from each other that the surrounding landscape can meet most of their needs, is more sustainable. Therefore, compactness needs to be assessed at a certain scale (as is the case with *DIS*).

3. The *WUP* metric is sensitive to all changes in the amount and spatial configuration of built-up areas and to changes in *LUP*.

4. The *WUP* metric can be calculated at any scale of interest (from single neighbourhoods to entire countries, and even beyond).

5. Targets and limits for sprawl can be established using the *WUP* method, for which the limit can be a function of the increase of the number of inhabitants (as is done in an ongoing project in Switzerland by Schwick et al. (publication scheduled for August 2016); see practical example 4 in Section 4.3.2). This is a major advantage, since there is a greater potential for densification if the population increases strongly, that is, if *LUP* decreases strongly, sprawl will be reduced more significantly.

The assessment of *WUP*, on the basis of 34 criteria related to environmental indicators, reveals that it is highly suitable as an environmental incator, as it meets all of these criteria well. We have systematically checked how well the *WUP* method meets environmental indicator requirements. Niemeijer and de Groot (2008) reviewed the environmental indicator criteria in the literature and have integrated them into six groups, comprising a total of 34 criteria. Nine of these criteria (policy relevance, progress towards targets, available and routinely collected data, spatial coverage, temporal coverage, national scale and representativeness of data, understandability of indicators, methodologically well founded, and EU priority policy issues) were proposed by the EEA (2005) and are of particular importance for this report because the EEA provides the results for environmental reporting at the European level.

The results of this study can also be included in the national monitoring systems of the countries investigated. However, some countries may have a more accurate definition and delineation of built-up areas and jobs, and may prefer to use their own definitions for their national reporting rather than the data sets of the built-up areas used in this report. In some countries, more accurate data regarding built-up areas at higher resolutions, that also contain information regarding earlier points in time, are already available. For example, a long series (for 1885 to 2010) is available for the development of *WUP* and its components for Switzerland as a whole, for its cantons and for its municipalities, and a relatively long series (1935 to 2010) is also available for a raster grid (Figure 4.1a). This allows a comparison of current sprawl dynamics with historic sprawl at various points in time. The value of *WUP* for Switzerland in 2010 was 2.48 UPU/m^2 (Schwick et al., 2013); it has steadily increased since 1885, at which time it was 0.38 UPU/m^2. Therefore, sprawl in Switzerland has increased more than sixfold in the last 125 years. By 1959, half the 2010 value had been reached; therefore, in just 51 years, urban sprawl doubled. The sharpest leaps took place between 1960 and 1980, a period of suburbanisation in Switzerland, and between 2002 and 2010, during which time Switzerland's population and economy grew rapidly.

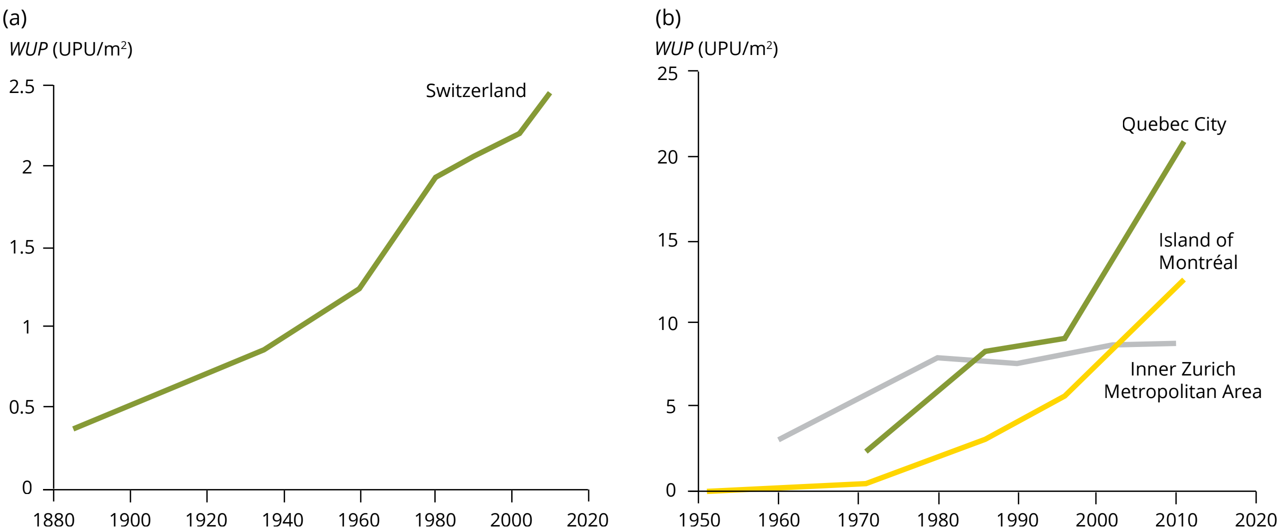
The *WUP* method was implemented in the Swiss landscape observation system (*Landschaftsbeobachtung Schweiz* (LABES)) in 2010 and was updated in 2015 (Kienast et al., in preparation). The indicator is updated every 6 years. Urban sprawl has been included in this monitoring system because urban sprawl alters the visual perception of landscapes: built-up areas are among the most prominent contributors to the transformation of natural landscapes into technically dominated cultural landscapes. As a result, the delineation of areas that are built up and areas that are not built up is becoming fuzzy. A survey of 2 800 households shows that the lowest values for authenticity and perceived landscape identity were assigned to fast-growing suburban communities (i.e. sprawled areas), whereas urban and rural areas were deemed to have more authentic landscapes and more distinctive landscape character than sprawled areas (Kienast et al., 2015). However, the *WUP* method and the other quantitative indicators do not capture the various qualitative aspects of sprawl (e.g. aesthetics). Qualitative aspects are also important and should be considered (using qualitative methods) for regional planning; the *WUP* method does not replace these qualitative methods, but it can complement them in order to improve the toolbox of regional planners. Therefore, LABES combines quantitative data and qualitative information from questionnaire surveys to capture changes in the landscape and in landscape perception.

The results regarding urban sprawl in Germany, obtained using the *WUP* method and 2010 data from the official topographic–cartographic information system of Germany (*Amtliches Topographisch–Kartographisches Informationssystem* (ATKIS)), are included in the system for monitoring the development of settlements and open spaces, called 'IÖR-Monitor' (http://www.ioer-monitor.de) (Schwarzak et al., 2014). In addition, the Alternative Bank of Switzerland (ABS) uses the *WUP* method in order to prevent further increases in urban sprawl; they assess the contribution that new construction projects and mortgage lending are likely to make to sprawl (see Box 4.4), and do not give mortgages to projects that would strongly contribute to urban sprawl (Alternative Bank of Switzerland, 2012). The *WUP* indicator is also part of a new assessment system for sustainable construction in Switzerland (*Standard Nachhaltiges Bauen Schweiz* (SNBS)). The SNBS aims to reduce the negative impacts of new construction projects on society, the economy and the environment. The *WUP* metric serves as an indicator to assess the likely losses of soils, biodiversity and landscape.

The *WUP* method has also been applied in North America, for which patterns of development different from those seen in Europe are apparent. A comparison between Montréal and Quebec City (both in Canada) and Zurich (in Switzerland) for the period 1951–2011 (Figure 4.1b) shows that the phases of the largest increases in urban sprawl have been more recent in Montréal and Quebec City than they have been in Zurich (Nazarnia et al., 2016). Urban sprawl has increased exponentially in Montréal since 1951 (Figure 4.1b). The most rapid increases in sprawl in Montréal and Quebec City have occurred in the last 25 years, whereas in Zurich the largest acceleration in the rate of sprawl occurred in the 1960s. In contrast, the level of sprawl in Zurich was higher before 1980, but was then surpassed by Montréal and Québec City. The largest increases in *LUP* were observed in Quebec City and on the Island of Montréal, while *LUP* increased only slightly in Zurich. Two major factors can explain this striking difference in sprawl dynamics: Swiss planning legislation and a much higher availability of public transport in Zurich than in Montréal or Quebec City. Such a comparative analysis of urban sprawl can greatly help land-use planners to critically assess projected plans, and control urban sprawl and its negative consequences. Measuring only the extent of built-up areas is not sufficient to reveal the full extent of these patterns.

Indicators of urban sprawl are also relevant for monitoring the integration of transport and the environment. Transport infrastructure may contribute to increased urban sprawl, and sprawling development may lead to additional transport infrastructure (see Section 4.3). To measure progress towards existing objectives and targets on the European level, the EEA developed the Transport and Environment Reporting Mechanism (TERM) programme and has published TERM reports annually since 2000. Including urban sprawl indicators in TERM reports would contribute to a better understanding of the spatial effects of transport infrastructure.

Figure 4.1 Two examples of using the *WUP* method for monitoring urban sprawl in Switzerland (a) and the Island of Montréal and Quebec City, Canada, and Zurich, Switzerland (b)



Note: The data shown in (a), for the period 1885–2010, are used in LABES. In (b), the time series (1951–2011) for the Island of Montréal and Quebec City, and the comparison with the Inner Zurich Metropolitan Area, are shown. The values for Switzerland, in (a), are for the entire country. Therefore, they are much lower than the values for the metropolitan areas of Montréal, Quebec City and Zurich, in (b).

Sources: Nazarnia et al., 2016; Kienast et al. (in preparation) and Schwick et al. (in revision).

The reassuring experiences and results regarding the monitoring of landscape quality in Switzerland suggest that a monitoring system of landscape quality could also be implemented at the European level in the near future. Urban sprawl, in particular, is a highly important indicator with regard to monitoring landscape quality. The results from this report can be included for this purpose at the European scale. In addition to the degree of urban sprawl, other indicators of landscape quality, such as landscape fragmentation (EEA and FOEN, 2011a), are also useful and should be considered in the future. Both urban sprawl and landscape fragmentation are candidates for the EEA's CSI. The results of this report are highly relevant for environmental monitoring and provide a comparative basis for further investigations. We recommend that sprawl values are updated on a regular basis in order to detect trends in the development of urban sprawl in Europe.

4.2 Implications for urban and regional planning, and for nature conservation

4.2.1 Relevance for urban and regional planning

Planning instruments and procedures play an important role in shaping land-use change and, particularly, urban sprawl. However, there are various other societal factors (e.g. planning legislation and household sizes) that may have an even stronger influence on changes in land use and urban sprawl; some of these factors are reflected in the analysis of the driving forces in this report.

Regional planners often already have a good knowledge of the factors that contribute to urban sprawl in their region, and about the measures and planning instruments that would control sprawl (Box 4.1). For example, an extensive list of potential measures have been discussed in the literature (Sustainability Advisory Board of Baden-Württemberg, 2004; Bizer et al., 2014; Bovet et al., 2013). In many regions, a strengthening of regional planning may be required to enable planners to more effectively control urban sprawl. However, unfortunately, the institutional set-up in some countries (e.g. the United Kingdom and Denmark) has terminated regional bodies that previously monitored municipalities in terms of environment and land development. Therefore, because of a lack of monitoring, this has increased the risk of undertaking land development that contributes to urban sprawl without any repercussions. How then can a statistical analysis of driving forces generate any new knowledge, and inform urban and regional planning? One way in which this can be achieved is through discussions of how regional planning can address each of the drivers.

However, the means by which planners can influence these drivers are limited because the most important decisions about drivers are made at a political level, and some drivers reflect trends that are difficult to influence, even at a political level.

Socio-economic data are available on the European level for some factors that have been shown to have an influence on sprawl (e.g. the number of cars per inhabitant). Geophysical data (e.g. with regard to relief energy and irreclaimable areas) are also available. The geophysical factors are considered in planning, because they usually do not change over time and cannot be modified, while socio-economic variables can change, sometimes relatively quickly. At least some of the socio-economic variables can be influenced to some degree. For example, building cooperatives can have an effect on household size by setting a minimum number of people that can live in a given apartment size (e.g. at least three inhabitants in a four-room apartment).

However, there is a lack of European data for several socio-economic factors that almost certainly contribute to urban sprawl, such as the wish for more privacy (Bruegmann, 2005), the strength of regional planning legislation and practices, land prices and land ownership. All of these factors can affect sprawl differently in different places and act at different scales, and often exhibit time lags. This makes it difficult to disentangle their effects and interactions if data are incomplete or are available for only a short period.

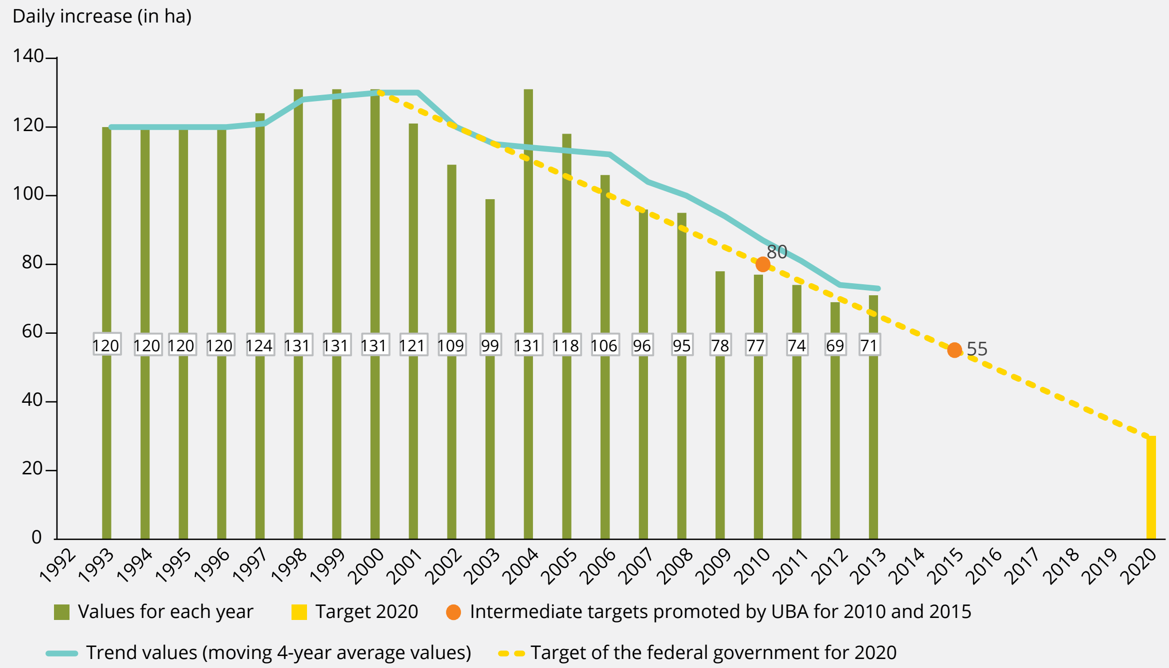
Nevertheless, the results of our statistical analysis reveal that several socio-economic variables are important drivers of urban sprawl. These variables relate to transport infrastructure (road density and railway density), demography (population density and age structure), the economic situation (*GDP*c and employment ratio), governmental effectiveness and changes in lifestyle (e.g. household size and car ownership). These factors are of fundamental importance, although various other variables are missing. For driving forces of urban sprawl that cannot be influenced, it may be more promising to develop strategies that decouple these drivers from sprawl rather than attempt to change them.

Transport infrastructure strongly contributes to urban sprawl, as our analysis has demonstrated. European transport infrastructure projects have had a particularly strong influence on spatial development in Europe, since transport and settlement development reinforce each other (Section 4.3). This is important to consider on all planning levels because road and railway infrastructures last for

Box 4.1 The 30-ha target in Germany

The 2011 *Roadmap to a resource efficient Europe*, which is part of the Europe 2020 Strategy, has the following aim: 'By 2020, EU policies take into account their direct and indirect impact on land use in the EU and globally, and the rate of land take is on track with an aim to achieve *no net land take by 2050*' (EC 2011). However, so far, no country in Europe has truly established effective quantitative limits for urban sprawl, although some countries have established targets aimed at reducing the *rate* of land uptake for built-up areas. Although this approach does not take into account the spatial arrangement of the built-up areas and does not limit the land uptake per person, it is a major step towards controlling urban sprawl. For example, Germany has been discussing a target with regard to urban development for more than two decades. The National Sustainability Strategy for Germany of 2002 has implemented a target, to be reached by 2020, of a maximum rate of 30 ha/day for the increase in built-up areas in Germany (Government of Germany 2002). In the 1990s, the rate of increase had been about 130 ha/day (Figure 4.2). Most recently, the Christian Democratic Union (CDU) party and the Social Democratic Party (SPD) confirmed the 30-ha target in their contract of coalition upon forming a new German government in 2013. However, the German government has implemented few measures to achieve its target so far. The target corresponds to a maximum increase in *PBA* of 0.34 % per year. Although the rate of increase has slowed down since 2000, to 73 ha/day in 2013 (i.e. by 0.82 % per year) (Government of Germany 2015), the target has not been reached. Recent estimates anticipate that the rate of increase will most likely remain at 63 ha/day for the years between 2015 and 2025 (Government of Germany 2015). This implies that the target will probably be missed by more than 100 %, and that more effective measures to control urban sprawl are urgently needed.

Figure 4.2 The daily increase, between 1993 and 2013, in the amount of built-up area (settlements and transport areas combined) in Germany, and the target for 2020



Note: UBA, Federal Environmental Office (Umweltbundesamt) of Germany.

Source: Penn-Bressel, 2015.

generations, and their influence on future sprawl will, essentially, be permanent. However, the influence of these infrastructures differs. Railway lines are linear features of the landscape that have stops at only certain locations, while roads provide access to much larger areas of the landscape, because they can easily be branched into hierarchies of highways and access roads. Therefore, new railway lines can either decrease or increase urban sprawl, depending on the location and density of the built-up areas around the railway stations, while new roads, most often, lead to an increase in urban sprawl. This is apparent from the statistical analysis: road density is more significantly correlated with urban sprawl than railway density. Accordingly, planning should give a much higher priority to the development of public transport rather than new roads, and give more emphasis to high-density urban development around public transport stations.

Demography also has a strong influence on urban sprawl and all of its components. From rural to peri-urban to suburban areas, sprawl increases with increasing population density; however, in urban areas (i.e. towns and cities), sprawl decreases with increasing population density. This effect of higher population densities leading to a reduction in sprawl (i.e. through a reduction in land uptake per person) is apparent from our statistical analysis. Because of demographic trends and the free movement of all people in Europe, there are regions with increasing and regions with shrinking populations, and planning must anticipate and respond to these changes. Regional planners cannot control changes in the population of a region, but it is possible to limit building zones in order to facilitate a decrease in the land uptake per person in built-up areas. This implies that, through planning measures (see Section 4.3), planners should support the development of suburban areas, and all other areas, towards areas with a more urban character and a lower land uptake per person. In order to achieve a lower *LUP*, future population changes need to be anticipated. Suburban areas will then develop a more urban character (i.e. they will become less sprawled).

The ***GDP* per person** is also a driver of sprawl, at least in some parts of Europe and through its effects on other explanatory variables. Accordingly, higher levels of sprawl are expected if the *GDP* per person continues to grow in the future. Specifically, if the *GDP*c increases, this means that more money will be available, and past experiences have demonstrated that more available money is often used for larger houses and second homes; this has strongly contributed to sprawl in the past. To counteract this undesirable development, planners should direct any newly acquired wealth into compact, well-mixed built-up areas, with short distances between homes, places of work and places of recreation. This combination of wealth and good planning practices should allow a high quality of living at a relatively low land uptake per person.

Governmental effectiveness measures how effectively national administrative institutions manage their tasks. This includes many kinds of tasks, and urban and regional planning are only small parts of these tasks. High effectiveness will usually result in a higher *GDP*c, a higher road density and a higher population density, and will lead to higher levels of sprawl in most cases, which is clearly apparent from our statistical results. Urban and regional planning, therefore, need to be strengthened considerably in order to cope with such forces and need to be provided with the required resources, regulations and instruments (see measure 4 in Section 4.4).

The regions in Europe exhibit a large diversity of geophysical and historical conditions, patterns of economic development, institutional settings, and planning processes and instruments. This is reflected in our statistical analysis, since, for each part of Europe, different driving forces are responsible to different degrees for the current levels of urban sprawl. The significant differences between the actual and predicted levels of sprawl (Section 3.3) provide a foundation for a more in-depth analysis of regions that have performed better than others in terms of avoiding urban sprawl. This will also help to identify more best-practice examples from the European regions.

4.2.2 Relevance for biodiversity and nature conservation

Urban sprawl affects biodiversity in various ways (Johnson and Klemens, 2005; Gagné and Fahrig, 2010; Faiths et al., 2011). For a given human population, sprawled areas take up more land and, therefore, reduce the amount of habitat available for wildlife than less sprawled areas do; furthermore, human disturbances are more spatially distributed in areas with high levels of sprawl. The development of residential and industrial areas often destroys or degrades exiting habitats, including microhabitats, which are essential for many insect and plant species, and directly reduces species richness. Transport networks that connect built-up areas fragment and isolate habitats (EEA and FOEN, 2011a). This increases traffic-related wildlife mortality, impedes the movement of animals in the landscape, reduces the probability that animals will find mates, increases the likelihood of inbreeding, reduces genetic diversity (Noël et al., 2007) and lowers the ability to resist stochastic events, which leads to higher extinction rates.

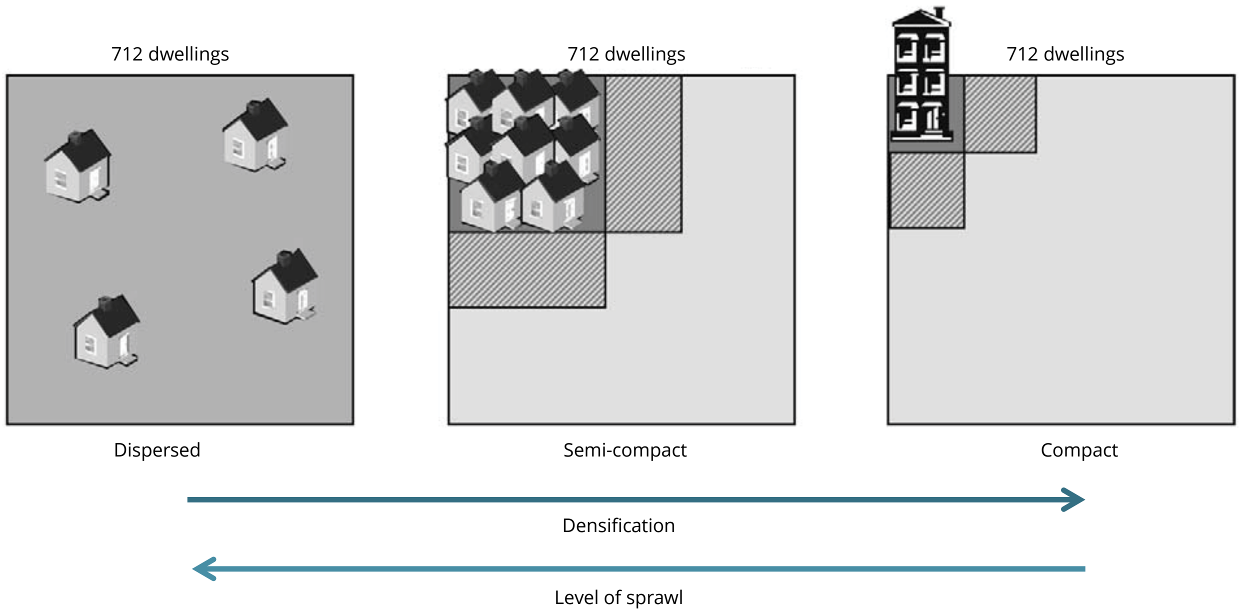
Interestingly, the diversity of plant species is often higher in sprawled regions than in surrounding open landscapes that are dominated by intensive agriculture. However, this is not necessarily good news for biodiversity because (1) intensive agriculture clears many open landscapes of their former richness of habitat structures; and (2) the higher species numbers in sprawled regions are usually the result of the introduction of non-native species, which often occurs at the expense of native species (McKinney, 2008; Kowarik, 2011). Even though a certain number of native species, including some rare species, can be observed in built-up areas, these areas play only a limited, although still important, role in biodiversity conservation. For example, urban areas often host special habitat types for rare species that are not available elsewhere and deserve protection. However, built-up areas cannot, or can to only a limited degree, compensate for the loss of other habitats in the open landscape, and biodiversity in cities depends, to a large degree, on the availability of natural and semi-natural habitats in the vicinity of the cities, and can be successfully conserved only in combination with these habitats (Lambelet-Haueter et al., 2010).

Urban sprawl often contributes to the invasion of habitats of the native flora and fauna by non-native species (Hansen et al., 2005; Nobis et al., 2009; Concepción et al., 2016). Several invasive species establish more easily in sprawled areas, in which they can successfully compete with native species (Manchester, and Bullock, 2000; Bertolino, and Genovesi, 2003; Genovesi et al., 2009). For example, in many European regions, giant cow parsnip (*Heracleum mantegazzianum*) and Himalayan Indian balsam (*Impatiens glandulifera*) dominate the vegetation. These plants have escaped from botanical and private gardens. In sprawled areas, the border between built-up areas and the open landscape is longer than it is in non-sprawled areas and, therefore, invasive species can spread more easily in the landscape. Himalayan Indian balsam negatively affects the visitation rates of co-occurring native plant species by pollinating insects (Chittka, and Schürkens, 2001). As many plant species rely on pollinating insects to set seeds, fewer visits can result in reduced offspring. Grey squirrels (*Sciurus carolinensis*) were introduced to London (in the United Kingdom) and Turin (in Italy) in the 20th century and this has led to the extermination of some local populations of the native red squirrel (*Sciurus vulgaris*) (Bertolino and Genovesi, 2003). Urban areas provide suitable conditions for many invasive species, because the climatic conditions are more favourable for them in urban areas than in rural areas.

The pressure on native species is further increased by the presence of domestic animals. For example, cats in sprawled settlement areas may prey on birds and small mammals (Thomas et al., 2014), which, in some cases, can result in local extinctions of rare species.

Studies of the ecological effects of urban sprawl have not always controlled for the number of people living in a given area. Urban sprawl has three components: the number of people, the amount of built-up area per person and the spatial distribution of their dwellings. It is important to distinguish between the effects of the number of people and the spatial distribution of their dwellings. When a certain number of people need to live in a landscape, the magnitude of the effects on biodiversity and the level of sprawl should be minimised. To make the results of future studies about the effects of urban sprawl more comparable, such studies should control for the size of the human population. This is illustrated by the hypothetical development scenarios in Figure 4.3, which represent gradients of land uptake per person and decreasing sprawl. In these scenarios, the total number of people is assumed to be the same and, for a given landscape, the same number of dwellings is constructed but at different densities, according to a rural (dispersed scenario), suburban (semi-compact scenario) or urban (compact scenario) character. In the semi-compact and compact scenarios, the medium-grey shading

Figure 4.3 Studies on the effects of urban sprawl should take the size of the human population into account



Note: In these hypothetical examples, the same number of dwellings is constructed at different densities according to a rural (dispersed), suburban (semi-compact) or urban (compact) character. The medium-grey shading in the semi-compact and compact scenarios represents the 'edge effect' of the built-up areas; more area is unaffected by the 'edge effect' in the compact scenario that in the semi-compact scenario.

Source: Modified from Gagné and Fahrig, 2010.

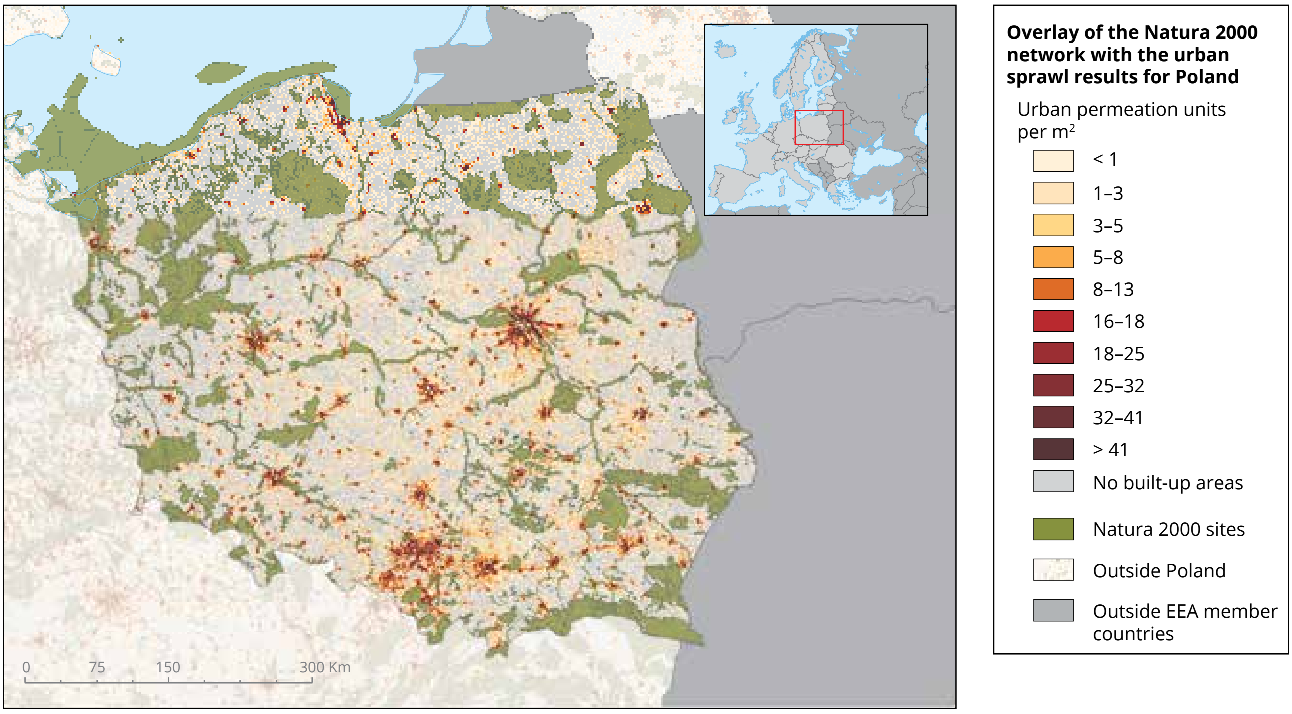
represents the areas that are affected by the 'edge effect' of the built-up areas (i.e. areas that are adjacent to the built-up areas). More area is unaffected by the 'edge effect' in the compact scenario than in the semi-compact scenario. Gagné and Fahrig (2010) applied this design to their study of forest-breeding birds and found that forest birds and forest-interior birds were most abundant in the compact scenario and most speciose in the semi-compact scenario, whereas forest-edge birds were most abundant and speciose in the dispersed scenario; however, the evenness of all three bird groups was highest in the compact scenario (Figure 4.3). The study concluded that compact housing developments (i.e. those built at a high density over a relatively small area) minimise the impacts of a given human population on forest-breeding birds.

The expansion of built-up areas increases the potential for conflicts with protected areas (Map 4.1), as a result of an increase in the spread of disturbances and higher pollution. For example, noise and light emissions can affect the behaviour, reproductive success and survival rates of animals. A reduction in urban sprawl reduces the costs associated with implementing wastewater treatment facilities that can reduce particularly harmful pollution by endocrine disruptors and other compounds. These pollutants have increased substantially in recent years (Van Metre et al., 2000) and are responsible for declines in freshwater fish and amphibian populations (Bryer et al., 2006).

The implications for nature conservation, related to the analysis of driving forces of urban sprawl investigated in this study, are similar to the implications for urban and regional planning (Section 4.2.1). Since many driving forces are expected to increase in the coming decades, urban sprawl is also likely to further increase. Because of time lags between changes in urban sprawl and the responses of the fauna and flora, effects on biodiversity are expected from the impacts of both earlier and future pressures from urban sprawl.

The conservation of unsprawled and unfragmented habitats, such as Natura 2000 areas and roadless areas (Map 4.1), is particularly important (Selva et al., 2011, 2015). The bundling of transport infrastructures can help to avoid landscape fragmentation and protect large unfragmented areas, just as the densification of built-up areas can help to prevent urban sprawl.

Map 4.1 Overlay of the Natura 2000 network with the urban sprawl results (*WUP$_p$* values for 2009) for the 1-km² LEAC grid, using Poland as an example



Note: In some parts of the country, the areas of urban sprawl are very close to the Natura 2000 areas. The Natura 2000 areas are much smaller in regions with higher levels of urban sprawl.

Sources: EEA, 2015c for Natura 2000; this report for map of *WUP*p values. http://www.eea.europa.eu/data-and-maps/data/natura-2000-eunis-database#tab-metadata (accessed 19 March 2015).

The contribution of cities to the slow down of the loss of biodiversity is important for biodiversity conservation (Box 4.2) (Chan et al., 2014). Therefore, natural areas, green spaces within built-up areas and green belts adjacent to built-up areas should be preserved if built-up areas are densified. This is part of a high-quality densification for both humans and biodiversity (see guideline 4 in Section 4.3). An increase in *GDP*c would allow for higher quality standards in planning, for both human needs and nature conservation. Green belts and green infrastructure (e.g. wildlife corridors) are important for biodiversity and should not be disrupted by built-up areas and the associated road networks.

In many parts of Europe, populations of large terrestrial mammals are either endangered or live in small numbers. Many of these species require large habitats and migrate or disperse over long distances (Boitani, 2000; Mysterud et al., 2007). The long response times of many species to changes in landscape structure present a particular challenge. The current wildlife population densities may not be a response to the current degree of urban sprawl, but to sprawl levels from decades ago, and wildlife populations may continue to decline for many years, even after the degree of urban sprawl has stopped increasing. In addition, urban sprawl affects wildlife populations in combination with other stress factors, such as climate change, the intensification of agriculture and other cumulative land-use changes. Therefore, it is usually impossible to predict when thresholds will be crossed at which native species will no longer be able to adapt and will disappear. As a result of such losses of native species, ecosystems will change to a different state and exhibit a different community composition, which will affect their ability to provide ecosystem services. This lag in the occurrence of extinctions in response to landscape changes has been called an 'extinction debt' (Tilman et al., 1994; Kuussaari et al., 2009). This makes it all the more important that a precautionary approach is adopted, which guides urban sprawl and other land-use changes in the desired direction in the coming decades.

All these aspects are very important and should be considered by planners in relation to their activities, in addition to the considerations listed in Section 4.2.1. For example, the goals of preserving and linking wildlife habitats and of conserving the natural scenery will become more and more difficult to achieve with increasing levels of sprawl. Furthermore, the more dispersed that settlements become in the future, the more expensive the restoration and maintenance costs for green infrastructure will be.

4.3 Measures to control urban sprawl

The current trends of urban sprawl in many parts of Europe clearly contradict the goals of sustainable development, and cannot continue in the long term. Thus, sustainability will become more and more difficult to achieve as sprawl advances (Haber, 2007). However, the use of appropriate countermeasures today to significantly slow down the increase of the problem still seems realistic. Such measures should be applied now — the longer the delay, the faster the target of sustainability will slip from Europe's grasp.

Box 4.2 Biodiversity monitoring and the City Biodiversity Index (CBI)

There are several systems already in place for monitoring biodiversity. Two examples are the EuMon project, which aims to develop 'EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest' and hosts a web portal which covers a total of 663 monitoring schemes in Europe (http://eumon.ckff.si/index1.php). Some of these are based on citizen science to better cover large spatial and temporal extents (EEA, 2014). This project was established to evaluate biodiversity monitoring in Europe and to develop relevant tools and methods via this portal. The second example is the Biodiversity Monitoring Switzerland (BDM) programme. The Swiss Federal Office for the Environment (FOEN) launched this programme which includes 34 indicators based on the 'pressure–state–response' (PSR) model developed by the OECD. Accordingly, these indicators are grouped into 15 **state indicators**, which capture the most important changes in biodiversity, 12 **pressure indicators**, which capture factors that affect species diversity, and seven **response indicators**, which measure activities that contribute to maintaining biodiversity. Urban sprawl is a threat to biodiversity, but it is not yet covered well by these monitoring systems. Therefore, a recent initiative created the City Biodiversity Index (CBI) to better consider links between urban areas and biodiversity, since cities can contribute significantly to global efforts to reduce the rate of biodiversity loss. The CBI has been developed as a tool to evaluate the state of biodiversity in cities and to provide insights with regard to improving conservation efforts (Chan et al., 2014; Kohsaka et al., 2013). It was proposed at the ninth meeting of the Conference of the Parties (COP-9) to the Convention on Biological Diversity (CBD) in May 2008. Three expert workshops, held in 2009, 2010 and 2011, were organised by the National Parks Board of Singapore and the Secretariat of the CBD, in collaboration with the Global Partnership on Cities and Biodiversity, to develop the index. The CBI, also called the Singapore Index, includes 23 indicators, such as the proportion of natural areas in a city. Several of these indicators are affected by urban sprawl. Barcelona, Brussels, Edinburgh, Heidelberg, Lisbon and Tallinn are among the first cities to have applied the CBI.

Particular attention needs to be paid to these mutual influences: regional planning with regard to transport needs and the transport network with regard to regional development (Figure 4.4). These influences can play off each other in two ways:

1. negatively, by promoting dispersed settlements and increased fragmentation, starting with the designation of building zones in the periphery, which leads to new traffic, requires the removal of bottlenecks in road construction and results in the designation of additional building zones (Figure 4.4);

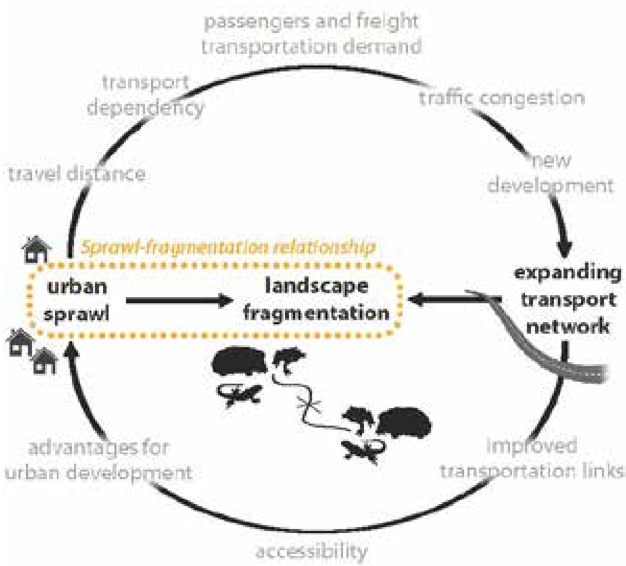
2. positively, by encouraging compact settlements so that sprawl is contained or reduced; this positive feedback effect is both possible and desirable.

These considerations apply not only to road traffic, but also to public transport networks. If attention is not paid to these factors, there is the danger of a lock-in effect, which would result in lower transformability (Walker et al., 2004). Existing and future transport developments exert a powerful influence on people's mobility and on future settlements. Such projects could lock urban sprawl into an undesirable course for years ahead. To avoid this lock-in effect, the vicious circle must be broken (see Figure 4.4).

Measures for controlling urban sprawl can be implemented effectively only if there is an awareness of the issue and if feasible solutions are proposed. Decision-makers and the general public should, therefore, be made more aware of the long-term consequences of urban sprawl, habitat loss and the loss of agricultural soils, and need to be informed about suitable countermeasures. According to our results, the most effective approach for keeping further sprawl to a minimum involves the reduction of land uptake per inhabitant and the concentration of settlement areas (i.e. without extending settlement borders). Consequently, the following five general guidelines are essential with regard to supporting efforts to control urban sprawl.

1. **A clear separation of building zones and non-building zones, and long-term settlement restriction.** Building zones and non-building zones should be clearly distinguished. The built-up areas should be compact, and should not fray at the fringes. The sizes of the building zones should be determined in a rigorous way that does not easily allow for the extension of their boundaries. These boundaries should be fixed on a long-term basis. Green belts may be one feasible option for setting these boundaries (Siedentop et al., 2016).

Figure 4.4 The expansion of road networks and urban sprawl are interlinked through a feedback loop, which may result in a lock-in effect



Note: A lock-in effect would result in areas of high *LUP* that could not be served efficiently by public transport and, therefore, people would depend more and more on the use of cars.

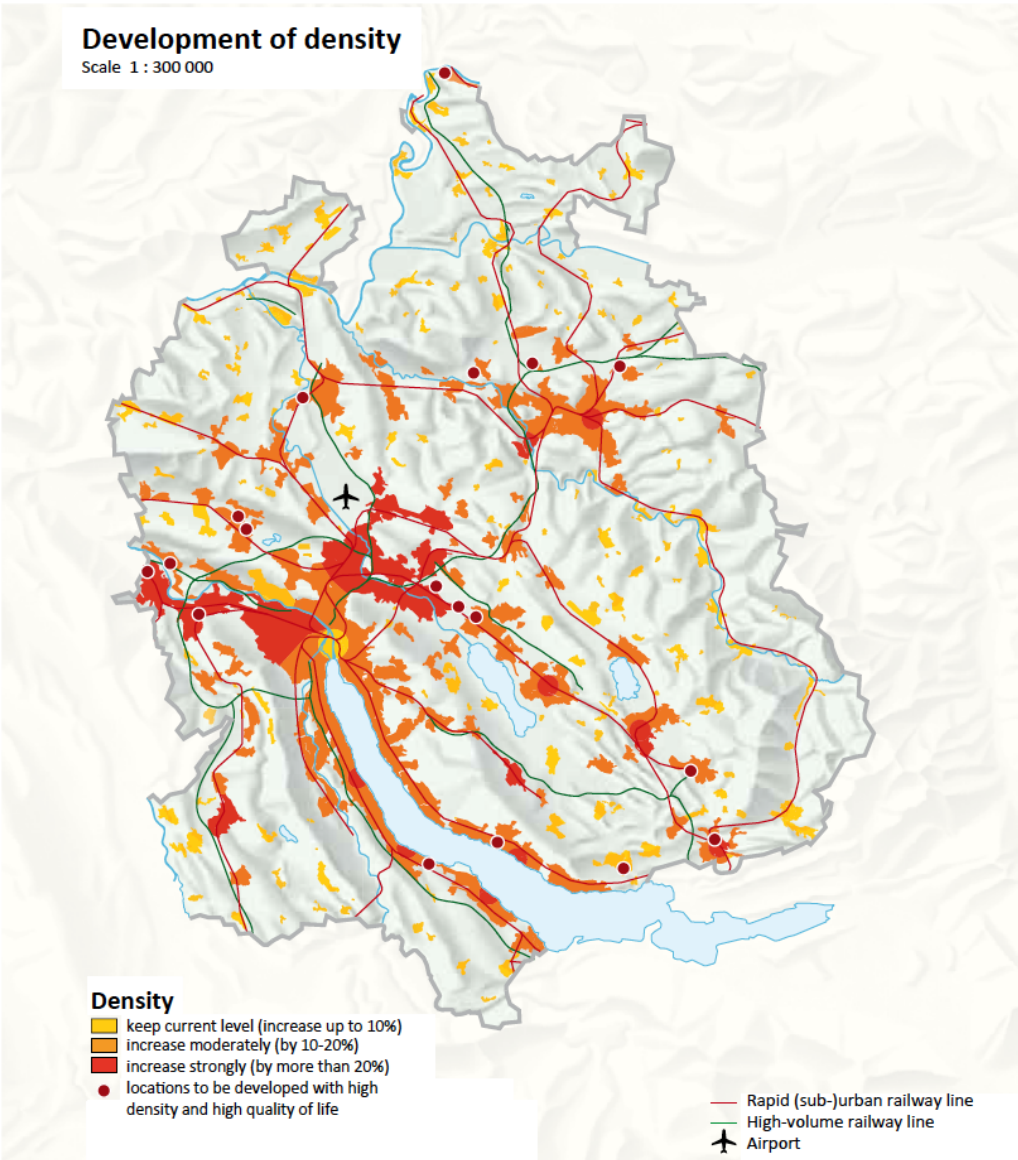
Source: Torres, 2016.

2. **Building in only designated building zones.** Construction outside designated building zones creates considerable sprawl because it badly affects *DIS* values and, as a rule, results in higher *LUP* values. Exceptions are permitted only if new buildings must be constructed in a particular location because of their function (e.g. water supply facilities).

3. **Preventing the dispersed expansion of built-up areas.** New built-up areas and individual buildings should only be allowed at locations in which *DIS* values are low (i.e. have a compact configuration). This can be done by in-filling (i.e. the use of gaps within existing built-up areas such as unused sites or brownfields). If such in-filling is not possible, then in-filling should be done on the edge of existing built-up areas or at other places with low *DIS* values. For example, in the Netherlands, 34 % of residential developments between 2001 and 2005 took place in existing urban areas (Buitelaar et al., 2008). In England, the national government successfully introduced a brownfield housing target of 60 % in 1998, which stipulated that 60 % of all residential developments must take place on previously developed land or through the conversion of existing buildings. Since 2000, this target has been achieved every year (Adams et al., 2010).

4. **The densification of existing built-up areas and minimum densities of new built-up areas.** Not all built-up areas have the same potential for densification, but even moderate densification is desirable because sprawl is reduced at locations in which densification takes place and further sprawl elsewhere is prevented (i.e. fewer new built-up areas should be needed). If the construction of new built-up areas is unavoidable, the *LUP* should be, at least, as low as the average *LUP* in the region surrounding the new built-up areas. Densification should occur in a way that increases the quality of the built-up areas. An important part of this is that green spaces in built-up areas should be preserved and improved in their quality with regard to recreation. The required levels of densification do not imply that urban areas will be dominated by high-rises in the future. Even if no new built-up areas are planned, the level of densification is predicted to be in the range of 5 % to 30 % over the next 50 years (depending on population growth). For example, the Canton of Zurich (in Switzerland) is planning to densify the existing built-up areas by approximately 20 % by 2040 (Map 4.2). Therefore, urban sprawl will be significantly reduced in the Canton of Zurich. Almost no further expansion of the built-up areas is allowed in the Canton of Zurich. Therefore, any increases in population have to be

Map 4.2 An example of a densification plan from the Canton of Zurich, Switzerland



Note: The projected population growth between 2013 and 2040 is 20 %.

Source: Regierungsrat Kanton Zürich, 2014.

accommodated mostly in the existing built-up areas. The necessary densifications are relatively modest (on average, less than 20 % of the existing density). The densification will take the existing settlement types into account. Rural areas will keep their rural character (densification will be < 10 %). The highest levels of densification (> 20 %) will occur in the suburban areas shown in red on Map 4.2. They are predicted to transition from having a suburban character to having an urban character (Regierungsrat Kanton Zürich 2014). This is in accordance with the results of the Swiss National Research Programme 65 'New Urban Quality', which concluded that the urbanisation of suburban areas is one of the main tasks of society in the 21st century (Sulzer and Desax, 2015).

5. **The integrated planning of transport and settlement development.** The relationship between built-up areas and public transport is important to consider because the density of built-up areas is related to the attractiveness (level of service) and cost effectiveness of public transport (see Box 1.2 in Chapter 1). Therefore, planning of settlement development and transport infrastructure should be integrated. This requires a planning process that transcends administrative boundaries and integrates various sectors in order to control the development of compact settlements and ensure a well-functioning transport infrastructure. A central condition for breaking the vicious circle of transport and sprawl (Figure 4.4) is the comprehensive coordination of infrastructure, mobility and regional development (Matthey, 2012).

These guidelines can be applied in regions in which the population is growing, stable or declining. However, in regions in which the population is shrinking, additional guidelines should be considered. In such cases, it is desirable that built-up areas are reduced in proportion to the decrease in the population. If this is not feasible, the construction of new built-up areas should, at least, be prevented (i.e. no further built-up areas should be allowed). Otherwise, the *LUP* would increase even more drastically. Since the population is shrinking in several regions in Europe, this is an important consideration for many places. However, there is a risk that the removal of built-up areas will be carried out in a way that increases the dispersion of the remaining built-up areas in such regions. For example, this is true for cases in which parts of central urban areas are being perforated, rather than built-up areas on the outskirts being removed. The *WUP* method can be used to detect locations in which the removal of built-up areas would decrease, and hence improve, the value of *DIS* rather than increase it (see measures 2 and 3 in Section 4.3.1).

The following three sections present measures and best-practice examples for limiting or even preventing the further growth of sprawl in Europe. In many areas, it should even be possible to reduce the level of sprawl.

4.3.1 Recommendations for controlling urban sprawl using weighted urban proliferation

This section proposes six measures, primarily related to the *WUP* method. The authors of this report recommend that these measures be broadly applied in urban and regional planning, and that their feasibility and effectiveness be evaluated in more detail. The issue of sprawl can be addressed on several scales in parallel. Likewise, the *WUP* method can be applied on several scales in accordance with the corresponding scale of the measures being considered. For example, the monitoring of sprawl can be implemented on European, national and regional scales simultaneously.

1. **The assessment of future developments.** The analysis of data regarding anticipated future developments reveals the extent to which planned construction projects (e.g. the filling up of designated building zones or the densification of existing built-up areas) will increase or decrease the level of sprawl. The values of *WUP* and its components can be compared with targets and benchmarks (see example 4 in Section 4.3.2), and to earlier trends. This approach will take into account the cumulative effects of several projects on the level of sprawl (see Box 4.3).

2. **The comparison of planning scenarios and alternatives.** Planners can assess the potential for densification to reduce the level of urban sprawl in existing built-up areas, that is, they can identify locations in which the potential is significant. The potential is significant for most built-up areas in transition zones, in which the character of the built-up areas is changing from suburban to urban. Various planning alternatives for built-up areas and for specific construction projects can be assessed and compared with respect to their impacts on sprawl using the *WUP* method as a tool in urban planning. If different scenarios are considered for designated building zones, the corresponding changes in the values of *WUP*, *DIS* and *LUP* can be compared and taken into consideration at the time at which designated building zones are set. In turn, if existing built-up areas in shrinking regions are to be removed, the consideration of the resulting changes in *WUP* and its components could help to determine which areas should be removed to reduce sprawl most effectively. This is useful for

demonstrating the long-term consequences of decisions in settlement policies for the landscape and the paths of development that are possible. The method can be applied to balance new settlement areas and areas in which buildings are demolished to reduce sprawl.

3. **Zonal planning.** If measures 1 and 2 are applied, they will be specified in municipal zoning plans. They can be complemented by the results of the *WUP* analysis in order to improve them with regard to *UD* and *DIS*. The *WUP* method can be used with regard to the planning of new building zones to determine their contribution to future urban sprawl. Their extent, spatial location and density can be analysed and modified in order to minimise their contribution to sprawl. Similarly, the *WUP* method can be used to help identify which existing building zones (that have not yet been built on) would contribute strongly to urban sprawl and, therefore, which should be de-zoned in zoning plans. Furthermore, the *WUP* approach could be used to assess the effect of demolishing buildings or built-up areas in sensitive regions (e.g. agriculturally or ecologically valuable land, or areas in which the population is shrinking) in order to reduce sprawl. Many existing zoning plans indicate the extent of built-up areas and a maximum allowable density. In order to promote a more efficient utilisation of the built-up areas, zoning plans can also include a minimum density value. This is relevant not only for residential areas, but can also be applied to commercial areas and industrial parks in order to promote the creation of multistorey buildings on such sites more often. Densification can improve the quality of built-up areas and the quality of life for their inhabitants if done prudently (e.g. through the process of a *Gestaltungsplan* in Switzerland; Hersperger and Cathomas, in preparation).

4. **The use of *WUP* as a tool in master plans controlling at the regional scale.** The *WUP* method is also suitable as an assessment tool for regional master plans on a larger scale, that is, to assess their contributions to urban sprawl in a region. The extent, spatial location and density of new building zones can be analysed and modified in order to minimise their contribution to sprawl in the region. Similarly, planning alternatives can be compared with respect to their impacts on sprawl, and the potential of the densification of existing built-up areas to reduce sprawl can also be assessed.

5. **The application of the *WUP* method as a tool for performance review.** The success of efforts to control urban sprawl should be evaluated on a regular basis. A performance review compares the findings from the monitoring of sprawl with the anticipated effect. For example, if quantitative targets or limits are available in the zoning plans or master plans (see example 4 in Section 4.3.2), the degree of sprawl can be re-calculated after new building zones have been designated or existing built-up areas have been densified, and compared with the original targets or limits. The use of quantitative data regarding urban sprawl as a tool for performance review is also a promising approach for increasing efforts to achieve the goal of minimising urban sprawl and for increasing the awareness of policymakers and the general public.

6. **Including *WUP* analysis in environmental impact assessments (EIAs) and strategic environmental assessments (SEAs).** The *WUP* method can be applied as an assessment tool in EIAs, including cumulative environmental assessments, for projects that may influence settlement structures, including projects that involve the construction of buildings or that influence some likely drivers of urban sprawl (e.g. roads). It can also be used in SEAs to ensure that urban sprawl is given more attention in future development projects. Regional SEAs are a particularly promising approach for this (Gunn and Noble, 2009).

4.3.2 Best-practice examples of measures with a positive influence on weighted urban proliferation

There are several examples available in which existing measures to control urban sprawl were evaluated using the *WUP* method, and the results confirm that these measures were effective. There are also some examples of projects in which the design of measures to counteract urban sprawl was based on the *WUP* method. This section presents five practical examples:

1. **Limiting the total extent of designated building zones.** Designated building zones are usually determined by municipal zoning plans and regional master plans. If there is no evidence of an increased need, then the total extent of designated building zones is frozen (see example in Box 4.4).

2. **Settlement restriction through the long-term application of settlement boundary lines.** Open countryside can be preserved through the application of settlement boundary lines, green belts (to separate settlement areas) and zoning plans that stipulate internal settlement development (Gennaio et al., 2009) (see Box 4.4). Green belts are also very important for animal movement and constitute boundary marks that make the landscape easier to read and interpret.

Box 4.3 An online tool for applying the *WUP* method: the Urban Sprawl Metrics tool

To facilitate the calculation of *WUP* and its components, a geographic information system (GIS) tool is available. The Urban Sprawl Metrics (USM) tool can be used in the ArcGIS-toolbox (written in Python). The tool is freely available for use and can be downloaded from the Swiss Federal Institute of Forest, Snow and Landscape Research (WSL) homepage (www.wsl.ch/zersiedelung). The language of the user interface is English.

The tool is straightforward to use. Only three input data sets are required:

- data on built-up areas (settlements or solitary buildings, ESRI raster file);
- information on the reporting units, namely a shape file of the reporting units (e.g. municipalities, districts or countries, or a grid with a certain cell size) for which the value of *WUP* is to be calculated;
- the number of inhabitants and jobs for all reporting units has to be saved by the user in the attribute table, in the shape file of the reporting units, as a separate column.

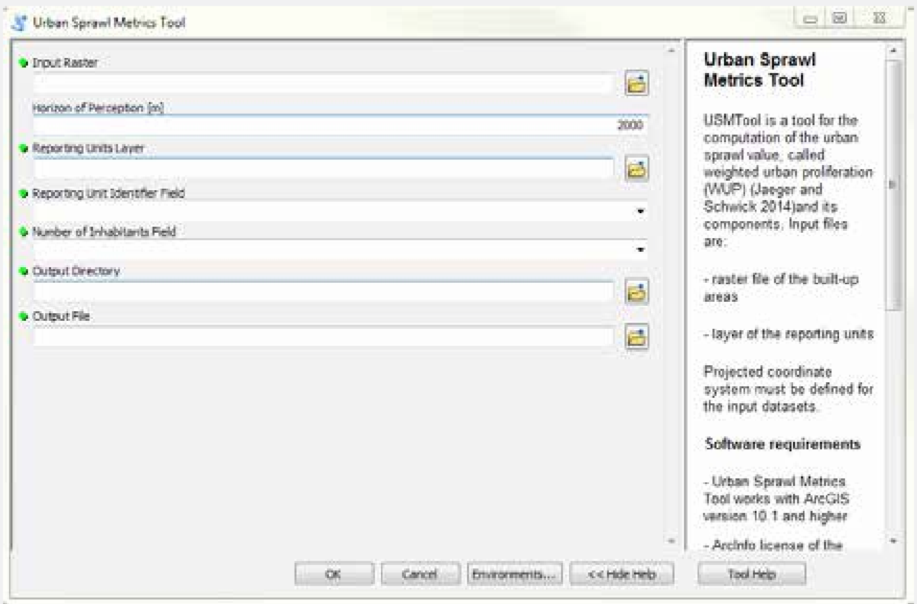
The user can choose the size of the *HP* (between 0.2 and 10 km). The default value is 2 km.

The results of the calculation are written in the shape file of the reporting units as separate columns for:

- the built-up area (in m^2 and as a percentage of the reporting unit)
- *DIS* (in UPU/m^2)
- w_1(*DIS*) (between 0.5 and 1.5)
- *UP* (in UPU/m^2)
- *UD* (number of inhabitants and jobs per ha of built-up area)
- w_2(*UD*) (between 0 and 1)
- *WUP* (in UPU/m^2).

It is important that the users consider which delineation of the built-up areas they want to use. This delineation depends on the data layer available and the particular question of the analysis (see also Box 2.3).

Figure 4.5 Screenshot from the USM tool



Note: A user manual with examples is also available on the website.

3. **Land recycling.** Land recycling, including the reuse of brownfield sites, makes an important contribution to reducing land uptake and to the prevention of additional urban sprawl (Photo 4.2). For example, NRW, Germany, has adopted a goal of increasing the reuse of brownfields. In 2011, 10 ha of open area were taken up per day for new built-up areas in NRW. The government of NRW aims to reduce the daily land uptake to 5 ha/day by 2020, and zero land uptake is intended in the long term (NRW SPD - Bündnis 90/Die Grünen NRW 2012). Some municipalities in NRW have already achieved a recycling ratio of 75 % in the last 20 years (Neite and Berief, 2013). To encourage a higher ratio of land recycling, a moratorium on settlement area expansion could be implemented for 10 years or more. This would increase the value of brownfield sites, vacant lots and other underused areas. The moratorium could apply until land recycling possibilities have been exhausted. Critical success factors for bringing sites back into use have been identified in case studies in England and Japan, and these factors include the presence of strong potential markets, a long-term vision that views a recession as an opportunity, strong branding, strong partnerships, integrated development and the provision of appropriate infrastructure (Dixon et al., 2011).

4. **Setting targets, limits and benchmarks for sprawl.** The EU's 7EAP calls for indicators of resource efficiency. Targets to limit land uptake can contribute to higher resource efficiency. Setting limits for sprawl may be a challenge, but many other branches of environmental protection have successfully managed to overcome similar problems. Many countries have long-term experience of solving common-pool problems through setting limits, and similar changes in legislation have clearly improved the situation. Therefore, the authors of the present report suggest that targets, limits and benchmarks for sprawl should be formulated on the basis of the *WUP* metric. This is one of the most promising measures for controlling future development and the handling of scarce resources. The following basic considerations should guide the development of such targets, limits and benchmarks.

   - A significant reduction in urban sprawl can be achieved by a pure densification of existing urban

Photo 4.2 Belval was the site of the large steelworks that has suffered from the abandonment of steel production in Luxembourg. An extensive regeneration programme has turned the brownfield site into a large scientific and cultural centre, including the science faculty of the University of Luxembourg.

Source: © Luxmaster051 at lb.wikipedia areas (i.e. no new built-up areas). However, this scenario may not be very realistic because of economic, political, and social reasons.

- A minimal requirement is to limit the increase of urban sprawl to the rate of increase in population. However, if sprawl increases at the same rate as the population, this is still not sustainable.

- Therefore, the authors of this report propose that urban sprawl should be limited to the *current level* of sprawl. In shrinking regions, sprawl should be reduced in the same rate as the population is decreasing.

The values can be set according to region and reflect differences in municipalities, natural conditions, and historical development. Limits and benchmarks, for example, can be stricter in Natura 2000 areas than elsewhere. Concrete targets, limits, and benchmarks can be subdivided in three ways according to the type of region: (1) priority spaces for large unsprawled areas, i.e. further sprawl is unauthorised, and the demolition of vacant buildings has priority; (2) specification of target values and benchmarks for rural spaces; (3) toleration of further settlements in agglomerations or along axes of development up to a certain level, as compactly as possible, to avoid sprawl (low *LUP*, urban character). For example, a recent research project in Switzerland has proposed limits and targets for sprawl for all its municipalities (Box 4.4).

5. **The granting of mortgages and the awarding of energy labels.** The decisions by banks to grant mortgages for existing or potential new buildings could be evaluated on the basis of the contribution of such buildings to urban sprawl. Such evaluations could also be the basis for awarding energy labels (see Box 4.4).

4.3.3 Other measures

In addition to these guidelines, measures and examples that are related to *WUP*, a range of other measures for controlling land consumption also exist. The planning literature discusses five types of measures which include (1) regulatory instruments (administrative law), (2) planning instruments, (3) incentive-oriented (economic) instruments, (4) participatory and cooperative instruments, and (5) educational instruments (Sustainability Advisory Board of Baden-Württemberg, 2004). Important examples of these measures are given below.

- **Long-term settlement planning based on guiding principles for landscape management.** Long-term objectives outline the design of future sustainable settlement and transport systems. Accordingly, settlement and transport planning are increasingly based on targets rather than on demand. Guiding principles are needed for landscape quality (Rodewald, 2008).

- **Cooperative large-scale planning.** Competition between municipalities and regions and countries with regard to jobs, taxpayers and inhabitants is counterproductive and contributes heavily to sprawl (Frey and Zimmermann, 2005). To solve this problem, cooperative planning on a larger scale is needed to, for example, minimise the number and the scale of industrial and residential areas, and to limit their dispersion as much as possible. Large-scale cooperation is also needed across political boundaries so that clear measures to control urban sprawl on one side of such a boundary do not result in higher levels of urban sprawl on the other side of the boundary.

Photo 4.3 Brownfield recycling with ongoing construction

Source: Aarhus, Denmark: re-development of the harbour (Photo: Rastislav Stanik)

Box 4.4 Some best-practice examples of addressing urban sprawl in Switzerland

Urban sprawl has been a topic of intense public debate in Switzerland in recent years. Accordingly, public awareness of the problem is high in this country and efforts to address urban sprawl are more advanced than in many other countries in Europe. Various best-practice measures have already been implemented or are currently being discussed, as outlined below.

- The Swiss parliament proposed a revision of the Swiss Spatial Planning Act in 2013 (Loi fédérale sur l'aménagement du territoire de la Suisse 2014). The Swiss population accepted this proposal in the referendum of 3 March 2013, with a clear majority of 63 %. The revision requires the introduction of levies, of at least 20 % of the increase of the property value, to compensate for the increases in property values that occur after the designation of new building zones (Article 5). The revision also imposes limitations for newly designated building zones. An expansion of designated building zones is possible only if an evaluation clearly demonstrates that there is an increased future need, based on the projected increase in population, that cannot be accommodated by different means. If the population is predicted to decline, this implies a reduction in the extent of the designated building zones. Even before this revision, several cantons and municipalities in Switzerland implemented rigorous limitations and sometimes the de-zoning of building zones, and achieved a stabilisation or reduction of sprawl. For example, the Canton of Geneva achieved a 33 % reduction in sprawl between 1980 and 2010, and sprawl stabilisation has been occurring in the municipalities of Könitz and Sils/Segl since 1980.

- The Canton of Zug implemented rigorous measures that were demonstrably successful in reducing urban sprawl (*WUP* values decreased by 11 % between 1980 and 2010) despite the substantial increase in the number of inhabitants and jobs (+66%). This trend reversal was a consequence of four essential requirements, implemented as part of the cantonal master plan of Zug: '(1) The canton and the municipalities separate the settlement area from the non-settlement area. (2) Boundaries delimit the extent of the built-up area. (3) The canton and the municipalities strengthen the core areas of the municipalities and the most important intersections of public transport. (4) The municipalities authorize high densities of built-up areas.' These four regulations have slowed down the increase of built-up area and *DIS*, and have promoted the reduction of *LUP* (Jaeger and Schwick, 2014).

- Green belts can be used as separation zones between built-up areas to prevent them from merging. For example, the cantonal master plan of Zurich of 2014 has implemented 73 green belts in which construction is prevented (Canton of Zürich 2014).

- The setting of limits is one of the most important tools for solving common-pool problems. For example, there are documents, which predate the formation of Switzerland in 1291, that limit the density of cows on Alpine pastures in Switzerland, through Alpine cooperatives, in order to avoid overgrazing, limits were established by the introduction of the total protection of forest areas in 1879, strict limits of air pollution were introduced in 1983, and the water-pollution law was established in 1991. A recent research project in Switzerland proposed limits and targets for sprawl for all Swiss municipalities (Schwick et al., in preparation). This proposal for an adjustment of the Swiss Regional Planning Act aims to make the changes indicated in bold below to Articles 1, 3 and 8 (Muggli, in preparation).

  - 'The federation, the cantons, and the municipalities ensure that the land is used economically, that the building areas are separated from the non-building areas, **and that an increase in urban sprawl is prevented**.' (Article 1).

  - 'The agencies responsible for planning tasks consider the following principles: **Urban sprawl is to be limited in accordance to settlement types.**' (Article 3).

  - '**The cantons determine for themselves and for subordinated agencies how an increase in urban sprawl is prevented. The federation and the cantons determine in technical guidelines how urban sprawl is quantified**.' (Article 8).

  These proposed adjustments to the Regional Planning Act would provide a legislative basis for the introduction of limits or targets with regard to urban sprawl.

- The Alternative Bank of Switzerland used the *WUP* method for the evaluation of specific construction projects according to social and environmental criteria (including sprawl), in addition to economic criteria (Alternative Bank of Switzerland, 2012) (https://www.abs.ch). This allows existing and potential new buildings to be evaluated with regard to their contribution to urban sprawl, which can be used as a basis for decisions regarding the granting of mortgages. Such evaluations can also be the basis for awarding energy labels: the *WUP* indicator is part of a new assessment system for sustainable construction in Switzerland (SNBS) which aims to reduce the negative impacts of new constructions on society, the economy and the environment. The *WUP* method serves as an indicator for the assessment of the loss of soils, effects on biodiversity and landscape consumption (http://www.nnbs.ch/fr/standard-snbs).

- **The introduction of levies to compensate for the increase in property values after planning, development or infrastructure activities.** This type of measure has been included in the new Swiss Regional Planning Act of 2014 (Article 5). It requires a levy of at least 20 % of the increase of the property value (Box 4.4).

- **The abolishment of tax deductions for commuting between homes and workplaces.** These subsidies contribute to longer travel distances and the separation of places of work, living and recreation, which increases sprawl.

- **Charges for the use of roads ('road pricing') or congestion taxes.** This type of measure can be used to discourage the use of cars, particularly in congested regions (e.g. in the City of London and Stockholm) (Gayda et al., 2005).

- **Sprawl certificates, sprawl taxes and tax on ground surface sealing.** These economic incentives can encourage a more economic use of land and a lower *LUP* (Bovet et al., 2013; Bizer et al., 2014).

- **Land banking.** The control of house prices by local authorities through land-use reduction and land-price regulation is called 'land banking'. This type of measure is already well developed in, for example, Rennes, France.

- **A preference for mixed-use urban areas.** Mixed-use areas combine places for work, living and recreation. This can reduce travel distances and the amount of traffic. As a consequence, less transport infrastructure is required and the dispersion of urban areas is lower.

- **Local Agenda 21.** This participatory action plan was developed by the United Nations (UN) in the context of sustainable development and includes sustainable settlement (Smardon, 2008). It supports bottom-up initiatives for the better control of urban sprawl.

- **Campaigns against urban sprawl and for lifestyle changes.** These educational campaigns aim to increase the awareness of the general public with regard to the negative impacts of sprawl and the long-term benefits of changing lifestyles towards a more sustainable way of living.

- **Anti-sprawl certification for municipalities that are good models.** This type of label would act as a performance certificate for municipalities, cities or regions that have put anti-sprawl policies in place and have successfully contained or reduced urban sprawl and, therefore, provide a good example for others.

These measures are particularly important in regions in which the drivers of urban sprawl are likely to increase in the future. The measures have the objective of decoupling the population increase (or decrease) and the socio-economic development from the level of urban sprawl.

4.3.4 Future research needs

There is a need for more in-depth research regarding urban sprawl in Europe. Important examples of relevant topics for future research are outlined below.

1. **An improvement of the data on urban sprawl for earlier points in time.** Urban sprawl can also be measured for earlier points in time in a consistent way based on old maps, for example by using CLC data from 1990, 2000 and 2006. For a more detailed representation of urban sprawl, job data at the 1-km^2-grid level would be highly useful.

2. **The improved availability of consistent data across Europe regarding the factors that influence urban sprawl.** More detailed research about the history and the political and economic conditions of different parts of Europe is of interest, but these are not captured by the 14 predictive variables in this report. For example, such variables include land prices, land ownership, subsidies, tax levels, the availability of public transport (other than just railway densities), the strength of regional planning legislation and planning practices, and lifestyle characteristics. Ideally, such data would be available for relatively long periods and for regions that are smaller than the country level (e.g. the NUTS-2 or NUTS-3 level, or municipalities). In addition, the influences of historic settlement patterns on the current degree of *DIS*, and also on *WUP* and its other components, are of high interest. Therefore, historic factors should also be included in future analysis.

3. **The improvement of the statistical analysis of the drivers of urban sprawl.** With improved data, the relative importance of these factors and their interactions in different places and at various scales could be disentangled. Clusters of regions that behave similarly could be identified. In addition, Structural Equation Modelling (SEM) could be used to analyse causal networks that include causal chains (rather than only direct relationships between a response variable and various predictor variables) in which predictor variables can also influence each

other (Grace, 2006). Improved data would also allow an analysis of time lags and feedback loops. This may answer the question of why certain regions are more (or less) sprawled than predicted by the statistical models.

4. **Population scenarios and the implications of EU policies.** Different scenarios can be considered in order to investigate the implications of an increasing or shrinking population for sprawl. In addition, the effects of EU-wide programmes and policies regarding transport infrastructure, economic development, nature conservation and common agricultural policy on the spatial distribution of the population and the resulting influence on urban sprawl could be investigated (e.g. Reginster and Rounsevell, 2006; Eigenbrod et al., 2011; Plata-Rocha et al., 2011; Fuglsang et al., 2013; Rienow et al., 2014). This could also include the assessment of transport infrastructure projects (e.g. the trans-European transport network) for which the EU provides some financial support. The cumulative effects scenarios of new transport infrastructure on the degree of urban sprawl could be analysed quantitatively in the planning process.

5. **The environmental, social and economic effects of urban sprawl.** Subjects for future research include more detailed studies of the relationships between urban sprawl and the distribution and abundance of native and invasive animal and plant species (e.g. Concepción et al., 2016). The effects of sprawl on ecosystem services (Eigenbrod et al., 2011), on tourism, the health of humans (LaDeau et al., 2015) and on the cost of service provision infrastructure for the human population also deserve to be researched more closely.

6. **The analysis and assessment of open countryside and sprawl-sensitive areas.** The remaining unsprawled (or only sparsely settled) areas can be identified through a European analysis, similar to the identification of roadless areas in Europe (Selva et al., 2011, 2015). Such areas may include protected areas (e.g. Natura 2000 sites, national protected areas, hotspots of biodiversity and landscapes of national importance or significant scenery), landscapes with historical settlement structure, unfragmented lands with little traffic or few settlements, areas that are important for connectivity (e.g. wildlife corridors), undeveloped pockets of countryside, agricultural areas with valuable soils and others.

7. **Assessing the degree of decoupling economic welfare from urban sprawl.** It would be informative to study the extent to which regions have been successful in decoupling their economic welfare from their level of urban sprawl. For example, such a study could identify regions in which economic growth is taking place in parallel to the growth of urban sprawl, and those in which it has been detached from the level of sprawl, using data about the historical development.

However, there is a danger that these research interests could be misused to postpone the implementation of measures to control urban sprawl. Since it often takes decades for the negative effects of sprawl to become apparent, sprawl that has taken place already is still likely to continue to exert ecological, economic and social impacts over the coming decades. It is important to consider the changes that will occur if the countermeasures listed above are not implemented: extensive areas would be built over with high levels of dispersion and *LUP*. This would have serious consequences — urban sprawl would continue unchecked along with all of its negative effects on energy consumption, air pollution, health, biodiversity, ecosystem services, etc. The limitation of sprawl might be perceived by some as a reduction in freedom with regard to land uptake for built-up areas. However, given the negative consequences of sprawl, the limitation of sprawl will, in fact, provide more freedom and scope for action for society in general and for individuals today and in the future in terms of food and energy production, landscape scenery and recreation, and nature conservation. Therefore, sprawl should be addressed as soon as possible. The following section proposes some priorities.

4.4 Most immediate priorities

The results of this report show that even within the short period examined, namely 2006–2009, urban sprawl has increased significantly in most countries, by more than 1.5 % per year; in many countries, sprawl has increased by even more than 2 % per year. This problem is likely to worsen. Four measures, described below, to address this problem have been given particularly high priority. Measures 1 and 2 could be implemented immediately without any need for new research, but measures 3 and 4 are likely to have the strongest influence on urban sprawl.

1. **The monitoring of urban sprawl** It appears that presenting the problem of sprawl in figures is the most effective basis for an objective and constructive discussion. Figures allow one to grasp the problem more easily, and data provide concrete proof of developments in sprawl over time and changes in trends. The new sprawl metrics serve this role well. The *WUP* method can be implemented

by monitoring systems of landscape quality, sustainable development and biodiversity. Tracking the changes in urban sprawl on a regular basis is a precondition for being able to diagnose the rates of increase and any changes in trends. It is also a precondition for implementing targets and limits (see measure 3 below).

2. **The application of sprawl analysis as a tool in planning.** The *WUP* method can be used, at any level in urban, regional and transport planning, as an instrument to assess the consequences of planned projects and zoning alternatives with regard to their influence on urban sprawl. This measure is of high priority because it could influence important decisions about future urban development. Similar quantitative analysis and assessments in other environmental sectors have often resulted in significant improvements and a reduction in negative effects.

3. **The implementation of targets, limits and benchmarks.** The EU's 7EAP calls for indicators of resource efficiency. Targets and limits can be set according to regions, in order to reflect differences in natural conditions, and historic and socio-economic development. The *WUP* method provides the quantitative information and benchmarks that are required for the setting of such targets and limits. The level at which the targets and limits are set will depend on the particular planning processes and regulations in each country.

4. **The strengthening of regional planning.** Europe has a rich diversity in planning legislation and planning processes (Reimer et al., 2014). This provides great opportunities to analyse and compare the effectiveness and efficiency of different planning systems, and to learn from best-practice examples. Knowledge transfer, allowing regions to learn from each other, will foster the improvement of regional planning legislation and planning processes. The EU could greatly promote and contribute to this knowledge transfer. In addition, legislation that contradicts strong regional planning and promotes urban sprawl could be identified and changed; for example, by avoiding that the taxes of municipalities strongly depend on the continuous creation of new building zones. Urban and regional planning could contribute more effectively to controlling urban sprawl than is the case today. The regional planning acts have the opportunity to focus more strongly on the sustainability of land use and should be applied more rigorously than they are today. Accordingly, the existing institutions responsible for urban and regional planning could be strengthened and, if needed, new institutions could also be created in some parts of Europe.

If measures to control urban sprawl are combined appropriately and applied consistently then the scenery of European landscapes will benefit significantly, that is the edges of built-up areas will be more rounded and not frayed. Furthermore, the ratio of buildings outside designated building zones to those within such zones will decline. Built-up areas, in general, will become more compact and suburban areas will become more urban. New settlements will be built mainly in areas with good public transport connections, and not in those in which land is cheap and public transport is hard to access. Aesthetically, the distinctions among urban-looking settlements, rural-looking settlements, historical settlements and open countryside will become more apparent. The high-quality planning of densification will be key for its acceptability by the general public. These changes will be accompanied by a significant shift towards public transport, an increase in densities, a decrease in the distances between places of living, work and recreation, and an increase in intersocial mixing.

References

Adamczyk, I., Andrusiuk, K., Dec, A., Knyszewska, E., Przybylska, M., Rozańska, B. and Sobczyk, M., 2013, 'ZAMIESZKANE BUDYNKI — Narodowy Spis Powszechny Ludności i Mieszkań 2011 [Inhabited buidlings — General national registry of population and accomodations]' (http://www.stat.gov.pl/cps/rde/xbcr/gus/L_zamieszk_budynki_nsp_2011.pdf).

Adams, D., De Sousa, C., Tiesdell, S., 2010, Brownfield development: a comparison of North American and British approaches, *Urban Studies* 47 (1), 75–104.

Akademie für Raumforschung und Landesplanung, 1970, *Handwörterbuch der Raumforschung und Raumordnung*, Band III, Gebrüder Järnecke Verlag, Hannover, 3 974 pp.

Akbari, H., Matthews, H.D. 2012, 'Global cooling updates: Reflective roofs and pavements', *Energy and Buildings* 55: 2–6.

Alberti, 2005, 'The effects of urban patterns on ecosystem function', *International Regional Science Review* 28, 168–192.

Alternative Bank of Switzerland, 2012, 'La Banque Alternative Suisse engage la lutte contre le mitage', Communiqué de presse du 18 juin 2012. (https://www.abs.ch/fileadmin/absch/21_Medienmitteilungen/FR/2012_06_18_CP_BAS_engage_lutte_contre_mitage.pdf).

Anas, A., Arnott, R. and Small, K. A., 1998, 'Urban spatial structure', *Journal of Economic Literature* 36(3), 1 426–1 464.

Andriotis, K., 2006, 'Hosts, guests and politics. Coastal resorts morphological change', *Annals of Tourism Research* 33(4), 1 079–1 098.

Arribas-Bel, D., Nijkamp, P. and Scholten, H., 2011, 'Multidimensional urban sprawl in Europe: A self-organizing map approach', *Computers, Environment and Urban Systems* 35(4), 263–275 (DOI: http://dx.doi.org/10.1016/j.compenvurbsys.2010.10.002).

Atkinson, R. and Blandy, S., 2005, 'Introduction: International perspectives on the new enclavism and the rise of gated communities', *Housing Studies* 20(2), 177–186 (DOI: 10.1080/0267303042000331718).

Bai, X., Chen, J. and Shi, P., 2012, 'Landscape urbanization and economic growth in China: Positive feedbacks and sustainability dilemmas', *Environmental Science Technology* 46, 132–139 (DOI: 10.1021/es202329f).

Barbero-Sierra, C., Marques, M. J. and Ruíz-Pérez, M., 2013, 'The case of urban sprawl in Spain as an active and irreversible driving force for desertification', *Journal of Arid Environments* 90, 95–102 (DOI: 10.1016/j.jaridenv.2012.10.014).

Barredo, J. I. and Engelen, G., 2010, 'Land use scenario modeling for flood risk mitigation', *Sustainability* 2(5), 1327–1344 (DOI: 10.3390/su2051327).

Bart, I. L., 2010, 'Urban sprawl and climate change: A statistical exploration of cause and effect, with policy options for the EU', *Land Use Policy* 27(2), 283–292 (DOI: 10.1016/j.landusepol.2009.03.003).

Becker, J. and Heller, W., 2009, 'Migration without integration? Polish seasonal labour migrants in today's Germany', *Revue Roumaine de Géographie/Romanian Journal of Geography* 53(1), 19–32.

Bennie, J., Davies, T. W., Duffy, J. P., Inger, R. and Gaston, K. J., 2014, 'Contrasting trends in light pollution across Europe based on satellite observed night time lights', *Scientific Reports* 4(3789) (DOI: 10.1038/srep03789).

Bento, A. M., Cropper, M. L., Mobarak, A. M. and Vinha, K., 2005, 'The effects of urban spatial structure on travel demand in the United States', *Review of Economics and Statistics* 87(3), 466–478 (DOI: 10.1162/0034653054638292).

Berry, H. L., 2007, '"Crowded suburbs" and "killer cities": A brief review of the relationship between urban environments and mental health', *New South Wales Public Health Bulletin* 18(12), 222–227.

Bertaud, A. and Brueckner, J. K., 2005, 'Analyzing building-height restrictions: Predicted impacts and welfare costs', *Regional Science and Urban Economics* 35(2), 109–125 (DOI: 10.1016/j.regsciurbeco.2004.02.004).

Bertaud, A. and Malpezzi, S., 2003, *The spatial distribution of population in 48 world cities: Implications for economies in transition*, Report supported by the World Bank, WAGE and the Center for Urban Land Economics Research.

Bertolino, S. and Genovesi, P., 2003, 'Spread and attempted eradication of the grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia', *Biological Conservation* 109(3), 351–358 (DOI: http://dx.doi.org/10.1016/S0006-3207(02)00161-1).

Besussi, E. and Chin, N., 2003, 'Identifying and measuring urban sprawl', in: Longley, P. A. and Batty, M. (eds), *Advanced spatial analysis: The CASA book of GIS*, ESRI Press, Redlands, CA, pp. 109–128.

Bizer, K., Henger, R., Meub, L. and Proeger, T., 2014, *The political economy of certificates for land use in Germany — Experiment evidence*, Discussion Paper 225, Georg-August University in Goettingen, Center for European Governance and Economic Development Research (CEGE).

Böhme, K., Doucet, P., Komornicki, T., Zaucha, J. and Świątek, D., 2011, *How to strengthen the territorial dimension of 'Europe 2020' and EU Cohesion Policy*, Warsaw.

Boitani, L., 2000, *Action plan for the conservation of wolves in Europe (*Canis Lupus*)*, Nature and Environment, Council of Europe.

Bontje, M., 2001, 'Dealing with deconcentration: Population deconcentration and planning response in polynucleated urban regions in north-west Europe', *Urban Studies* 38(4), 769–785 (DOI: 10.1080/00420980120035330).

Borrego, C., Martins, H., Tchepel, O., Salmim, L., Monteiro, A. and Miranda, A. T., 2006, 'How urban structure can affect city sustainability from an air quality perspective', *Environmental Modelling & Software* 21(4), 461–467 (DOI: 10.1016/j.envsoft.2004.07.009).

Bosker, M. and Marlet, G., 2006, *Urban growth and decline in Europe*, Tjalling C. Koopmans Research Institute.

Bovet, J., Bizer, K., Henger, R., Ostertag, K. and Siedentop, S., 2013, 'Handelbare Flächenzertifikate — vom akademischen Diskurs über einen Modellversuch in die Planungspraxis? [Tradable planning permits — from academical discourse via model experiment to planning practice?]', *Raumforschung und Raumordnung* 71(6), 497–507 (DOI: 10.1007/s13147-013-0255-6).

Brade, I., Herfert, G. and Wiest, K., 2009, 'Recent trends and future prospects of socio-spatial differentiation in urban regions of Central and Eastern Europe: A lull before the storm?', *Cities* 26(5), 233–244 (DOI: 10.1016/j.cities.2009.05.001).

Bramwell, B., 2004, ' Coastal Mass Tourism: Diversification and Sustainable Development in Southern Europe', *Aspects of Tourism* 12, 1–31, ed. by B. Bramwell.

Bresson, G., Madre, J.-L. and Pirotte, A., 2004, 'Is urban sprawl stimulated by economic growth ? A hierarchical Bayes estimation on the largest metropolitan areas in France' (http://ideas.repec.org/p/erm/papers/0404.html).

Bring, J., 1994, 'How to standardize regression coefficients', *The American Statistician* 48(3), 209–213 (DOI: 10.1080/00031305.1994.10476059).

Brueckner, J. K., 2000, 'Urban sprawl: diagnosis and remedies', *International Regional Science Review* 23(2), 160–171 (DOI: 10.1177/016001700761012710).

Bruegmann, R., 2005, *Sprawl — A compact history*, New edition, University of Chicago Press.

Bryer, P. J., Elliott, J. N. and Willingham, E. J., 2006, 'The effects of coal tar based pavement sealer on amphibian development and metamorphosis', *Ecotoxicology* 15(3), 241–247 (DOI: 10.1007/s10646-005-0055-z).

Bühlmann, P. and van de Geer, S. (eds), 2011, *Statistics for high-dimensional data. methods, theory and applications*, 1st ed, Springer Series in Statistics, Springer-Verlag, Berlin, Heidelberg.

Buitelaar, E., Segeren, A., Kronberger, A., 2008. Stedelijke transformatie en grondeigendom. NAI Uitgevers/PBL, The Hague.

Bundesamt für Statistik, Schweiz, 2013, 'Raum und Umwelt — Landwirtschaftliche Betriebe, Landwirtschaftliche Nutzfläche (LN) und Nutztiere auf Klassifizierungsebene 2'.

Burchell, R. and Galley, C., 2003, 'Projecting incidence and costs of sprawl in the United States', *Transportation Research Record: Journal of the Transportation Research Board* 1831, 150–157 (DOI: 10.3141/1831-17).

Burchell, R. W., Listokin, D., Galley, C. C. (2000). Smart growth: More than a ghost of urban policy past, less than a bold new horizon. *Housing Policy Debate* 11: 821–879.

Burkey, T. V., 1989, 'Extinction in nature reserves: The effect of fragmentation and the importance of migration between reserve fragments', *Oikos* 55(1), 75–81 (DOI: 10.2307/3565875).

Buzar, S., Ogden, P., Hall, R., Haase, A., Kabisch, S. and Steinfiihrer, A., 2007, 'Splintering urban populations: Emergent landscapes of reurbanisation in four European cities', *Urban Studies* 44(4), 651–677 (DOI: 10.1080/00420980601185544).

Camagni, R., Cristina, M. G. and Rigamonti, P., 2002, 'Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion', *Ecological Economics* 40(2), 199–216 (DOI: 10.1016/S0921-8009(01)00254-3).

Canton of Zürich, 2014, *Kanton Zürich Richtplan. Beschluss des Kantonsrates (Festsetzung)*, Kanton Zürich.

Cassiers, T. and Kesteloot, C., 2012, 'Socio-spatial inequalities and social cohesion in European cities', *Urban Studies* 49(9), 1 909–1 924 (DOI: 10.1177/0042098012444888).

Catalán, B., Saurí, D. and Serra, P., 2008, 'Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993–2000', *Landscape and Urban Planning* 85(3–4), 174–184 (DOI: http://dx.doi.org/10.1016/j.landurbplan.2007.11.004).

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A. and Calcaterra, E., 2014, *User's manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index)*, National Parks Board, Singapore.

Charnes, A., Cooper, W. W. and Sueyoshi, T., 1986, 'Operational research/statistics interface: Recent development & real-world applicationsleast squares/ ridge regression and goal programming/constrained regression alternatives', *European Journal of Operational Research* 27(2), 146–157 (DOI: 10.1016/0377-2217(86)90056-1).

Chen, J., 2007, 'Rapid urbanization in China: A real challenge to soil protection and food security', *CATENA* 69(1), 1–15 (DOI: 10.1016/j.catena.2006.04.019).

Cheshire, P. and Sheppard, S., 2002, 'The welfare economics of land use planning', *Journal of Urban Economics* 52(2), 242–269 (DOI: 10.1016/S0094-1190(02)00003-7).

Chittka, L. and Schürkens, S., 2001, 'Successful invasion of a floral market', *Nature* 411(6838), 653–653.

Christiansen, P. and Loftsgarden, T., 2011, *Drivers behind urban sprawl in Europe*, TØI Report 1136/2011, Institute of Transport Economics, Oslo, https://www.toi.no/getfile.php/Publikasjoner/TØI%20rapporter/2011/1136-2011/1136-2011-el.pdf.

Cieslewicz, D. J., 2002, 'The environmental impacts of sprawl', in: Squires, G. (ed), *Urban sprawl: causes, consequences & policy responses*, Urban Institute Press, Washington, DC, pp. 23–38.

Cinyabuguma, M. and McConnell, V., 2013, 'Urban growth externalities and neighborhood incentives: another cause of urban sprawl?', *Journal of Regional Science* 53(2), 332–348 (DOI: 10.1111/jors.12008).

Cirtautas, M., 2013, 'Urban sprawl of major cities in the Baltic states', *Architecture and Urban Planning* 7, 72–79 (DOI: 10.7250/aup.2013.009).

Clark, W. A. V., 1986, 'Residential segregation in American cities: A review and interpretation', *Population Research and Policy Review* 5(2), 95–127 (DOI: 10.1007/BF00137176).

Concepción, E.D., Obrist, M.K. Moretti, M., Altermatt, F., Baur, B., Nobis, M.P., 2016, 'Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds: not only built-up area matters', *Urban Ecosystems* 19(1), 225–242.

Costal, G., Pickup, L. and Martino, V., 1988, 'Commuting — A further stress factor for working people: Evidence from the European Community', *International Archives of Occupational and Environmental Health* 60(5), 377–385 (DOI: 10.1007/BF00405674).

Couch, C., Karecha, J., Nuissl, H., Rink, D., 2005, 'Decline and sprawl: an evolving type of urban development — observed in Liverpool and Leipzig', *European Planning Studies* 13(1), 117–136.

Couch, C., Leontidou, L. and Petschel-Held, G., 2007, *Urban Sprawl in Europe. Landscapes, Land Use Change & Policy*, Wiley-Blackwell, Oxford; Malden, MA.

Council of Europe, 2000, *European Landscape Convention and reference documents*, Cultural Heritage, Landscape and Spatial Planning Division, Directorate of Culture and Cultural and Natural Heritage, Strasbourg, France.

Csefalvay, Z., Webster, C. 2012, 'Gates or No Gates? A Cross-European Enquiry into the Driving Forces behind

Gated Communities', *Regional Studies,* Vol. 46(3), 293–308 (DOI: 10.1080/00343404.2010.50597).

Cumming, G. S., Buerkert, A., Hoffmann, E. M., Schlecht, E., von Cramon-Taubadel, S. and Tscharntke, T., 2014, 'Implications of agricultural transitions and urbanization for ecosystem services', *Nature* 515(7525), 50–57 (DOI: 10.1038/nature13945).

Dale, M., Fortin, M. J., 2005, 'Spatial analysis — A guide for ecologists', Cambridge University Press, Cambridge, 365 pp.

Dharmaratne, G. S. and Brathwaite, A. E., 1998, 'Economic valuation of the coastline for tourism in Barbados', *Journal of Travel Research* 37(2), 138–144 (DOI: 10.1177/004728759803700205).

Dixon, T., Otsuka, N., Abe, H., 2011, 'Critical success factors in urban brownfield regeneration: an analysis of 'hardcore' sites in Manchester and Osaka during the economic recession (2009–10)', *Environment and Planning* A 43 (4), 961–980

Downs, A., (2005) 'Smart Growth: Why We Discuss It More than We Do' It', *Journal of the American Planning Association* 71(4): 367–378.

Duffy, A., 2009, 'Land use planning in Ireland — A life cycle energy analysis of recent residential development in the greater Dublin area', *The International Journal of Life Cycle Assessment* 14(3), 268–277 (DOI: 10.1007/s11367-009-0059-7).

Dura-Guimera, A., 2003, 'Population deconcentration and social restructuring in Barcelona, a European Mediterranean city', *Cities* 20(6), 387–394 (DOI: 10.1016/j.cities.2003.08.004).

Duzan, H. and Shariff, N. S. B. M., 2015, 'Ridge regression for solving the multicollinearity problem: Review of methods and models', *Journal of Applied Sciences* 15(3), 392–404.

Dye, C. J., Willoughby, D. F. and Battisto, D. G., 2010, 'Advice from rural elders: What it takes to age in place', *Educational Gerontology* 37(1), 74–93 (DOI: 10.1080/03601277.2010.515889).

EC, 1998, *European Community Biodiversity Strategy*, Office for Official Publications of the European Communities, Luxembourg.

EC, 1999, *ESDP: European Spatial Development Perspective — Towards balanced and sustainable development of the territory of the European Union*, Office for Official Publications of the European Communities, Luxembourg.

EC, 2007, 'LEIPZIG CHARTER on Sustainable European Cities' (http://ec.europa.eu/regional_policy/archive/themes/urban/leipzig_charter.pdf).

EC, 2009, *Economic crisis in Europe: Causes, consequences and responses*, European Economy, European Commission Directorate General for Economic and Financial Affairs.

EC, 2011a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Roadmap to a resource efficient Europe', COM(2011) 571 final, Brussels, 20.11.2011.

EC, 2011b, 'Our life insurance, our natural capital: an EU biodiversity strategy to 2020', Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. COM(2011) 244 final, 16 pages, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN.

EC, 2011c, 'Regions in the European Union. Nomenclature of territorial units for statistics — NUTS 2010/EU-27', Methodologies & Working Papers, EuroStat, Luxembourg.

EC, 2013a, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions 'Green infrastructure (GI) — Enhancing Europe's natural capital', COM(2013) 659 final.

EC, 2013b, 'Living well, within the limits of our planet: 7th EAP — The new general Union Environment Action Programme to 2020', European Commission.

EEA, 2005, *EEA core set of indicators — Guide*, EEA Technical report No 1/2005, European Environment Agency.

EEA, 2006a, *Land accounts for Europe 1990–2000 — Towards integrated land and ecosystem accounting*, EEA Report No 11/2006, European Environment Agency.

EEA, 2006b, *Urban sprawl in Europe — The ignored challenge*, EEA Report No 10/2006, European Environment Agency.

EEA, 2010, 'Urban Atlas' (http://www.eea.europa.eu/data-and-maps/data/urban-atlas) accessed 9 August 2015.

EEA and FOEN, 2011a, *Landscape fragmentation in Europe — Joint EEA–FOEN report*, EEA Report No 2/2011, European Environment Agency, Swiss Federal Office for the Environment.

EEA, 2011b, 'Land take' (http://www.eea.europa.eu/data-and-maps/indicators/land-take-2) accessed 12 August 2015.

EEA, 2013, 'Land take' (http://www.eea.europa.eu/data-and-maps/indicators/land-take-2/assessment-2) accessed 10 August 2015.

EEA, 2014, *Biodiversity monitoring in Europe*, Brochure No 2/2013, European Environment Agency.

EEA, 2015a, *GIO land imperviousness HRL: definitions and product specifications, Lots 1–5*, European Environment Agency.

EEA, 2015b, *The European environment — state and outlook 2015*, Synthesis report, European Environment Agency.

EEA, 2015c, *Natura 2000 data* (last modified 11 September 2015), (http://www.eea.europa.eu/data-and-maps/data/natura-2000-eunis-database#tab-metadata) last accessed 14 January 2016.

Eichhorn, D., Oertel, H., Iwanow, I., Effenberger, K.-H. and Schumacher, U., 2009, *Entwicklung des Nachfragepotenzials nach Wohnungsneubau für Baden-Württemberg bis 2020 und 2025 [Development of potential demand of new home constructions in Baden-Württtemberg until 2020 and 2025]*, Leibniz Institute of Ecological Urban and Regional Development.

Eigenbrod, F., Bell, V. A., Davies, H. N., Heinemeyer, A., Armsworth, P. R. and Gaston, K. J., 2011, 'The impact of projected increases in urbanization on ecosystem services', *Proceedings of the Royal Society of London B: Biological Sciences* 278, 3201–3208 (DOI: 10.1098/rspb.2010.2754).

European Parliament, 2013, European Parliament Resolution of 12 December 2013 on Green Infrastructure — Enhancing Europe's Natural Capital.

Evers, D. V. H., 2004, *Building for consumption: an institutional analysis of peripheral shopping center development in northwest Europe*, PhD thesis, Amsterdam Institute for Social Science Research (AISSR), Faculty of Social and Behavioural Sciences, University of Amsterdam, Amsterdam.

Ewald, K. C. and Klaus, G., 2009, *Die ausgewechselte Landschaft: Vom Umgang der Schweiz mit ihrer wichtigsten natürlichen Ressource [The exchanged landscape: How Switzerland is dealing with its most important natural resource]*, 1., Aufl., Haupt Verlag, Bern, Stuttgart, Wien.

Ewing, R.H., 1994, 'Characteristics, Causes, and Effects of Sprawl: A Literature Review', *Environmental and Urban Issues* 21 (2) pp. 1–15.

Ewing, R., 1997, 'Is Los Angeles-style sprawl desirable?', *Journal of the American Planning Association* 63(1), 107–126 (DOI: 10.1080/01944369708975728).

Ewing, R., Pendall, R., Chen, D., 2002, *Measuring sprawl and its impact: The character and consequences of metropolitan expansion*. Washington, DC: Smart Growth America.

Ewing, R., Pendall, R. and Chen, D., 2003, 'Measuring sprawl and its transportation impacts', *Transportation Research Record: Journal of the Transportation Research Board* 1831(1), 175–183.

Ewing, R. H., 2008, 'Characteristics, causes, and effects of sprawl: A literature review', in: Marzluff, J. M., Shulenberger, E., Endlicher, W., et al. (eds), *Urban ecology: an international perspective on the interaction of humans and nature*, Springer US, pp. 519–535.

Faiths, S. H., Bang, C. and Saari, S., 2011, 'Urban biodiversity: patterns and mechanisms', *Annals of the New York Academy of Sciences* 1223(1), 69–81 (DOI: 10.1111/j.1749-6632.2010.05925.x).

Faeth, S. H., Warren, P. S., Shochat, E. and Marussich, W. A., 2005, 'Trophic dynamics in urban communities', *BioScience* 55(5), 399–407 (DOI: 10.1641/0006-3568(2005)055[0399:TDIUC]2.0.CO;2).

FAO, 2011, *The state of the world's land and water resources for food and agriculture — Managing systems at risk*, Summary Report, Food and Agriculture Organization of the United Nations, Rome.

Faraway, J. J., 2005, *Linear models with R*, Texts in Statistical Science, Chapman & Hall/CRC.

Feyen, L. and Dankers, R., 2009, 'Impact of global warming on streamflow drought in Europe', *Journal of geophysical research* 114 (D17) (DOI: 10.1029/2008JD011438),

Fischer, J., Lindenmayer, D., Manning, A., 2006, 'Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes', F*rontiers in Ecology and the Environment* 4(2), 80–86.

FOEN, 2015, *Indicator Urban sprawl. In: Data, indicators, maps -> Landscape indicators*, http://www.bafu.admin.ch/umwelt/indikatoren/08611/09514/index.html?lang=en, last updated on: 26.01.2015.

Frenkel, A. and Ashkenazi, M., 2008, 'Measuring urban sprawl — How can we deal with It?', *Environment and Planning B: Planning and Design* 35(1), 56–79 (DOI: 10.1068/b32155).

Frey, R. L. and Zimmermann, H., 2005, 'Neue Rahmenbedingungen für die Raumordnung als Chance für marktwirtschaftliche Instrumente', *disP — The Planning Review* 41(161), 5––8 (DOI: 10.1080/02513625.2005.10556920).

Frumkin, H., Frank, L. and Jackson, R. J., 2004, *Urban sprawl and public health — Designing, planning, and building for healthy communities*, 1st ed, Island Press, Washington, DC.

Fuglsang, M., Münier, B. and Hansen, H. S., 2013, 'Modelling land-use effects of future urbanization using cellular automata — An Eastern Danish case', *Environmental Modelling & Software* 50, 1–11 (DOI: 10.1016/j.envsoft.2013.08.003).

Gagné, S. A. and Fahrig, L., 2010, 'The trade-off between housing density and sprawl area: Minimising impacts to forest breeding birds', *Basic and Applied Ecology* 11(8), 723–733 (DOI: http://dx.doi.org/10.1016/j.baae.2010.09.001).

Galea, S. and Vlahov, D., 2005, 'Urban health — Evidence, challenges, and directions', *Annual Review of Public Health* 26(1), 341–365 (DOI: 10.1146/annurev.publhealth.26.021304.144708).

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S. and Freihage, J., 2001, 'Wrestling sprawl to the ground — Defining and measuring an elusive concept', *Housing Policy Debate* 12(4), 681–717 (DOI: 10.1080/10511482.2001.9521426).

García-Palomares, J. C., 2010, 'Urban sprawl and travel to work — The case of the metropolitan area of Madrid', *Journal of Transport Geography* 18(2), 197–213 (DOI: 10.1016/j.jtrangeo.2009.05.012).

Garden, F. and Jalaludin, B., 2009, 'Impact of urban sprawl on overweight, obesity, and physical activity in Sydney, Australia', *Journal of Urban Health* 86(1), 19–30 (DOI: 10.1007/s11524-008-9332-5).

Gayda, S., Haag, G., Besussi, E., Lautso, K., Noël, C., Martino, A., Moilanen, P. and Doirmois, R., 2005, *The SCATTER project — Sprawling cities and transporT: From evaluation to recommendations*, Summary Report, European Commission, Brussels.

Gennaio, M.-P., Hersperger, A. M. and Bürgi, M., 2009, 'Containing urban sprawl — Evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan', *Land Use Policy* 26(2), 224–232 (DOI: http://dx.doi.org/10.1016/j.landusepol.2008.02.010).

Genovesi, P., Bacher, S., Kobelt, M., Pascal, M. and Scalera, R., 2009, 'Alien mammals of Europe', in: *Handbook of Alien Species in Europe*, Springer Netherlands, pp. 119–128.

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B. K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G. K. and Wilmoth, J., 2014, 'World population stabilization unlikely this century', *Science* 346(6206), 234–237 (DOI: 10.1126/science.1257469).

Gillham, O., 2002, *The limitless city: A primer on the urban sprawl debate*, Island Press.

Girvetz, E. H., Thorne, J. H., Berry, A. M. and Jaeger, J. A. G., 2008, 'Integration of landscape fragmentation analysis into regional planning: A statewide multi-scale case study from California, USA', *Landscape and Urban Planning* 86(3–4), 205–218 (DOI: http://dx.doi.org/10.1016/j.landurbplan.2008.02.007).

Glaeser, E. L. and Kahn, M. E., 2004, 'Sprawl and urban growth', *Handbook of Regional and Urban Economics* 4, 2 481–2 527.

González, A., Donnelly, A., Jones, M., Chrysoulakis, N., Lopes, M. 2013, 'A decision-support system for sustainable urban metabolism in Europe, *Environmental Impact Assessment Review* 38, 109–119.

Gordon, P. and Richardson, H. W., 2000, 'Defending suburban sprawl', *Public Interest* 139, 65–71.

Gospodini, A., 2002, 'European cities in competition and the new "uses" of urban design', *Journal of Urban Design* 7(1), 59–73 (DOI: 10.1080/13574800220129231).

Government of Germany, 2002, *Perspectives for Germany — Our strategy for sustainable development [Perspektiven für Deutschland — Unsere Strategie für eine nachhaltige Entwicklung]*, Government of Germany.

Government of Germany, 2015, *Antwort der Bundesregierung 'Flächenverbrauch und das 30-ha-Ziel der Bundesregierung'*, [Response from the federal government 'Area consumption and the 30-ha target of the federal government'] Drucksache 18/4172 of March 3rd, Government of Germany.

Grace, J. B., 2006, *Structural equation modeling and natural systems*, Cambridge University Press.

Grahn, P. and Stigsdotter, U. A., 2003, 'Landscape planning and stress', *Urban Forestry & Urban Greening* 2(1), 1–18 (DOI: 10.1078/1618-8667-00019).

Grigorescu, I., Mitrica, B., Kucsicsa, G., Popovici, E.-A., Dumitraşcu, M. and Cuculici, R., 2012, 'Post-communist land use changes related to urban sprawl in the Romanian metropolitan areas', *Human Geographies — Journal of Studies and Research in Human Geography* 6(1), 35–46.

Grossmann, K., Haase, A., Rink, D. and Steinführer, A., 2008, 'Urban shrinkage in east eentral Europe? Benefits and limits of a cross-national transfer of research approaches', in: Nowak, M. and Nowosielski, M. (eds), *Declining cities/developing cities: Polish and German perspectives*, Instytut Zachodni, Poznan, pp. 77–99.

Gunn, J. H. and Noble, B. F., 2009, 'A conceptual basis and methodological framework for regional strategic environmental assessment (R-SEA)', *Impact Assessment and Project Appraisal* 27(4), 258–270 (DOI: 10.3152/146155109X479440).

Haase, A., Rink, D., Grossmann, K., Bernt, M. and Mykhnenko, V., 2014, 'Conceptualizing urban shrinkage', *Environment and Planning A* 46, 1 519–1 534 (DOI: 10.1068/a46269).

Haase, D., 2009, 'Effects of urbanisation on the water balance — A long-term trajectory', *Environmental Impact Assessment Review* 29(4), 211–219 (DOI: 10.1016/j.eiar.2009.01.002).

Haase, D., Kabisch, N. and Haase, A., 2013, 'Endless urban growth? On the mismatch of population, household and urban land area growth and Its effects on the urban debate', *PLoS ONE* 8(6), e66531 (DOI: 10.1371/journal.pone.0066531).

Haase, D., Seppelt, R. and Haase, A., 2007, 'Land use impacts of demographic change — Lessons from Eastern German urban regions', in: Petrosillo, I., Müller, F., Jones, K. B., et al. (eds), *Use of landscape sciences for the assessment of environmental security*, Springer Netherlands, pp. 329–344.

Haber, W., 2007, 'Energy, food, and land — The ecological traps of humankind', *Environmental Science and Pollution Research International* 14(6), 359–365 (DOI: 10.1065/espr2007.09.449).

Habibi, S. and Asadi, N., 2011, 'Causes, results and methods of controlling urban sprawl', *Procedia Engineering* 21(0), 133–141 (DOI: 10.1016/j.proeng.2011.11.1996).

Halás, M. and Formanová, L., 2010, 'Sociological, demographic and spatial aspects of the singles phenomenon in the Czech Republic', *Acta Universitatis Palackianae Olomucensis — Geographica* 41(2), 37–52.

Halleux, J.-M., Marcinczak, S. and van der Krabben, E., 2012, 'The adaptive efficiency of land use planning measured by the control of urban sprawl. The cases of the Netherlands, Belgium and Poland', *Land Use Policy* 29(4), 887–898 (DOI: 10.1016/j.landusepol.2012.01.008).

Hansen, A. J., Knight, R. L., Marzluff, J. M., Powell, S., Brown, K., Gude, P. H. and Jones, K., 2005, 'Effects of exurban development on biodiversity: patterns, mechanisms, and research needs', *Ecological Applications* 15(6), 1 893–1 905 (DOI: 10.1890/05-5221).

Hardill, I. and Green, A., 2003, 'Remote working — Altering the spatial contours of work and home in the new economy', *New Technology, Work and Employment* 18(3), 212–222 (DOI: 10.1111/1468-005X.00122).

Hardin, G., 1968, 'The tragedy of the commons', *Science* 162(3859), 1243–1248 (DOI: 10.1126/science.162.3859.1243).

Hartig, T., Mang, M. and Evans, G. W., 1991, 'Restorative effects of natural environment experiences', *Environment and Behavior* 23(1), 3–26 (DOI: 10.1177/0013916591231001).

Hasse, J. E. and Lathrop, R. G., 2003, 'Land resource impact indicators of urban sprawl', *Applied Geography* 23(2–3), 159–175 (DOI: http://dx.doi.org/10.1016/j.apgeog.2003.08.002).

Hastie, T., Tibshirani, R. and Friedman, J., 2009, *The elements of statistical learning*, Springer Series in Statistics, Springer New York, New York, NY.

Haug, B., M.S. Dann, G. and Mehmetoglu, M., 2007, 'Little Norway in Spain: From tourism to migration', *Annals of Tourism Research* 34(1), 202–222 (DOI: 10.1016/j.annals.2006.07.011).

Heinsch, F.A., Reeves, M., Votava, P., Kang, S., Milesi, C., Zhao, M., Glassy, J., Jolly, W.M., Loehman, R., Bowker, C.F., Kimball, J.S., Nemani, R.R., Running, S.W., 2003, *NASA MODIS MOD17A2/A3 Land Algorithm 2003*, Version 2.0. 57 pp.

Hennig, E. I., Schwick, C., Soukup, T., Orlitová, E., Kienast, F. and Jaeger, J. A. G., 2015, 'Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy', *Land Use Policy* 49, 483–498 (DOI: http://dx.doi.org/10.1016/j.landusepol.2015.08.001).

Hersperger, A. M. and Bürgi, M., 2009, 'Going beyond landscape change description: Quantifying the importance of driving forces of landscape change in a central Europe case study', *Land Use Policy* 26(3), 640–648 (DOI: 10.1016/j.landusepol.2008.08.015).

Hersperger, A. and Cathomas, G., in preparation, 'Hindernisse und Potentiale bei der Implementierung von Massnahmen und Zielvorgaben',[Barriers and potentials in the implementation of measures and targets], in: Steuerung der Zersiedelung in der Schweiz. Ed. by C. Schwick, J. Jaeger, A. Hersperger, R. Muggli.

Hoerl, A. E. and Kennard, R. W., 1970, 'Ridge regression: Applications to nonorthogonal problems', *Technometrics* 12(1), 69–82 (DOI: 10.2307/1267352).

Horner, M. W., 2004, 'Exploring metropolitan accessibility and urban structure', *Urban Geography* 25(3), 264–284 (DOI: 10.2747/0272-3638.25.3.264).

Hortas-Rico, M. and Solé-Ollé, A., 2010, 'Does urban sprawl increase the costs of providing local public services? Evidence from Spanish municipalities', *Urban Studies* 47(7), 1513–1540 (DOI: 10.1177/0042098009353620).

Howley, P., 2009, 'Attitudes towards compact city living: Towards a greater understanding of residential behaviour', *Land Use Policy* 26(3), 792–798 (DOI: 10.1016/j.landusepol.2008.10.004).

Hoymann, J., 2011, 'Accelerating urban sprawl in depopulating regions: a scenario analysis for the Elbe River Basin', *Regional Environmental Change* 11(1), 73–86 (DOI: 10.1007/s10113-010-0120-x).

Hutyra, L. R., Yoon, B., Hepinstall-Cymerman, J. and Alberti, M., 2011, 'Carbon consequences of land cover change and expansion of urban lands: A case study in the Seattle metropolitan region', *Landscape and Urban Planning* 103(1), 83–93 (DOI: 10.1016/j.landurbplan.2011.06.004).

Illés, S., 2006, 'International elderly migration in Hungary', *Migracijske i etniçke teme* 22(1–2), 53–77.

Ingram, G. K., 1998, 'Patterns of metropolitan development: What have we learned?', *Urban Studies* 35(7), 1019–1035 (DOI: 10.1080/0042098984466).

Informal Ministerial Meeting on Housing and Urban Development, 2010, *Declaration, Toledo*, 22 June 2010, http://www.lexcivitas.ro/images/stories/norme/Declaratia-Toledo.pdf.

Jaeger, J., 2002, *Landscape fragmentation. A transdisciplinary study according to the concept of environmental threat [Landschaftszerschneidung. Eine transdisziplinäre Studie gemäß dem Konzept der Umweltgefährdung]*, Verlag Eugen Ulmer, Stuttgart.

Jaeger, J. A. G., Bertiller, R., Schwick, C., Cavens, D. and Kienast, F., 2010a, 'Urban permeation of landscapes and sprawl per capita: New measures of urban sprawl', *Ecological Indicators* 10(2), 427–441 (DOI: http://dx.doi.org/10.1016/j.ecolind.2009.07.010).

Jaeger, J. A. G., Bertiller, R., Schwick, C., and Kienast, F., 2010b, 'Suitability criteria for measures of urban sprawl', *Ecological Indicators* 10(2), 427–441, (DOI: 10.1016/j.ecolind.2009.07.007).

Jaeger, J. A. G. and Schwick, C., 2014, 'Improving the measurement of urban sprawl: Weighted Urban Proliferation (*WUP*) and its application to Switzerland', *Ecological Indicators* 38, 294–308 (DOI: http://dx.doi.org/10.1016/j.ecolind.2013.11.022).

Jaeger, J. A. G., Schwick, C., Bertiller, R. and Kienast, F., 2008, *Urban sprawl in Switzerland: Quantitative analysis 1935 to 2002 and implications for regional planning*, Swiss National Science Foundation.

Jat, M. K., Garg, P. K. and Khare, D., 2008, 'Monitoring and modelling of urban sprawl using remote sensing and GIS techniques', *International Journal of Applied Earth Observation and Geoinformation* 10(1), 26–43 (DOI: http://dx.doi.org/10.1016/j.jag.2007.04.002).

Jetzkowitz, J., Schneider, J. and Brunzel, S., 2007, 'Suburbanisation, mobility and the 'Good Life in the Country': A lifestyle approach to the sociology of urban sprawl in Germany', *Sociologia Ruralis* 47(2), 148–171 (DOI: 10.1111/j.1467-9523.2007.00431.x).

Johnson, E. A. and Klemens, M. W., 2005, 'The impacts of sprawl on biodiversity', in: Johnson, E. A. and Klemens, M. W. (eds), *Nature in fragments: The legacy of sprawl*, American Museum of Natural History, pp. 18–53.

Johnson, M. P., 2001, 'Environmental impacts of urban sprawl: A survey of the literature and proposed research agenda', *Environment and Planning A* 33(4), 717–735 (DOI: 10.1068/a3327).

Jones, C. and Kammen, D. M., 2014, 'Spatial distribution of U.S. household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density', *Environmental Science & Technology* 48(2), 895–902 (DOI: 10.1021/es4034364).

Jordan, P., 2000, 'Restructuring Croatia's coastal resorts: Change, sustainable development and the incorporation of rural hinterlands', *Journal of Sustainable Tourism* 8(6), 525–539 (DOI: 10.1080/09669580008667384).

Kasanko, M., Barredo, J. I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V. and Brezger, A., 2006, 'Are European cities becoming dispersed? A comparative analysis of 15 European urban areas', *Landscape and Urban Planning* 77(1–2), 111–130 (DOI: 10.1016/j.landurbplan.2005.02.003).

Kaufmann, D., Kraay, A. and Mastruzzi, M., 2010, 'The Worldwide Governance Indicators: Methodology and Analytical Issues' (September 2010). World Bank Policy Research Working Paper No. 5430. Available at SSRN: http://ssrn.com/abstract=1682130.

Kenworthy, J. R., Laube, F. B., Newman, P., Barter, P., Raad, T., Poboon, C. and Guia Jr, B., 1999, 'An international sourcebook of automobile dependence in cities 1960–1990' (http://trid.trb.org/view.aspx?id=648499).

Kidwell, J. S. and Brown, L. H., 1982, 'Ridge regression as a technique for analyzing models with multicollinearity', *Journal of Marriage and Family* 44(2), 287–299 (DOI: 10.2307/351539).

Kienast, F., Frick, J., Strien, M. J. van and Hunziker, M., 2015, 'The Swiss landscape monitoring program — A comprehensive indicator set to measure landscape change', *Ecological Modelling* 295, 136–150 (DOI: http://dx.doi.org/10.1016/j.ecolmodel.2014.08.008).

Kienast, F., Hunziker, M., Stremlow, M., in preparation, Zustand der Landschaft Schweiz 2015 [State of the landscape in Switzerland 2015].

King, R., Warnes, A. M. and Williams, A. M., 1998, 'International retirement migration in Europe', *International Journal of Population Geography* 4(2), 91–111 (DOI: 10.1002/(SICI)1099-1220(199806)4:2<91::AID-IJPG97>3.0.CO;2-S).

Klein, Y. L., Osleeb, J. P. and Viola, M. R., 2004, 'Tourism-generated earnings in the coastal zone: A regional analysis', *Journal of Coastal Research*, 1 080–1 088 (DOI: 10.2112/003-0018.1).

Klug, S. and Hayashi, Y., 2012, 'Urban Sprawl and local infrastructure in Japan and Germany', *Journal of Infrastructure Systems* 18(4), 232–241 (DOI: 10.1061/(ASCE)IS.1943-555X.0000101).

Knowles, R. D., 2006, 'Transport shaping space: Differential collapse in time-space', *Journal of Transport Geography* 14(6), 407–425 (DOI: http://dx.doi.org/10.1016/j.jtrangeo.2006.07.001).

Kohsaka, R., Pereira, H. M., Elmqvist, T., Chan, L., Moreno-Pe naranda, R., Morimoto, Y., Inoue, T., Iwata, M., Nishi, M., da Luz Mathias, M., Cruz, C. S., Cabral, M., Brunfeldt, M., Parkkinen, A., Niemelä, J., Kulkarni-Kawli, Y. and Pearsell, G., 2013, 'Indicators for management of urban biodiversity and ecosystem services: City Biodiversity Index', in: Elmqvist, T., Fragkias, M., Goodness, J., et al. (eds), *Urbanization, biodiversity and ecosystem services: Challenges and opportunities*, Springer Netherlands, pp. 699–718.

Kotus, J., 2006, 'Changes in the spatial structure of a large Polish city — The case of Poznań', *Cities* 23(5), 364–381 (DOI: http://dx.doi.org/10.1016/j.cities.2006.02.002).

Kovats, R. S. and Hajat, S., 2008, 'Heat stress and public health: A critical review', *Annual Review of Public Health* 29(29), 41–55 (DOI: 10.1146/annurev.publhealth.29.020907.090843).

Kowarik, I., 2011, 'Novel urban ecosystems, biodiversity, and conservation', *Environmental Pollution* 159 (8–9), 1974–1983 (DOI: http://dx.doi.org/10.1016/j.envpol.2011.02.022).

Kroll, F. and Haase, D., 2010, 'Does demographic change affect land use patterns? A case study from Germany', *Land Use Policy* 27(3), 726–737 (DOI: 10.1016/j.landusepol.2009.10.001).

Krstajic, D., Buturovic, L. J., Leahy, D. E. and Thomas, S., 2014, 'Cross-validation pitfalls when selecting and assessing regression and classification models', *Journal of Cheminformatics* 6(1), 1–15 (DOI: 10.1186/1758-2946-6-10).

Kundzewicz, Z. W., Ulbrich, U., Brücher, T., Graczyk, D., Krüger, A., Leckebusch, G. C., Menzel, L., Pińskwar, I., Radziejewski, M. and Szwed, M., 2005, 'Summer floods in central Europe — Climate change track?', *Natural Hazards* 36(1–2), 165–189 (DOI: 10.1007/s11069-004-4547-6).

Kurz, C. and Rieger, F., 2013, *'Arbeitsfrei.' Eine Entdeckungsreise zu den Maschinen, die uns ersetzen ['Freed from work.' An expedition to the machines, which replace us]*, Riemann.

Kuttler, W., 2011, 'Climate change in urban areas, Part 1, Effects', *Environmental Sciences Europe* 23(11).

Kuussaari, M., Bommarco, R., Heikkinen, R. K., Helm, A., Krauss, J., Lindborg, R., Öckinger, E., Pärtel, M., Pino, J., Rodà, F., Stefanescu, C., Teder, T., Zobel, M. and Steffan-Dewenter, I., 2009, 'Extinction debt: A challenge for biodiversity conservation', *Trends in Ecology & Evolution* 24(10), 564–571 (DOI: http://dx.doi.org/10.1016/j.tree.2009.04.011).

LaDeau, S.L., Allan, B.F., Leisnham, P.T., and Levy, M.Z., 2015, 'The ecological foundations of transmission potential and vector-borne disease in urban landscapes', *Functional Ecology* 29, 889-901 (DOI: 10.1111/1365-2435.12487).

Lal, R., 2003, 'Global potential of soil carbon sequestration to mitigate the greenhouse effect', *Critical Reviews in Plant Sciences* 22(2), 151–184 (DOI: 10.1080/713610854).

Lambelet-Haueter, C., Burgisser, L., Clerc, P., Gloor, S., Moeschler, P., Monney, J. C., Müller, A., Price, M., Ruckstuhl, M., Cavin, J. S. and Zbinden, N., 2010, 'Siedlungsentwicklung', in: Lachat, T., Pauli, D., Gonseth, Y., et al. (eds), *Wandel der Biodiversität in der Schweiz seit 1900. Ist die Talsohle erreicht?*, Bern, Stuttgart, Wien, Haupt-Verlag, pp. 224–265.

Lambin, E. F., Turner, B.L., Geist, H. J., Agbola, Samuel B., Angelsen, A., Bruce, J.W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, John F., Skånes, H., Steffen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C., Xu, J., 2001, 'The causes of land-use and land-cover change: moving beyond the myths', *Global Environmental Change* 11 (4), 261–269 (doi:10.1016/S0959-3780(01)00007-3).

Landscape Gesellschaft für Geo-Kommunikation, 2000–2002. *Lexikon der Geowissenschaften*. Band 5. Spektrum Akademischer Verlag, Heidelberg, Berlin.

Langanke, T., Büttner, G., Dufourmont, H., Iasillo, D., Probeck, M., Rosengren, M., Sousa, A., Strobl, P., Weichselbaum, J. and 1–6, other representatives of service providers for G. land lots, 2013, 'GIO land (GMES/Copernicus initial operations land) High Resolution Layers (HRLs) — Summary of product specifications' (http://land.copernicus.eu/user-corner/publications/gio-land-high-resolution-layers/view).

Lawrence, B. L., 2005, 'The context and causes of sprawl', in: Johnson, E. A. and Kiemens, M. W. (eds), *Nature in fragments: The legacy of sprawl*, Columbia University Press, pp. 3–17.

Le Goix, R., 2005, 'Gated communities: Sprawl and social segregation in Southern California', *Housing Studies* 20(2), 323–343 (DOI: 10.1080/026730303042000331808).

Lehner, B., Döll, P., Alcamo, J., Henrichs, T. and Kaspar, F., 2006, 'Estimating the impact of global change on flood and drought risks in Europe: A continental, integrated analysis', *Climatic Change* 75(3), 273–299 (DOI: 10.1007/s10584-006-6338-4).

Leser, H., Huber-Fröhli, J., 1997, *Diercke-Wörterbuch allgemeine Geographie*. Westermann, Braunschweig, and Deutscher Taschenbuch Verlag, München, 1 037 pp.

Lo, C. P. and Yang, X., 2002, 'Drivers of land-use/land-cover changes and dynamic modeling for the Atlanta, Georgia metropolitan area', *Photogrammetric Engineering and Remote Sensing* 68(10), 1 073–1 082.

Logan, J. R. and Schneider, M., 1984, 'Racial segregation and racial change in American suburbs, 1970–1980', *American Journal of Sociology* 89(4), 874–888.

Manchester, S. J. and Bullock, J. M., 2000, 'The impacts of non-native species on UK biodiversity and the effectiveness of control', *Journal of Applied Ecology* 37(5), 845–864 (DOI: 10.1046/j.1365-2664.2000.00538.x).

Mann, S., 2009, 'Institutional causes of urban and rural sprawl in Switzerland', *Land Use Policy* 26(4), 919–924 (DOI: 10.1016/j.landusepol.2008.11.004).

March, H. and Saurí, D., 2010, 'The suburbanization of water scarcity in the Barcelona metropolitan region: Sociodemographic and urban changes influencing domestic water consumption', *The Professional Geographer* 62(1), 32–45 (DOI: 10.1080/00330120903375860).

Margo, R. A., 1992, 'Explaining the postwar suburbanization of population in the United States: The role of income', *Journal of Urban Economics* 31(3), 301–310 (DOI: 10.1016/0094-1190(92)90058-S).

Marull, J., Pino, J., Tello, E. and Cordobilla, M. J., 2010, 'Social metabolism, landscape change and land-use planning in the Barcelona Metropolitan Region', *Land Use Policy* 27(2), 497–510 (DOI: 10.1016/j.landusepol.2009.07.004).

Matthey, M., 2012, 'Raumentwicklung, Verkehr und Energie als Knacknüsse der Nachhaltigkeitspolitik', in: *20 Jahre Nachhaltige Entwicklung. Die grossen Herausforderungen in der Schweiz und weltweit*, Bundesamt für Raumentwicklung ARE & Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK), pp. 26–28.

Maucha, G., Büttner, G. and Kosztra, B., 2010, *European validation of GMES FTS Soil Sealing Enhancement data*, Institute of Geodesy, Cartography and Remote Sensing (FÖMI).

McKinney, M. L., 2006, 'Urbanization as a major cause of biotic homogenization', *Biological Conservation* 127(3), 247–260 (DOI: 10.1016/j.biocon.2005.09.005).

McKinney, M. L., 2008, 'Effects of urbanization on species richness: A review of plants and animals', *Urban Ecosystems* 11(2), 161–176 (DOI: 10.1007/s11252-007-0045-4).

Merki, M., 2009, 'Obwalden hält an Sonderwohnzonen für Reiche fest [Obwalden adheres to gaited communities for the rich]', *Neue Zürcher Zeitung (NZZ)*, 2009 (http://www.nzz.ch/obwalden-haelt-an-sonderwohnzonen-fuer-reiche-fest-1.2552295) accessed 24 August 2015.

Miller, J. R., 2005, 'Biodiversity conservation and the extinction of experience', *Trends in Ecology & Evolution* 20(8), 430–434 (DOI: 10.1016/j.tree.2005.05.013).

Montgomery, D. C., Peck, E. A. and Vining, G. G., 2012, *Introduction to linear regression analysis*, 5th ed, John Wiley & Sons.

Montgomery, M. R., 2008, 'The urban transformation of the developing world', *Science* 319(5864), 761–764 (DOI: 10.1126/science.1153012).

Moon, H., 1990, 'Land use around suburban transit stations', *Transportation* 17(1), 67–88 (DOI: 10.1007/BF02125504).

Moser, B., Jaeger, J. A. G., Tappeiner, U., Tasser, E. and Eiselt, B., 2007, 'Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem', *Landscape Ecology* 22(3), 447–459 (DOI: 10.1007/s10980-006-9023-0).

Moudon, A. V., 2009, 'Real noise from the urban environment: How ambient community noise affects health and what can be done about it', *American Journal of Preventive Medicine* 37(2), 167–171 (DOI: 10.1016/j.amepre.2009.03.019).

Muggli, R., in preparation, Instrumente und gesetzliche Bestimmungen zur Begrenzung der Zersiedelung.

Müller, K., Steinmeier, C. and Küchler, M., 2010, 'Urban growth along motorways in Switzerland', *Landscape and Urban Planning* 98(1), 3–12 (DOI: http://dx.doi.org/10.1016/j.landurbplan.2010.07.004).

Mysterud, A., Bartoń, K. A., Jędrzejewska, B., Krasiński, Z. A., Niedzia\lkowska, M., Kamler, J. F., Yoccoz, N. G. and Stenseth, N. C., 2007, 'Population ecology and conservation of endangered megafauna: The case of European bison in Bia\lowie\.za Primeval Forest, Poland', *Animal Conservation* 10(1), 77–87 (DOI: 10.1111/j.1469-1795.2006.00075.x).

Navara, K. J. and Nelson, R. J., 2007, 'The dark side of light at night: Physiological, epidemiological, and ecological consequences', *Journal of Pineal Research* 43(3), 215–224 (DOI: 10.1111/j.1600-079X.2007.00473.x).

Nazarnia, N., 2012, *Measurement of urban sprawl in the metropolitan areas of Montreal and Quebec over 60 years*, MSc Thesis, Department of Geography, Planning and Environment, Concordia University, Montréal, Québec, Canada.

Nazarnia, N., Schwick, C. and Jaeger, J. A. G., 2016, 'Accelerated urban sprawl in Montreal, Quebec City, and Zurich: Investigating the differences using time series 1951–2011', *Ecological Indicators* 60, 1229–1251 (DOI: http://dx.doi.org/10.1016/j.ecolind.2015.09.020).

Neite, H. and Berief, K.-J., 2013, 'Brachflächenerhebung und -recycling, Erhebungsmethodik in Nordrhein-Westfalen', in: Meinel, G., Schumacher, U., and Behnisch, M. (eds), *Flächennutzungsmonitoring V: Methodik — Analyseergebnisse — Flächenmanagement*, Rhombos-Verlag, pp. 43–50.

Nemes, V., 2011, 'The favorability of relief for territorial expansion of Marghita City', *Analele Universitatii din Oradea — Seria Geografie* (211114-526), 127–133.

Niedziałkowska, M., Jędrzejewski, W., Mysłajek, R. W., Nowak, S., Jędrzejewska, B. and Schmidt, K., 2006, 'Environmental correlates of Eurasian lynx occurrence in Poland — Large scale census and GIS mapping', *Biological Conservation* 133(1), 63–69 (DOI: 10.1016/j.biocon.2006.05.022).

Niemeijer, D. and de Groot, R. S., 2008, 'A conceptual framework for selecting environmental indicator sets', *Ecological Indicators* 8(1), 14–25 (DOI: http://dx.doi.org/10.1016/j.ecolind.2006.11.012).

Nijkamp, P., Goede, E., 2002, ' Urban development in the Netherlands: New perspectives', Research Memorandum 2002-1A, Faculty of Economics, Business Administration and Econometrics, University of Amsterdam, (http://degree.ubvu.vu.nl/repec/vua/wpaper/pdf/2002001a.pdf accessed 03/03/2016).

Nivola, P. S., 1999, *Laws of the landscape: How policies shape cities in Europe and America*. Brookings Institution Press, Washington, DC.

Nobis, M. P., Jaeger, J. A. G. and Zimmermann, N. E., 2009, 'Neophyte species richness at the landscape scale under urban sprawl and climate warming', *Diversity and Distributions* 15(6), 928–939 (DOI: 10.1111/j.1472-4642.2009.00610.x).

Noël, S., Ouellet, M., Galois, P. and Lapointe, F.-J., 2007, 'Impact of urban fragmentation on the genetic structure of the eastern red-backed salamander', *Conservation Genetics* 8(3), 599–606 (DOI: 10.1007/s10592-006-9202-1).

NRW SPD — Bündnis 90/Die Grünen NRW, 2012, *Koalitionsvertrag 2012-2017: Verantwortung für ein starkes NRW — Miteinander die Zukunft gestalten,* https://netzpolitik.org/wp-upload/Koalitionsvertrag_2012-2017.pdf.

Nuissl, H. and Rink, D., 2005, 'The "production" of urban sprawl in eastern Germany as a phenomenon of post-socialist transformation', *Cities* 22(2), 123–134 (DOI: 10.1016/j.cities.2005.01.002).

OECD, 2013, *OECD regions at a glance 2013*, OECD Publishing.

Oke, T. R., 1973, 'City size and the urban heat island', *Atmospheric Environment (1967)* 7(8), 769–779 (DOI: 10.1016/0004-6981(73)90140-6).

Orlitová, E., Soukup, T., Kopecky, M., Vobora, V., Gregor, M., Schwick, C. and Jaeger, J., 2012, *Urban sprawl typology: Critical analysis of input datasets, indicators calculated and dataflows proposal*, Working document, European Environment Agency, Copenhagen.

Oueslati, W., Alvanides, S. and Garrod, G., 2015, 'Determinants of urban sprawl in European cities', *Urban Studies* 52(9), 1 594–1 614 (DOI: 10.1177/0042098015577773).

Pauleit, S., Ennos, R. and Golding, Y., 2005, 'Modeling the environmental impacts of urban land use and land cover change — A study in Merseyside, UK', *Landscape and Urban Planning* 71(2–4), 295–310 (DOI: 10.1016/j.landurbplan.2004.03.009).

Pauliuk, S., Venkatesh, G., Brattebø, H., Müller, D.B., (2014): Exploring urban mines: Pipe length and material stocks in urban water and wastewater networks, *Urban Water Journal* 11(4): 274–283.

Pelletier, F., 2013, *World population prospects: The 2012 revision*, Technical Report, United Nations Department of Economic and Social Affairs, Population Division, Population Estimates and Projections Section, New York, NY.

Peña, J., Bonet, A., Bellot, J., Sánchez, J. R., Eisenhuth, D., Hallett, S. and Aledo, A., 2007, 'Driving forces of land-use change in a cultural landscape of Spain', in: Koomen, E., Stillwell, J., Bakema, A., et al. (eds), *Modelling land-use change*, Springer Netherlands, pp. 97–116.

Penn-Bressel, G., 2015, 'Flächeninanspruchnahme durch Siedlung und Verkehr und nachhaltige Flächennutzung: aktuelle Trends und Lösungsansätze', in: Meinel, G., Schumacher, U., Behnisch, M., and Krüger, T. (eds), *Flächennutzungsmonitoring VII: Boden — Flächenmanagement — Analysen und Szenarien*, IÖR-Schriften Band 67, Rhombos-Verlag, Berlin, 39–50.

Pichler-Milanovič, N., Gutry-Korycka, M. and Rink, D., 2007, 'Sprawl in the post-socialist City: The changing economic and institutional context of central and eastern European cties', in: Couch, C., Leontidou, L., and Petschel-Held, G. (eds), *Urban Sprawl in Europe*, Blackwell Publishing Ltd, pp. 102–135.

Piorr, A., Ravetz, J. and Tosics, I., 2011, *Peri-urbanisation in Europe towards EUROPEAN policies to sustain urban-rural futures*, PLUREL Research Project Synthesis Report, http://plurel.net/images/Peri_Urbanisation_in_Europe_printversion.pdf.

Plata-Rocha, W., Gómez-Delgado, M. and Bosque-Sendra, J., 2011, 'Simulating urban growth scenarios using GIS and multicriteria analysis techniques: A case study of the Madrid region, Spain', *Environment and Planning B: Planning and Design* 38(6), 1 012–1 031 (DOI: 10.1068/b37061).

Power, A., 2001, 'Social exclusion and urban sprawl: Is the rescue of cities possible?', *Regional Studies* 35(8), 731–742 (DOI: 10.1080/00343400120084713).

Putnam, R.D., 2000. 'Bowling Alone - The Collapse and Revival of American Community'. Simon and Schuster, New York, 544 pp.

Raupp, M. J., Shrewsbury, P. M. and Herms, D. A., 2010, 'Ecology of herbivorous arthropods in urban landscapes', *Annual Review of Entomology* 55(1), 19–38 (DOI: 10.1146/annurev-ento-112408-085351).

Razin, E. and Rosentraub, M., 2000, 'Are fragmentation and sprawl interlinked? North American evidence', *Urban Affairs Review* 35(6), 821–836 (DOI: 10.1177/10780870022184697).

Reckien, D. and Karecha, J., 2007, 'Sprawl in European cities: The comparative background', in: Couch, C., Leontidou, L., and Petschel-Held, G. (eds), *Urban sprawl in Europe. Landscapes, land use change & policy*, Blackwell Publishing, pp. 39–68.

Regierungsrat Kanton Zürich, 2014, *Langfristige Raumentwicklungsstrategie Kanton Zürich*, Kanton Zürich.

Reginster, I. and Rounsevell, M., 2006, 'Scenarios of future urban land use in Europe', *Environment and Planning B: Planning and Design* 33(4), 619–636.

Reimer, M., Getimis, P. and Blotevogel, H. H. (eds), 2014, *Spatial planning systems and practices in Europe: A comparative perspective on continuity and changes*, Routledge, New York, NY. 336 pp.

Rich, C. and Loncore, T., 2006, *Ecological consequences of artificial light*, Island Press.

Ridder, K. D., Lefebre, F., Adriaensen, S., Arnold, U., Beckroege, W., Bronner, C., Damsgaard, O., Dostal, I., Dufek, J., Hirsch, J., IntPanis, L., Kotek, Z., Ramadier, T., Thierry, A., Vermoote, S., Wania, A. and Weber, C., 2008, 'Simulating the impact of urban sprawl on air quality and population exposure in the German Ruhr area. Part I: Reproducing the base state', *Atmospheric Environment* 42(30), 7059–7069 (DOI: 10.1016/j.atmosenv.2008.06.045).

Rienow, A., Stenger, D. and Menz, G., 2014, 'Sprawling cities and shrinking region — Forecasting urban growth in the Ruhr for 2025 by coupling cells and agents', *Erdkunde* 68(2), 85–107 (DOI: 10.3112/erdkunde.2014.02.02).

Rivas, V., Cendrero, A., Hurtado, M., Cabral, M., Giménez, J., Forte, L., del Río, L., Cantú, M. and Becker, A., 2006, 'Geomorphic consequences of urban development and mining activities; an analysis of study areas in Spain and Argentina', *Geomorphology* 73(3–4), 185–206 (DOI: 10.1016/j.geomorph.2005.08.006).

Rodewald, R., 2008, 'Welche Landschaft soll es sein? Von der Suche nach konsensfähigen Zielen der Landschaftsentwicklung' [Which landscape shall it be? The quest for broadly accepted goals in landscape development], *GAIA — Ecological Perspectives for Science and Society* 17(2), 189–195.

Rogerson, R. J., 1999, 'Quality of life and city competitiveness', *Urban Studies* 36(5–6), 969–985 (DOI: 10.1080/0042098993303).

Romanowicz, A., Daffner, F., Uhel, R. and Weber, J.-L., 2006, 'European Environment Agency developments of land and ecosystem accounts: General overview', *Systemics, Cybernetics and Informatics* 6(2), 65–70.

Romanowicz, A., Dafffner, F., Uhel, R. and Weber, J. L., 2007, 'European Environment Agency developments of land and ecosystem accounts: General overview', conference paper presented at: 11th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI); jointly with the 13th International Conference on Information Systems Analysis and Synthesis, Orlando, FL, 8 July 2007.

Roose, A., Kull, A., Gauk, M. and Tali, T., 2013, 'Land use policy shocks in the post-communist urban fringe: A case study of Estonia', *Land Use Policy* 30(1), 76–83 (DOI: http://dx.doi.org/10.1016/j.landusepol.2012.02.008).

Rosso, A. L., Auchincloss, A. H. and Michael, Y. L., 2011, 'The urban built environment and mobility in older adults: A comprehensive review', *Journal of Aging Research* 2011, 10 pages (DOI: 10.4061/2011/816106).

Roy, M., Curry, R., Ellis, G. (2015): Spatial allocation of material flow analysis in residential developments: a case study of Kildare County, Ireland, Journal of Environmental Planning and Management, 58:10, 1 749–1 769, DOI: 10.1080/09640568.2014.951115.

Runge, J., Klosowski, F., Runge, A., 2003, 'Conditions and trends of social-economic changes of Katowice region', *Bulletin of Geography* (Socio-Economic Series) No. 2, 85-101, http://apcz.pl/czasopisma/index.php/BGSS/article/viewFile/2527/2517.

Rusk, D., 2006, 'Social framework: Sprawl, race, and concentrated poverty — Changing the "Rules of the Game"', in: Soule, D. C. (ed), *Urban Sprawl: A comprehensive reference guide*, Greenwood Press, pp. 90–102.

Sabbagh, J. and Neef, M., 2007, 'The consequences of demographic change in Rhineland-Palatinate: Scenarios of landscape consumption for settlement and transportation area', in: Petrosillo, I., Müller, F., Jones, K. B., et al. (eds), *Use of Landscape Sciences for* *the Assessment of Environmental Security*, Springer Netherlands, pp. 345–356.

Sailer-Fliege, U., 1999, 'Characteristics of post-socialist urban transformation in east central Europe', *GeoJournal* 49(1), 7–16.

Salvati, L., Morelli, V. G., Rontos, K. and Sabbi, A., 2013, 'Latent exurban development: City expansion along the rural-to-urban gradient in growing and declining regions of southern Europe', *Urban Geography* 34(3), 376–394 (DOI: 10.1080/02723638.2013.778675).

Scalenghe, R. and Marsan, F. A., 2009, 'The anthropogenic sealing of soils in urban areas', *Landscape and Urban Planning* 90(1–2), 1–10 (DOI: 10.1016/j.landurbplan.2008.10.011).

Schwarzak, M., Behnisch, M. and Meinel, G., 2014, 'Zersiedelung in Deutschland — erste Ergebnisse nach Schweizer Messkonzept', in: Meinel, G., Schumacher, U., Behnisch, M., Krüger, T. (eds), *Flächennutzungsmonitoring VI. Innenentwicklung — Prognose — Datenschutz*, IÖR-Schriften Band 67, Rhombos-Verlag, Berlin, pp. 213–222.

Schwick, C., Jaeger, J. A. G., Bertiller, R. and Kienast, F., 2012, *L'étalement urbain en Suisse — Impossible à freiner? Analyse quantitative de 1935 à 2002 et conséquences pour l'aménagement du territoire / Urban sprawl in Switzerland — unstoppable? Quantitative Analysis 1935–2002 and implications for regional planning*, Haupt-Verlag.

Schwick, C., Jaeger, J. A. G., Hersperger, A. M. and Kienast, F., 2013, 'Stark beschleunigte Zunahme der Zersiedlung in der Schweiz', *Geomatik Schweiz* 111(2), 48–53.

Schwick, C., Jaeger, J. A. G., Hersperger, A. M. and Muggli, R., in preparation, Konkrete Massnahmen zur Steuerung der Zersiedelung in der Schweiz.

Schwick, C., Kienast, F. and Jaeger, J. A. G., in revision, The accelerated increase of urban sprawl in Switzerland: Time series from 1885 to 2010, potential drivers and scenarios for 2050.

Selva, N., Kreft, S., Kati, V., Schluck, M., Jonsson, B.-G., Mihok, B., Okarma, H. and Ibisch, P. L., 2011, 'Roadless and low-traffic areas as conservation targets in Europe', *Environmental Management* 48(5), 865–877 (DOI: 10.1007/s00267-011-9751-z).

Selva, N., Switalski, A., Kreft, S. and Ibisch, P. L., 2015, 'Why keep areas road-free? The importance of roadless areas', in: van der Ree, R., Smith, D. J., and Grilo, C. (eds), *Handbook of road ecology*, John Wiley & Sons, pp. 16–26.

Seto, K. C., Güneralp, B. and Hutyra, L. R., 2012, 'Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools', *Proceedings of the National Academy of Sciences of the United States of America* 109(40), 16083–16088 (DOI: 10.1073/pnas.1211658109).

Shochat, E., Lerman, S. B., Anderies, J. M., Warren, P. S., Faeth, S. H. and Nilon, C. H., 2010, 'Invasion, competition, and biodiversity loss in urban ecosystems', *BioScience* 60(3), 199–208 (DOI: 10.1525/bio.2010.60.3.6).

Siedentop, S., 2005, 'Urban sprawl — verstehen, messen, steuern', *disP — The Planning Review* 41(160), 23–35 (DOI: 10.1080/02513625.2005.10556903).

Siedentop, S., Junesch, R., Straßer, M, Zakrzewski, P.,Walter, M., Samaniego, L., Weinert, J., Dosch, F., 2009, *Einflussfaktoren der Neuinanspruchnahme von Flächen*. Bundesministerium für Verkehr (Berlin) and Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR) (Bonn). Schriftenreihe Forschungen Heft 139.
ISBN 978-3-87994-471-2. 124 pp.

Siedentop, S. and Fina, S., 2010, 'Urban sprawl beyond growth: the effect of demographic change on infrastructure costs', *Flux* 1(79–80), 90–100.

Siedentop, S. and Fina, S., 2012, 'Who sprawls most? Exploring the patterns of urban growth across 26 European countries', *Environment and Planning A* 44(11), 2 765–2 784.

Siedentop, S., Fina, S. and Krehl, A., 2016, 'Greenbelts in Germany's regional plans — An effective growth management policy?', *Landscape and Urban Planning* 145, 71–82 (DOI: http://dx.doi.org/10.1016/j.landurbplan.2015.09.002).

Slabbekoorn, H. and Peet, M., 2003, 'Ecology: Birds sing at a higher pitch in urban noise', *Nature* 424(6946), 267–267 (DOI: 10.1038/424267a).

Smardon, R. C., 2008, 'A comparison of Local Agenda 21 implementation in North American, European and Indian cities', *Management of Environmental Quality: An International Journal* 19(1), 118–137 (DOI: 10.1108/14777830810840408).

Solon, J., 2009, 'Spatial context of urbanization: Landscape pattern and changes between 1950 and 1990 in the Warsaw metropolitan area, Poland', *Landscape and Urban Planning* 93(3–4), 250–261 (DOI: http://dx.doi.org/10.1016/j.landurbplan.2009.07.012).

Song, Y., 2005, 'Influence of new town development on the urban heat island — The case of the Bundang area', *Journal of Environmental Sciences* 17(4), 641–645.

Squires, G. D., 2002, *Urban sprawl: Causes, consequences & policy responses*, The Urban Insitute.

Stone, B., Hess, J. J. and Frumkin, H., 2010, 'Research urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities?', *Environmental Health Perspectives* 118(10), 1 425–1 428.

Suditu, B., Ginavar, A., Muică, A., Iordăchescu, C., Vârdol, A. and Ghinea, B., 2010, 'Urban sprawl characteristics and typologies in Romania', *Human Geographies — Journal of Studies and Research in Human Geography* 4(2), 79–87.

Sulzer, J. and Desax, M., 2015, *Stadtwerdung der Agglomeration. Die Suche nach einer neuen urbanen Qualität. Synthese des Nationalen Forschungsprogramms 'Neue Urbane Qualität' (NFP 65)*, 1st ed, Scheidegger & Spiess.

Su, Q. and DeSalvo, J. S., 2008, 'The effects of transportation subsidies on urban sprawl', *Journal of Regional Science* 48(3), 567–594 (DOI: 10.1111/j.1467-9787.2008.00564.x).

Sustainability Advisory Board of Baden-Württemberg, 2004, 'New ways to a sustainable management of areas in Baden-Württemberg', Special report, Stuttgart. 63 pp.

Swiss Federal Council (Schweizerischer Bundesrat), 2008, *Strategie Nachhaltige Entwicklung: Leitlinien und Aktionsplan 2008-2011*, Swiss Federal Council (Schweizerischer Bundesrat).

Swisstopo, 2002, *Vector25*, Federal Office of Topography swisstopo.

Szirmai, V., Váradi, Z., Kovács, S., Schuchmann, J. and Baranyai, N., 2011, 'Territorial consumption issues of urban sprawl in central European capitals, especially in the Budapest metropolitan region', *Society and Economy* 33(1), 69–87 (DOI: 10.1556/SocEc.33.2011.1.7).

Taha, H., 1997, 'Urban climate and heat islands: Albedo, evapotranspiration, and anthropogenic heat', *Energy and Buildings* 25, 99–103.

Thayer, J. D., 1991, 'Interpretation of standardized regression coefficients in multiple regression', conference paper presented at: Annual Meeting of the American Educational Research Association, 3–7 April, Chicago, IL, 1991.

Thomas, R. L., Baker, P. J. and Fellowes, M. D. E., 2014, 'Ranging characteristics of the domestic cat (*Felis catus*) in an urban environment', *Urban Ecosystems* 17(4), 911–921 (DOI: 10.1007/s11252-014-0360-5).

Thurston, L. and Yezer, A. M. J., 1994, 'Causality in the suburbanization of population and employment', *Journal of Urban Economics* 35(1), 105–118 (DOI: 10.1006/juec.1994.1006).

Tibshirani, R., 1996, 'Regression shrinkage and selection via the LASSO', *Journal of the Royal Statistical Society B* 58(1), 267–288.

Tilman, D., May, R. M., Lehman, C. L. and Nowak, M. A., 1994, 'Habitat destruction and the extinction debt', *Nature* 371(6492), 65–66.

Torrens, P. M., 2006, 'Simulating sprawl', *Annals of the Association of American Geographers* 96(2), 248–275 (DOI: 10.1111/j.1467-8306.2006.00477.x).

Torrens, P. M., 2008, 'A toolkit for measuring sprawl', *Applied Spatial Analysis and Policy* 1(1), 5–36 (DOI: 10.1007/s12061-008-9000-x).

Torres, A., 2016, *Wildlife in a human-dominated world: Impacts of anthropogenic landscape changes on birds and mammals in Spain*. PhD thesis, Universidad Autónoma de Madrid, Madrid (Spain). 241 pp.

Travisi, C. M., Camagni, R. and Nijkamp, P., 2010, 'Impacts of urban sprawl and commuting: A modelling study for Italy', *Journal of Transport Geography* 18(3), 382–392.

Trombulak, S. C. and Frissell, C. A., 2000, 'Review of ecological effects of roads on terrestrial and aquatic communities', *Conservation Biology* 14(1), 18–30 (DOI: 10.1046/j.1523-1739.2000.99084.x).

Tsai, Y.-H., 2005, 'Quantifying urban form: Compactness versus "sprawl"', *Urban Studies* 42(1), 141–161 (DOI: 10.1080/0042098042000309748).

Tudor, D. T. and Williams, A. T., 2006, 'A rationale for beach selection by the public on the coast of Wales, UK', *Area* 38(2), 153–164 (DOI: 10.1111/j.1475-4762.2006.00684.x).

Tu, J., Xia, Z.-G., Clarke, K. C. and Frei, A., 2007, 'Impact of urban sprawl on water quality in eastern Massachusetts, USA', *Environmental Management* 40(2), 183–200 (DOI: 10.1007/s00267-006-0097-x).

Turbé, A., De Toni, A., Benito, P., Lavelle, P., Lavelle, P., Ruiz, N., Van der Putten, W.H., Labouze, E., Mudgal, S., 2010, *Soil biodiversity: functions, threats and tools for policy makers. Bio Intelligence Service, IRD, and NIOO*, Report for European Commission (DG Environment)., 248 pages, http://ec.europa.eu/environment/soil/biodiversity.htm.

Turok, I. and Mykhnenko, V., 2007, 'The trajectories of European cities, 1960–2005', *Cities* 24(3), 165–182 (DOI: 10.1016/j.cities.2007.01.007).

UN, 2006, *World urbanization prospects: The 2005 revision*, United Nations Department of Economic and Social Affairs, Population Division, New York, NY.

UN, 2012, *World urbanization prospects: The 2011 revision — Highlights*, United Nations Department of Economic and Social Affairs, Population Division, New York, NY.

UN, 2014, *World urbanization prospects: The 2014 revision*, United Nations Department of Economic and Social Affairs, Population Division, New York, NY.

UNCCD, 2012, *Zero net land degradation. A sustainable development goal for Rio+20*, UNCCD Secretariat Policy Brief, United Nations Convention to Combat Desertification, Bonn, Germany.

UNFPA, 2007, *State of world population 2007: Unleashing the potential of urban growth*, United Nations Population Fund.

USGS (U.S. Geological Survey), 2015, Global 30 Arc-Second Elevation GTOPO30 (USGS 2015). Long Term Archive. Page last modified January 2015, https://lta.cr.usgs.gov/GTOPO30.

Vallianatos, M., Gottlieb, R. and Haase, M. A., 2004, 'Farm-to-school strategies for urban health, combating sprawl, and establishing a community food systems approach', *Journal of Planning Education and Research* 23(4), 414–423 (DOI: 10.1177/0739456X04264765).

Van Metre, P. C., Mahler, B. J. and and Furlong, E. T., 2000, 'Urban sprawl leaves its PAH signature', *Environmental Science & Technology* 34(19), 4 064–4 070 (DOI: 10.1021/es991007n).

Verburg, P. H., Ritsema van Eck, J. R., de Nijs, T., Dijst, M. and Schot, P., 2004, 'Determinants of land-use change patterns in the Netherlands', *Environment and Planning B: Planning and Design* 31(1), 125–150 (DOI: 10.1068/b307).

Waitt, G. and Harada, T., 2012, 'Driving, cities and changing climates', *Urban Studies* 49(15), 3 307–3 325 (DOI: 10.1177/0042098012443858).

Walker, B., Holling, C. S., Carpenter, S. R. and Kinzig, A., 2004, 'Resilience, adaptability and transformability in social–ecological systems', *Ecology and Society* 9(2).

Warnes, A. M., 1993, 'The development of retirement migration in Great Britain', *Espace, populations, sociétés* 11(3), 451–464 (DOI: 10.3406/espos.1993.1608).

Weber, J.-L., 2007, 'Implementation of land and ecosystem accounts at the European Environment Agency', *Ecological Economics* 61(4), 695–707 (DOI: http://dx.doi.org/10.1016/j.ecolecon.2006.05.023).

Wells, N. M. and Evans, G. W., 2003, 'Nearby nature a buffer of life stress among rural children', *Environment and Behavior* 35(3), 311–330 (DOI: 10.1177/0013916503035003001).

White, M. P., Pahl, S., Ashbullby, K., Herbert, S. and Depledge, M. H., 2013, 'Feelings of restoration from recent nature visits', *Journal of Environmental Psychology* 35, 40–51 (DOI: 10.1016/j.jenvp.2013.04.002).

Wiewel, W., Persky, J. and Sendzik, M., 1999, 'Private benefits and public costs: Policies to address suburban sprawl', *Policy Studies Journal* 27(1), 96–114 (DOI: 10.1111/j.1541-0072.1999.tb01956.x).

Williams, A. M., King, R. and Warnes, T., 1997, 'A place in the sun: International retirement migration from northern to southern Europe', *European Urban and Regional Studies* 4(2), 115–134 (DOI: 10.1177/096977649700400202).

Wilson, B. and Chakraborty, A., 2013, 'The environmental impacts of sprawl: Emergent themes from the past decade of planning research', *Sustainability* 5(8), 3302–3327 (DOI: 10.3390/su5083302).

Wilson, E. H., Hurd, J. D., Civco, D. L., Prisloe, M. P. and Arnold, C., 2003, 'Development of a geospatial model to quantify, describe and map urban growth', *Remote Sensing of Environment* 86(3), 275–285 (DOI: 10.1016/S0034-4257(03)00074-9).

Wissen Hayek, U., Jaeger, J. A. G., Schwick, C., Jarne, A. and Schuler, M., 2011, 'Measuring and assessing urban sprawl: What are the remaining options for future settlement development in Switzerland for 2030?', *Applied Spatial Analysis and Policy* 4(4), 249–279 (DOI: 10.1007/s12061-010-9055-3).

Yang, G., Kong, L., Zhao, W., Wan, X., Zhai, Y., Chen, L. C. and Koplan, J. P., 2008, 'Emergence of chronic non-communicable diseases in China', *Lancet* 372(9650), 1697–1705 (DOI: 10.1016/S0140-6736(08)61366-5).

Yeh, A. G. O. and Li, X., 2001, 'Measurement and monitoring of urban sprawl in a rapidly growing region using entropy', *Photogrammetric Engineering And Remote Sensing* 67(1), 83–90.

Yepes, V. and Medina, J. R., 2005, 'Land use tourism models in Spanish coastal areas. A case study of the Valencia region', *Journal of Coastal Research*, 83–88.

Yue, W., Liu, Y. and Fan, P., 2013, 'Measuring urban sprawl and its drivers in large Chinese cities: The case of Hangzhou', *Land Use Policy* 31(0), 358–370 (DOI: http://dx.doi.org/10.1016/j.landusepol.2012.07.018).

Zhou, L., Dickinson, R. E., Tian, Y., Fang, J., Li, Q., Kaufmann, R. K., Tucker, C. J. and Myneni, R. B., 2004, 'Evidence for a significant urbanization effect on climate in China', *Proceedings of the National Academy of Sciences of the United States of America* 101(26), 9540–9544 (DOI: 10.1073/pnas.0400357101).

European Environment Agency and Federal Office for the Environment

Urban sprawl in Europe
Joint EEA-FOEN report

2016 — 135 pp. — 21 x 29.7 cm

ISBN 978-92-9213-738-0
doi:10.2800/143470

TH-AL-16-010-EN-N
doi:10.2800/143470

Swiss Federal Office for
the Environment FOEN
CH-3003 Berne
Switzerland

Tel.: +41 - 58 462 9311
Web: www.bafu.admin.ch
Enquiries: info@bafu.admin.ch

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Publications Office

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

European Environment Agency