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Final report

Land use monitoring and land take in international comparison

Methods and data

by:

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ILS – Institut für Landes- und Stadtentwicklungsforschung gGmbH, Dortmund

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Abstract: Land use monitoring and land take in international comparison

This report compares different international approaches to land use monitoring and examines the comparability of the results concerning land take. Within the context of an international literature study, key statements on European land take were made, with the underlying numbers reconstructed from the original data. Comparing these numbers with those of official land use statistics in Germany, it becomes clear that statements on land take in particular must be considered in a differentiated manner, taking into account the land monitoring methodology used in each case, in order to arrive at meaningful interpretations and allow international comparisons. The situation is similar when comparing national data from Belgium, Switzerland and England.

Kurzbeschreibung: Flächenmonitoring und Flächenverbrauch im internationalen Vergleich

Dieser Bericht stellt international unterschiedliche Ansätze für das Flächenmonitoring gegenüber und untersucht, inwieweit die dabei erzielten Ergebnisse zum Flächenverbrauch passfähig und vergleichbar sind.. Im Rahmen einer internationalen Literaturstudie wurden hierfür wesentliche Aussa-gen zur Flächenneuinanspruchnahme im europäischen Raum ermittelt und die zugrunde liegen-den Zahlen aus den Originaldaten rekonstruiert. Im Vergleich mit den Zahlen der amtlichen Flä-chenstatistik in Deutschland wird deutlich, dass insbesondere Aussagen zum Flächenverbrauch differenziert und jeweils unter Berücksichtigung der Methodik des Flächenmonitorings betrach-tet werden müssen, um sachgerechte Interpretationen und internationale Vergleiche durchzu-führen. Ähnlich verhält es sich beim Vergleich der nationalen Daten aus Belgien, der Schweiz und England.

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List of abbreviations

AAA model	Application scheme for the geoinformation systems AFIS, ALKIS and ATKIS
ALB	Amtliches Liegenschaftsbuch / Official land register
ALKIS	Amtlichen Liegenschaftskatasterinformationssystems / Land Registration System
ATKIS Basic DLM	Digital landscape model of the Official Topographic-Cartographic Information System
CHA	CLC Change Database
CLC	Corine Land Cover (CLC 2000 resp. CLC 2018 = annual data)
DLR	Deutsches Luft- und Raumfahrtzentrum / German Aerospace Centre
EAP	Environment Action Program
EEA	European Environment Agency
ESPON	European Research Network for Spatial Development and Territorial Cohesion
ESPON SUPER	Sustainable Urbanisation and Land-use Practices in European Regions
EU	European Union
FPS	Federal Civil Service (Belgium)
GHSL	Global Human Settlement Layer
GUF	Global Urban Footprint
ha/d	Hectares per day
ILS	Institut für Landes- und Stadtentwicklungsforschung gGmbH / Institute for Regional and Urban Development Research gGmbH
IÖR	Leibniz-Instituts für ökologische Raumentwicklung Dresden / Leibniz Institute for Ecological Spatial Development Dresden
km/km²	Kilometre/square kilometre
LUCAS	Land Use and Coverage Area frame Survey
LUCS	Land use change statistic
m/m²	Metre/square metre
NUTS	Nomenclature des Unités territoriales statistiques (Nomenclature for the unique identification and classification of the spatial reference units of official statistics in EU Member States)
PDL	Previously Developed Land
SDG	Sustainable Development Goals (United Nations)
SOER	State of the Environment Report

1 Introduction

Land take in Germany remains at a high level, with 55 hectares of new land (four-year rolling average from 2018 to 2021) being taken for settlement and transport purposes every day, predominantly at the expense of agricultural land. However, it is not the same as soil sealing, since settlement and transport surfaces also contain unsealed surfaces such as parks, allotments or sports fields.

While it is true that land take has fallen significantly since 2000 when it was still 129 ha per day, the target set in the 2002 national sustainability strategy to reduce land take to a maximum of "30 hectares per day by 2020" was not achieved. In the new edition of the German Sustainable Development Strategy 2021 (Die Bundesregierung 2021), the land take indicator was further developed for subsequent years. The goal is now to reduce settlement- and transport-related land take to an average of less than 30 hectares per day by 2030. Taking a longer-term perspective, a completely circular land use economy is to be achieved by 2050, i.e. with land take reduced to zero in the balance sheet ("net zero", Die Bundesregierung 2021: 271).

Land take monitoring in Germany is based on the official land use statistics published annually by the Federal Statistical Office in *Fachserie 3 Reihe 5.1* "Land by type of actual use". The land use type "settlement and transport" includes residential, industrial, retail and service surfaces, waste disposal and public facilities, sports, leisure and recreation surfaces, cemeteries, roads and paths, public squares, as well as rail, air and shipping infrastructures (Statistisches Bundesamt 2021).

High land take is a problem not only in Germany, but throughout Europe. According to the European Environment Agency (EEA), EU-28 land take was about 1,000 km^2 per year in the period 2000 - 2006 and 539 km^2 per year in the period 2012 – 2018, albeit with monitoring performed on the basis of aerial image data.

This project investigated the extent to which the land take figures for Germany are comparable with those for land take in other European countries, and the extent to which the data used in international studies for land use in Germany are comparable and compatible with the data found in official land statistics. This report documents the results of these investigations.

2 The data used in monitoring and calculating land take

This chapter documents the results of a literature review. The core question was how statements on land take in Germany and in international comparative studies are derived from selected data bases. The relevant literature can be divided into methodological documents based on remote sensing and earth observation and technical literature on land use and land tale. In addition to scientific literature on the keyword combinations land use/land take and indicator concepts, measurement methods or base data, reports on land take from national and EU authorities were reviewed. On this basis, an analysis was conducted on whether statements and interpretations from the monitoring of land take are influenced by the choice of available data bases.

For selected findings, the data analyses from the literature are reconstructed below and contrasted with the land take data used in Germany. Furthermore, monitoring approaches in three selected European countries are compared in Chapter 3, with the aim of assessing whether there are discrepancies between national and international land take figures outside Germany.

2.1 Comparison of data sources: Aerial photographs versus land register data from official land statistics

A key finding of the literature study is that the presentations of land use in Germany researched in international publications relate primarily to remote sensing data. At European level, data from the *Copernicus* Earth observation programme (Copernicus Land Monitoring Service) is used in particular, as is also the case in the European Environment Agency's State of the Environment Report (SOER) (EEA 2020). At global level, the Organisation for Economic Cooperation and Development (OECD) publishes figures on the loss of agricultural land due to urbanisation, again based on remote sensing data (OECD 2018). For these purposes, data from the Global Human Settlement Layer (GHSL) of the European Commission's *Joint Research Centre* (JRC) was used. This data goes further back in time than Copernicus but was only published in 2018 (Melchiorri et al. 2018).

The common denominator of both datasets is that the Earth observation methodology generates land cover data. This means that any findings on changes in land use are limited to changes in the spectral signature of image pixels detected by satellite sensors. Changes in use due to human activity that do not result in changes in the spectral signature are thus not detected. This represents a significant methodological difference to the monitoring performed in Germany, which takes into account changes in land use for purposes other than settlement and transport. One example are woodlands or meadows now used as sports, leisure and recreation areas, a change not considered by Earth observation to be a change in land cover. However, since sports, leisure and recreation areas are recorded in Germany as settlement and transport surfaces, the total settlement and transport surface area increases, i.e. the change in use is registered as land take.

The official land use statistics in Germany thus explicitly include such changes of use. These statistics are compiled while recording the data through differentiating the types of use of geoobjects in the official land registration system ALKIS, in which land use is classified by trained officials using a combination of geodata analyses (orthophotos, digital maps) and, where necessary, on-site surveys. Reflecting the actual use, these statistics are reported by the German federal states (*Länder*) to the Federal Statistical Office, DESTATIS.

To illustrate this, Table 1 shows the land use types "settlement" and "transport" recorded by the Federal Statistical Office (DESTATIS) in comparison with the artificial surfaces of the land cover classes from the European Earth observation programme Copernicus. The nomenclature for land cover data comes from the EU's CORINE Land Cover Classification developed in the 1980s, which was taken over by the Copernicus Land Monitoring Service in 2012 and continues to be used (Feranec et al. 2016). Therefore, the term CORINE Land Cover (or CLC for short) is used hereinafter in reference to EU land cover data.

Table 1: Land cover classification

Comparison of the land cover classification used by the Copernicus Land Monitoring Service (CORINE Land Cover, left) and the land use types used by the Federal Statistical Office (DESTATIS, right)

Artificial surfaces (CORINE Land Cover)	Settlement and transport surfaces (DESTATIS)
Continuous urban fabric	Residential, retail and service surfaces
Discontinuous urban fabric	
Industrial or commercial units	Industrial and commercial surfaces
Road and rail networks and associated land	Roads and paths, railways, squares
Port areas	Shipping areas
Airports	Air traffic areas
Dump sites	Waste disposal sites or public facilities
Green urban areas	Cemetery
Sport and leisure facilities	Sport, leisure and recreation surfaces
Construction sites	-

Source: Bundesamt für Kartografie und Geodäsie 2021 (left column), Statistisches Bundesamt 2021 (right column)

The comparison of artificial surfaces (CORINE Land Cover, left column) and settlement and transport areas (DESTATIS, right column) in Table 1 is made according to what the authors consider a logical assignment of semantically similar terms. However, this is not always successful as fundamentally different nomenclatures have been developed for earth observation survey methods and land register survey methods. For example, the land cover classes *continuous urban fabric and discontinuous urban fabric* also cover settlement and transport surfaces not juxtaposed in the corresponding row. Similarly, it is unclear which settlement and transport surface uses correspond to the land cover category *construction site* (see bottom row in Table 1).

In addition, there are significant differences in the accuracy of the surface units used. While ALKIS records geo-objects with an accuracy of 1,000 m^2 or higher (depending on the German federal state), the minimum CLC mapping unit is 25 hectares for the submission of area-wide land cover data for one year. In addition, a so-called *change layer* is published showing changes greater than five hectares (Feranec et al. 2016). In some publications / project reports, such as the ESPON SUPER project described in Chapter 2.2, the spatial resolution of CLC is improved through data fusion. To detect small-scale trends, CLC data is combined with sources such as the 2012 Global Urban Footprint (GUF) from the German Aerospace Centre (DLR), with a resolution of twelve metres. However, this approach is limited to data analyses for 2011; for later years, the Global Human Settlement Layer (GHSL) of the European Commission's (JRC) *Joint Research Centre* is used. The reports refer to the CLC Change Database (CHA) for more detailed information. However, reconstruction of the data analyses is not possible on this basis.

In summary, it is clear that significant deviations in land take monitoring results can already exist on account of different data sources. While the individual classes / land use types *artificial surfaces* (remote sensing-based) or *settlement and transport surfaces* (land-register-based) reported in national and international documents as a value for total land take hardly reflect these differences, the similarity of the terms may lead to misinterpretations in the monitoring of land take.

2.2 Data interpretation

Finding answers to the question of what influence the data source has on the interpretation of the data and on possible conclusions of the spatial observation was a key topic of the project.

In addition to looking at land take, the literature study also looked for publications using and assessing the monitoring results of the German land use statistics for their own analyses. A first finding was that hardly any literature exists in this respect. Apart from remote sensing data available across Europe, only one paper was found that evaluated the data sources used for policy objectives in the respective country (e.g., for Germany, land use statistics). The 2015 paper published by Decoville and Schneider "*Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study*" followed this approach, albeit without making any calculations for Germany. The focus was on assessing data options for achieving the European "no net land take objective".

Looking at Luxembourg, the authors concluded that land take monitoring in Luxembourg worked similarly to that in Germany. Interpretation problems for the national spatial observation arose from the fact that official statistics in Luxembourg were also derived from land register data, resulting in discrepancies with the results of the European spatial observation:

"The National Plan for sustainable development in Luxembourg has set the objective to limit to one hectare (ha) per day the process of land take by 2020 []. We have been confronted with a profusion of different data sets, all with very different results that affect the credibility of the 1 ha-goal" (p. 3f.).

In addition, the article referred to the importance of other indicators alongside land take in the monitoring, including soil sealing and planned "construction sites". At the same time, it was stated that smaller building plots were not covered by remote sensing methods in CLC, as the minimum mapping unit was too large. The study thus concluded that remote sensing-based EU land monitoring tools were not sufficiently accurate for smaller surfaces. These findings were tested in Luxembourg and Malta. The conclusion was thus that the goal of net-zero land take by 2050 could not be reliably assessed and efficiently pursued. This finding also related to the measures being discussed to limit land take in such countries.

"This problem of data quality may arise for all the small territories (small countries or regional territories), since the CLC project, which is the one tool broadly used to grasp the phenomenon at the European level, appears to be not precise enough. These reservations with respect to the definition of quantified objectives at the EU level are accentuated by the fact that the policy priorities strongly differ from one country to another..." (p. 11).

The vast majority of other literature collected in the course of the project with reference to land monitoring applications refers to evaluations of CLC data and other land cover data collected by the European Environment Agency, occasionally also on soil sealing. Appendix A lists selected studies with brief summaries of the key statements relevant to the research questions in this report.

In summary, it can be stated that in the European reporting and technical literature, remote sensing data is generally used to monitor land take. Due to the nomenclature and resolution-related geometric accuracy used, this data has little correspondence with German land use statistics. The big question is therefore whether these differences can lead to misinterpretations of land take trends. The finding that land take is declining in Germany provides initial indications of this. In the ESPON SUPER project and in the EEA SOER report, the declining land take in Germany is seen in connection with a decline in land take for industrial purposes. However, this explanation cannot be reconstructed from German land use statistics.

Another literature source points out that even in countries like Luxembourg, land take monitoring problems are caused by the variety of data sources. As a next step, therefore, three selected approaches to land use monitoring in other European countries were investigated (cf. Chapter 3).

In the following, based on the statements on land use developments in Germany in two international reports, the influence of the data source on the interpretation of the data and corresponding conclusions of the spatial observation is explained.

2.2.1 The *SUPER* project of the European Spatial Observation Network ESPON

The following statement on land take in Germany comes from the pan-European project *Super - Sustainable Urbanization and Land-use Practices in European Regions* conducted by the European Spatial Observation Network ESPON:

- Germany is one of the countries with the largest increase of industrial land per inhabitant* in the period 2000-2018 (ESPON 2020a: 23).

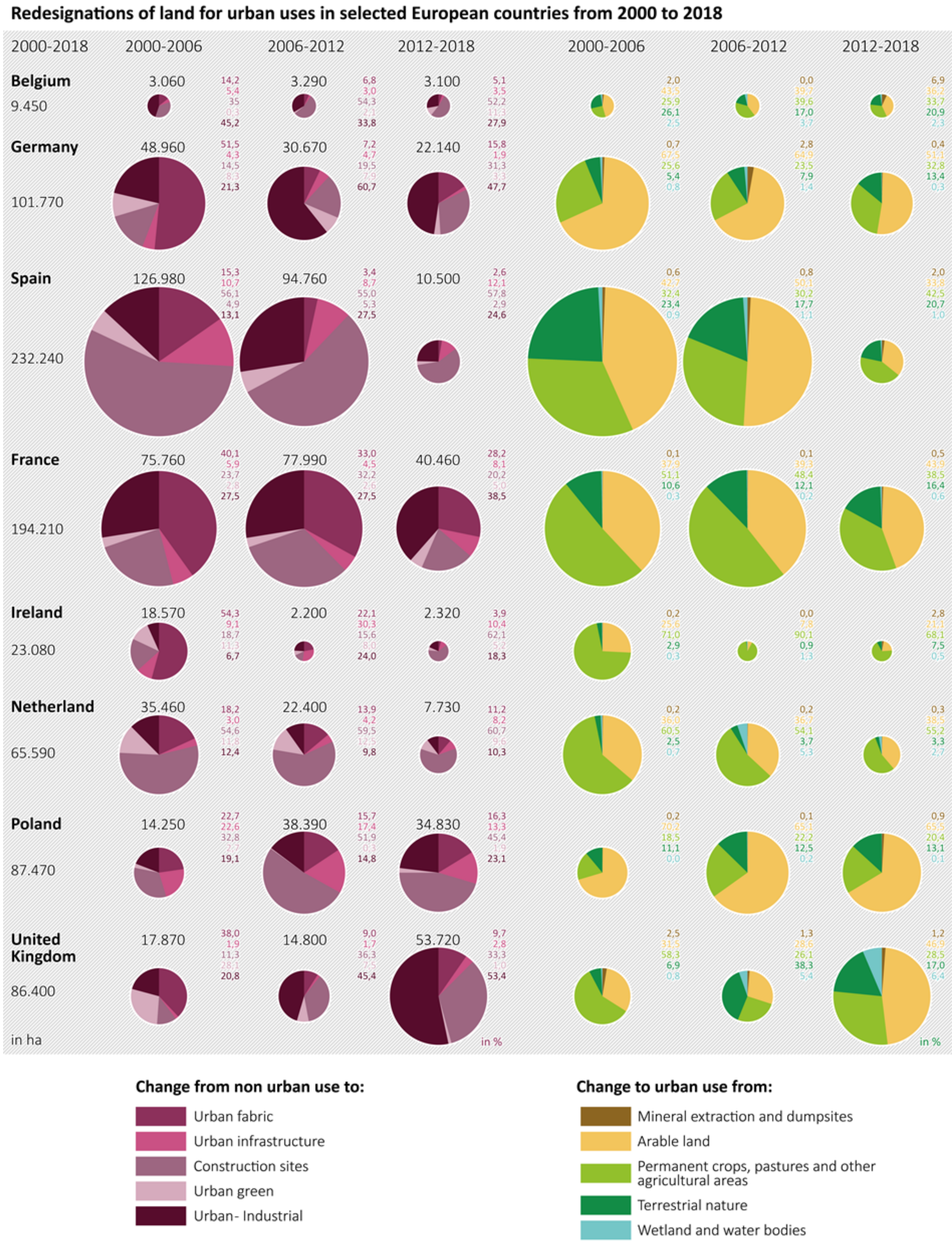
The report is based on Copernicus data using the CORINE Land Cover nomenclature explained above, supplemented by GUF and GHSL data. Figure 1[1] presents an overview of land use changes for the full observation period for individual countries. The figure confirms that land in Germany is being reused primarily for industrial development, at the expense of arable surfaces. However, according to the figures, this trend changed in the last observation period 2012-2018. Looking at land take – a smaller circle denotes a decrease –, the share of new industrial surfaces in total land take is significantly lower than in the previous observation period (2000-2012). This observation initially supports expert assessments clearly identifying a suburbanisation of industry and commerce in Germany since the 2010s. In the ILS's Monitoring StadtRegionen, this finding is corroborated by the significantly higher number of buildings completed on the outskirts of major cities. In connection with positive employment developments in these outskirts and the increasing number of commuters, it is concluded that commerce and industry are providing new jobs in these areas and are responsible for a large share of land take (Fina et al. 2020).

In contrast to the declining shares of commercial and industrial surfaces in Figure 1, there is no evidence in the German spatial monitoring that industrial surfaces have recently played a reduced role in the overall decline in land take. Concrete verification on the basis of data from German land use statistics is difficult, since the types of use for artificial and open spaces for industry and commerce were changed on switching to ALKIS, meaning that there is no stable time series (Georg 2016). What is striking, however, is that construction sites in Figure 1 account for an increasing share of land take in Germany. Since this land cover class has no

[1] For this report, the figure was recreated from the template (graphics: J. Rönsch).

equivalent in the German land use statistics (see Table 1), it can be assumed that many commercial and industrial premises are under construction in this class.

Figure 1: Redesignations of land for urban uses in selected European countries from 2000 to 2018



Source: Own representation. Graphics: J. Rönsch. Reproduced from ESPON 2020b, p. 9 with permission by © ESPON. Origin of data: ESPON EGTC.
Disclaimer: The interpretation of ESPON material does not necessarily reflect the opinion of the ESPON 2020 Monitoring Committee.

2.2.2 SOER 2020 of the European Environment Agency

Another publication of great relevance and visibility for European spatial monitoring is the *State of the Environment Report* (SOER) published by the European Environment Agency (EEA). These reports have been published every five years since 1995. In them, the term "land take" is used in reference to the expansion of settlement areas ("urban expansion") and its consequences ("land use change"). Monitoring is based on the Copernicus Land Monitoring Service using the CORINE Land Cover Nomenclature (see also Figure 2 and the interactive graphics on the agency's website[2]). In interpreting the results, it becomes apparent that the "no net land take" target is unachievable if the trends seen in recent years continue. Moreover, land take goes hand in hand with urban sprawl effects in nature and landscape – effects needing to be reduced.

Figure 2 shows land take in m^2 per km^2 in a country-by-country comparison, with Germany ranking 12th of the 39 countries considered. The United Kingdom, Switzerland and Belgium are also highlighted in the Figure, as these countries will be examined in greater depth in the following sections.

In addition to the country comparison, two further statements are made in the report in the context of "land take in Germany":

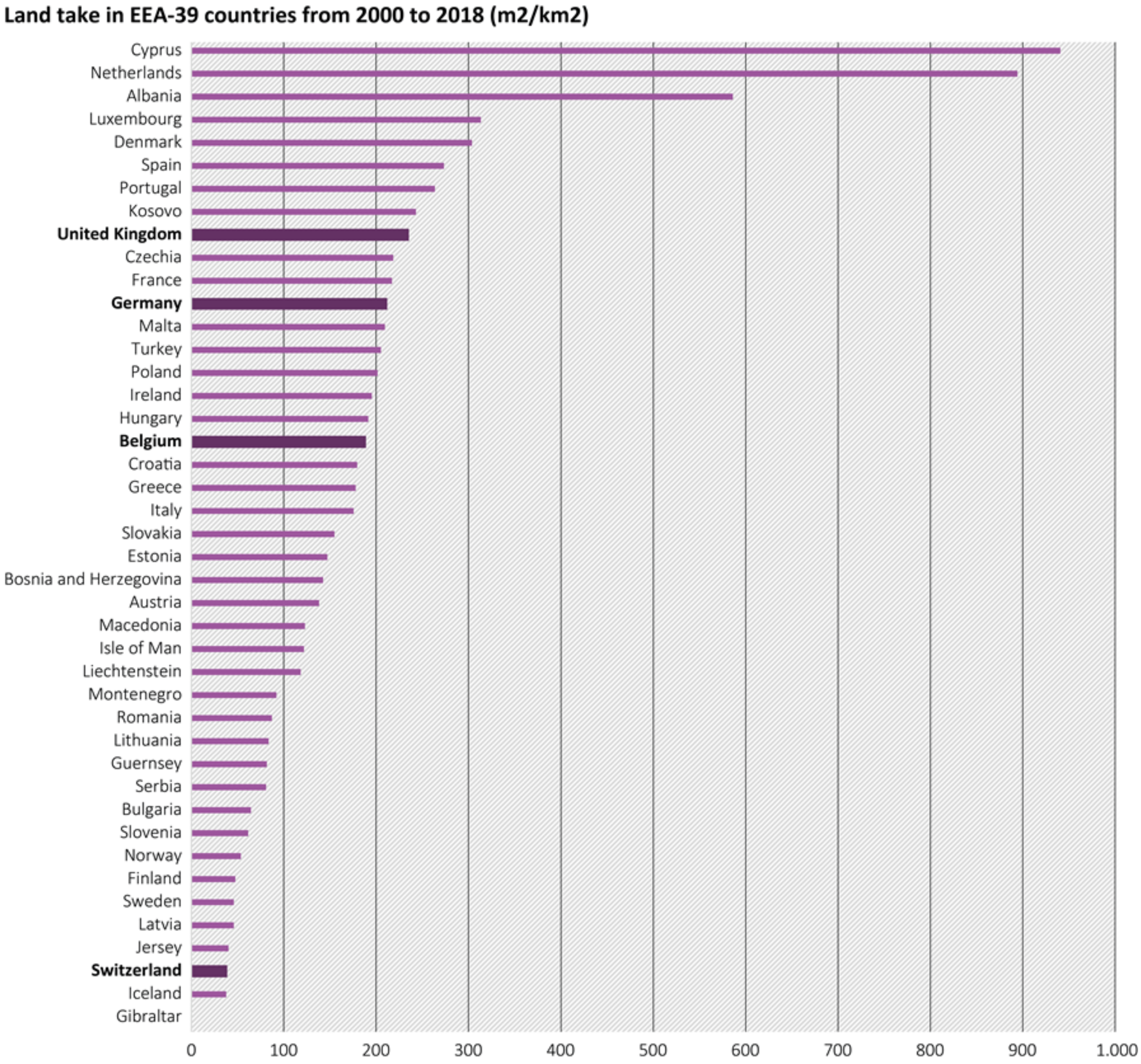
- Urban sprawl through new commercial and industrial surfaces has decreased by 45% in Germany since 2012.
- The conversion rate of "no-tillage agriculture" surfaces declined sharply (-97%).

While the second statement on the conversion rate of agricultural land has no relation to land take, the first statement on urban sprawl due to new commercial and industrial surfaces in Germany needs to be critically questioned. As explained above and as seen in Figure 1, we cannot rule out that new industrial and commercial sites were increasingly classified as construction sites in CORINE Land Cover during this monitoring period. What is true is that land take has declined overall in Germany. As mentioned above, commercial and industrial surfaces are not comparable with the official land use statistics for the observation period, as the types of use have changed. Nevertheless, the former uses of industrial and commercial surfaces (2012: 3,337 km^2) and the operational surfaces (2012: 2,528 km^2) total 5,866 km^2, compared to today's designated industrial and commercial surfaces (2018: 6,169 km^2). The statement in the EEA environmental report is not corroborated by this finding.

In addition, the question arises as to what extent the term "urban sprawl" is correctly chosen here. While urban sprawl implies increasing land take, it also involves a qualitative assessment, e.g., in terms of environmental impacts and resource efficiency. From the scientific point of view of the authors, a land take balance is unsuitable for such assessments.

[2] last visited 10 June 2021.

Figure 2: Land take in EEA-39 countries from 2000 to 2018 (m^2/km^2)



Data source: https://www.eea.europa.eu/data-and-maps/dashboards/land-cover-and-change-statistics, last visited on 09.10.2020, Graphics: J. Rönsch

3 Land cover monitoring methodology and the consistency of results

This chapter looks at the extent to which different monitoring approaches may affect the comparability of results, their interpretation and conclusions. With a view to international comparisons, selected approaches in other countries were also considered, with Switzerland, Belgium and England considered. For each of these countries, the monitoring methodology is first described and assessed in terms of strengths and weaknesses. Then, with the exception of England, the available national data on land use for these countries as well as for Germany - in this case the official German land statistics - are compared with the CLC data used by the European Environment Agency. Finally, available data sources on the development of industrial and commercial surfaces are also checked for consistency.

3.1 Monitoring methodologies in Switzerland, Belgium and England

3.1.1 Swiss land statistics (*Arealstatistik Schweiz*)

Switzerland's land statistics ("*Arealstatistik*") have been kept since the 1980s for the main purpose of documenting land cover changes. Based on aerial photography, both land use and land cover are surveyed. The results are then cross-checked against 4.1 million permanent sample points. The survey period for an aerial survey of the entire country is six years (Beyeler 2018: 47-49, BFS 2016).

Table 2 shows a summarised assessment using selected criteria.

Table 2: Characteristics of the Swiss land statistics with regard to their suitability for land use monitoring

Methodology	Strengths	Weaknesses	Topicality
Aerial photo interpretation on a sample basis Verification of land use at the sample point (hectare coordinates) The data is made up of digital aerial photographs of the Federal Office of Topography Characteristics collected: 46 land use categories, 27 land cover categories	Scaling of data possible for specific spatial units (construction sites, protected areas, hydrological catchment areas, biogeographical regions, etc.) Unambiguous categories Innovative approach, survey methodology is being continuously improved	Comparability of data for individual years only possible to a limited extent Pure land use statistics Time-consuming survey methodology Incomplete datasets (for Eastern Switzerland, information is not always available, e.g. for St. Gallen, Graubünden)	Based on the flight programme of the Federal Office of Topography Every twelve years since 1979/85; Four nationwide surveys to date: 1979/85, 1992/97, 2004/09; 2013/18

Source: own representation

In monitoring land take, Switzerland does not use quantitative targets for the whole country; instead, spatial planning authorities issue guidelines for the cantons on the use of building zones and the mobilisation of building land, on density requirements, on the protection of agricultural land, and on second homes. The cantons report on the goals every four years. Most recently, a slight decrease in land take was reported (2006-2015: 0.6 percentage point increase in residential and transport surfaces; 1994-2006: 0.07 percentage points; until 2006: 0.08 percentage points, Hoffmann 2021, p. 74). Most of the land take is for residential buildings, with spatial steering in favour of agglomerations (ibid., p. 91).

3.1.2 Belgium's Land Use Register

The data basis for Belgium's national area statistics is the land register kept by the "FPS Finance" (Federal Public Service Finance). Recording all plots of land (parcels and buildings), it provides a good national basis for establishing linkages to datasets - such as land use type - which relate to property boundaries and can be used for monitoring land take (FPS 2021).

The land use statistics have been updated annually since 1982, without any change to the methodology, enabling the analysis of long consistent time periods. The land use categories distinguish between undeveloped and developed land. Undeveloped land is divided into ten subcategories (including farmland, woodland and recreational land). In the case of developed land, the subdivision is made into 15 categories reflecting a building's use. In addition to developed (artificial) residential and industrial surfaces, more specialised categories are also listed, such as farms, workshops, or places of worship (Statbel 2020). Land use data is available for all spatial units, i.e. for 580 municipalities in the three regions Wallonia, Flanders and Brussels (Statbel 2020).

Table 3 provides an overview of selected characteristics of the Belgian land use monitoring system.

Table 3: Characteristics of Belgian land use statistics with regard to their suitability for land use monitoring

Methodology	Strengths	Weaknesses	Topicality
Land register-based recording of land use	Unchanged recording system since 1982, enabling analyses of long time series Data available for all administrative levels (regions, provinces, districts, municipalities)	Low adaptability to new developments The system's rigidity potentially limits the depth of analysis of land use data for new research questions	Very high topicality. Data for 2020 is already available (as of April 2021)

Source: own representation

The databases are used to check regional goals, as no overarching national goal exists. For example, the Spatial Policy Plan for Flanders established the 2012 land take target of "3 hectares per day by 2025". The Wallonia region (6 km^2 land take in 2030) has its own interim target; by 2040, land take in both regions should decrease to net zero. In 2021, the value for Flanders was six hectares per day; according to expert estimates, it is unlikely that the interim target will be reached (Hoffmann 2021, p. 125ff.).

3.1.3 "Land use change statistics" England

In England, a brownfield redevelopment target was introduced in 1999 as part of the so-called "Prescott Initiative"[3]. The initiative to redevelop previously developed (brownfield) land and at the same time reduce use of greenfield sites thus came from top government (until 2006 the Office of the Deputy Prime Minister, later replaced by the Department for Communities and Local Government). Monitoring involved innovative methods of 'sequential testing' being pioneered, whereby different land potentials were systematically compared with regard to their intended use (Department of Environment, Transport and the Regions 1998). To do this, the national land agency, Ordnance Survey, can refer to a comprehensive and accurate geographic dataset listing 40 million addresses and properties. The information contained in AddressBase® comes mainly from local authorities. The latter obtain the necessary address information from various sources.

Information on land use change and land take is available from this methodology in the national statistics ("Land use change statistics"). Among other things, the dataset provides opportunities to analyse the percentage of new residential addresses on previously developed land. This data can be contrasted with designated sites not previously used for building purposes. As a result, land monitoring in England has long been able to link land take policy objectives with the reuse of brownfields for housing.

Table 4 shows the main criteria for suitability in land use monitoring.

Table 4: Characteristics of the English land use change statistics with regard to their suitability for land use monitoring

Methodology	Strengths	Weaknesses	Topicality
Evaluation of address databases	Presentation of the annual change in land use subdivided into previously developed surfaces and new developments	The comparability of current data with pre-2011 data is not possible due to a change in methodology	Annual publication Latest publication 2017/2018

Source: own representation

The goal set in 1999 was that at least 60% of new housing construction should take place on brownfield sites by 2008. This was achieved shortly after the goal was introduced (ODPM 2004) and has since been mainstreamed at all planning levels as part of the New Urban Renaissance Agenda. The 2016 Planning Act extended the goal by targeting 90% of all brownfield sites for residential development by 2020 (DCLG, 2016). Information on the extent to which this goal has been achieved has not yet been published.

3.2 Comparison of the statements on land take

For the selected countries and Germany, the data was obtained and subsequently re-assessed on the basis of the questions published in the EEA's SOER. First, total land take was reconstructed using the CORINE change detection geodata. The results obtained were consistent with the

[3] Serving as deputy prime minister in the United Kingdom from 1997 to 2007, John Prescott advocated the reuse of brownfields to reduce land take.

figures published in the European Union's environmental reporting. In a second step, these results were contrasted with the land take figures found in the national statistics.[4]

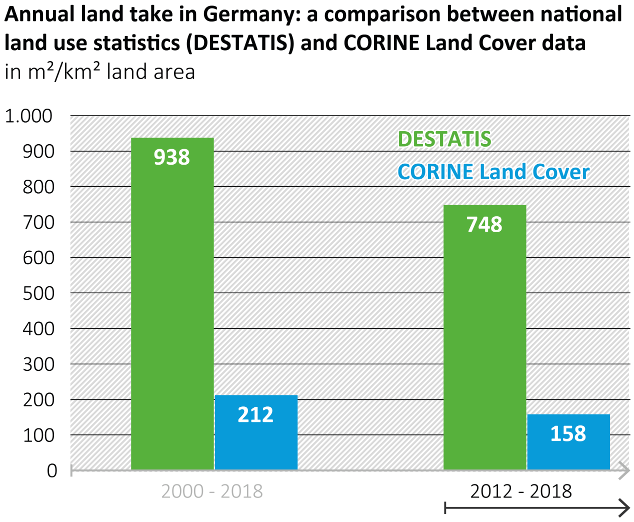
In line with the EEA's SOER, we show how many square metres per square kilometre of the country's total surface area are being additionally used or taken up for settlement purposes each year in the respective period under consideration. This method also allows countries of different sizes to be compared. To calculate land take, all land use changes in category 2 (agriculture areas) and category 3 (forests and semi-natural areas) included in the CLC dataset were added to category 1 (artificial surfaces).

For Germany, Switzerland and Belgium, the comparison with data from national statistics is presented below. This is not possible for England due to the lacking CLC data in the EEA environmental report.

3.2.1 Germany - Land take comparison

According to the EEA's SOER based on CLC data, long-term (2000-2018) annual land take in Germany was 211.9 m² per km² of national territory. Over the shorter period 2012-2018, annual land take was significantly lower at 158.4 m² per km² (EEA 2020). Based on the data of the official land use statistics, significantly higher values were calculated for the periods mentioned: 938 ha/d for the period 2000 to 2018 and 748 ha/d for the period 2012 to 2018 (cf. Figure 3).

Figure 3: Annual land take in Germany: a comparison between national land use statistics (DESTATIS) and CORINE Land Cover data



Source: Statistisches Bundesamt, Copernicus CLC, own design. Graphics: J. Rönsch

As was to be expected, Figure 3 shows that the DESTATIS national land use statistics differ significantly from CLC figures. It is plausible for CLC figures to be significantly lower, as open spaces in settlement areas are not included. The CLC-calculated land take figure is thus equivalent to just 22.6% (2000-2018) / 21.1% (2012-2018) of the figure for settlement- and transport-related land take calculated by DESTATIS. This difference cannot however be explained solely by the share of land take by types of use explicitly declared as open residential space (sports, leisure and recreation facilities, cemeteries), as these accounted for just 22.5% of overall land take for example in the last year of the observation period (Federal Statistical Office 2021 - DESTATIS).

[4] England is an exception, as no CORINE data is available here.

Other land use types such as residential, industrial and commercial premises (excluding quarries), public facilities, and transport surfaces also include open space (e.g., gardens and associated vegetation) that CLC does not capture in detail. This is neither provided for in the CLC land cover classes, nor does CLC register changes smaller than five hectares. This probably excludes a large number of smaller land take areas in CLC, while they are included in DESTATIS. The actual effect of these differences cannot be quantified. Nevertheless, the absolute numbers have clearly decreased in both cases over the periods under consideration, with overall land take dropping irrespective of the monitoring approach.

With regard to the German 30-hectare target, this comparison confirms that solely the national land take figures can be used when making land take statements relating to the objectives of the German Sustainable Development Strategy. In the expert discourses, we need to be quite clear about the fact daily land calculated on the basis of CLC data has no significance for the achievement of the German sustainability target for reducing land take. Otherwise, the political debate runs the risk of underestimating land take. While it is true that daily land take has declined from an average of 92 hectares per day (2000-2012) to 73 hectares per day (2012-2018) over the two monitoring periods, any conversion of CLC-based land take (21 hectares per day from 2000-2012 / 16 hectares per day from 2012-2018) would suggest that the 30-hectare goal has been achieved. This interpretation would be wrong and inadmissible.

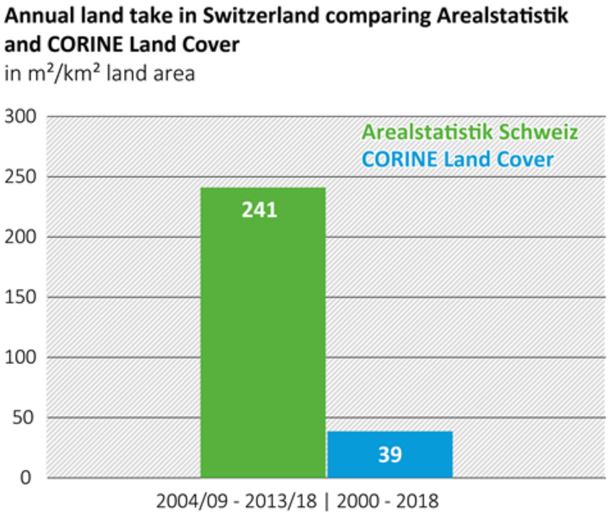
3.2.2 Switzerland - Land take comparison

The EEA's SOER lists an annual land take figure of 38.7 square metres per square kilometre for the whole of Switzerland between 2000 and 2018. The value has increased recently: in the period 2012 to 2018, it was quite higher (49.9 m^2 per km^2). In both observation periods, Switzerland is one of the European countries with the lowest land take figures under the CLC methodology.

As far as possible, this figure is compared below with the Swiss national land use statistics (*Arealstatistik*). Due to *Arealstatistik's* periodic recording system, annual land take for the period 2004-2018 can only be estimated, while a subdivision into a longer and shorter past observation period is not possible. In terms of content, land take according to the *Arealstatistik* nomenclature is the sum of paved surfaces (11) and building surfaces (12) (see Appendix B). The land take total of 13,938 hectares is calculated as the difference between the sum of these two categories from the 2013/2018 survey period and that from the 2004/2009 period. The conversion to the unit used in the EEA's environmental report again shows a significantly higher land take of 241 m^2/km^2 in the Swiss national statistics compared to the CLC data (39 m^2/km^2).

At 16.2%, the CLC-calculated land take is even further below the national *Arealstatistik* figure than in Germany (22.6% in the period 2000-2018 / 21.1% in 2012-2018). Consequently, it is reasonable to assume that Switzerland's land use statistics contain other uses which explain the higher discrepancy, for example, planned construction zones (cf. Hoffmann 2021, p. 79ff.). No account is taken of such planned zones in German land use monitoring.

Figure 4: Annual land take in Switzerland comparing Arealstatistik and CORINE Land Cover



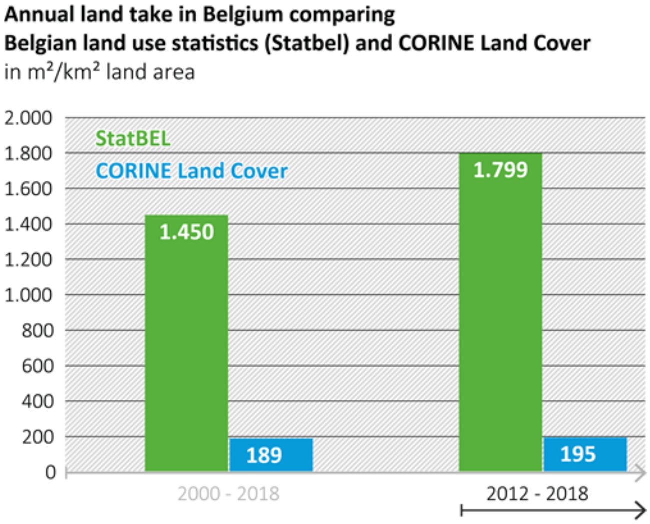
Source: Arealstatistik Schweiz, Copernicus CLC, own design. Graphics: J. Rönsch

3.2.3 Belgium - Land take comparison

With annual national land take of 188.9 (2000-2018) / 195.4 (2012-2018) m²/km², Belgium has a rate similar to that of Germany according to the EEA's SOER.

For verification purposes, annual land take was calculated using land use data from the Belgian land register (Statbel 2020). For the two periods looked at, land take can be calculated as the total surface area of residential, industrial and commercial premises, together with transport surfaces (see Appendix D). Overall, the total area devoted to these uses increased by 80,085 ha between 2000 and 2018 and by 33,122 ha between 2012 and 2018. As the chart shows, this corresponds to a significantly higher annual land take than the CLC data would suggest. In both monitoring approaches, the comparison of the two time periods consistently shows that annual land take was higher between 2012 and 2018 than in the longer period. In contrast to Germany, land take in Belgium thus increased. Compared with Germany (22.6% in the period 2000-2018 / 21.1% in 2012-2018) and Switzerland (16.2% in 2000-2018), however, the Belgian land use statistics diverge even more from the results of the EEA's environmental report. The CLC-calculated land take rate is equivalent to just 13.0% of the rate calculated on the basis of Belgian land use statistics for the whole 2000-2018 observation period, and to just 10.8% in the period 2012-2018.

Figure 5: Annual land take in Belgium comparing Belgian land use statistics (Statbel) and CORINE Land Cover



Source: Land use statistics Belgium, Copernicus CLC, own design. Graphic: J. Rönsch

This observation cannot be explained in detail in the context of this review. However, a look at the types of use (see Appendix D) in the context of the literature suggests that, as in the case of the Swiss *Arealstatistik*, the inclusion of planned building zones would seem to play a role. Built-up (artificial) surfaces are derived from the land registry. If the generous designations found in land use plans of the 1960s and 1970s referred to by Hoffmann 2021 (p. 125) are included as artificial surfaces, this would explain the high discrepancies. The same author points to the fundamental problem in Belgium that land take is not subject to strict spatial controls, and that approaches to saving land are still at the discussion stage (ibid., p. 125).

3.2.4 Interim conclusion I - Land take

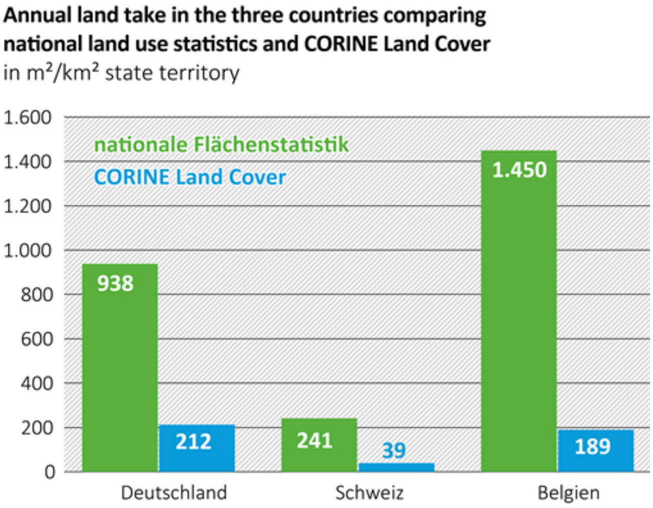
The summarising comparison in Figure 6 (annual land take) shows that in all three selected countries, the national statistics come up with significantly higher results for land take than the CLC data. The differences are attributable to the fundamentally different collection methods: land use information on the one hand (Germany's land use statistics, Switzerland's *Arealstatistik* and Belgium's land use statistics), and the land cover information in the EEA's SOER based on CLC data) on the other hand.

While land use is likely to contain a much larger proportion of residential open space that is counted as residential land from a land use perspective (e.g., inner-city parks, roadside verges, private gardens, allotments), remote sensing data is limited in coverage to image pixels whose spectral signature is classified as built over. Although object-oriented data harmonisation is also used in CLC methods to check spectral signatures for consistency with surrounding uses (Ferance et al. 2016), such rule-based mappings are unable to account for real usage information. Moreover, the minimum 5-hectare mapping unit in CLC Change Detection is a problem, as smaller areas are absorbed into surrounding uses. The effect on the overall balance can hardly be quantified, but is likely to be relatively high, especially for smaller-scale land take, such as that made possible by the German Building Land Mobilization Act for consolidating land on the outskirts of towns (§ 13 b BauGB) (Herrmann 2019).

A summarising comparison of this effect between three countries in Figure 6 shows that these deviations are smallest in Germany. Looking at the 2000-2018 period, CLC-calculated land take is 22.6% of the figure reported in the national land use statistics, while the figure for Switzerland is 16.2%, and 13.0% for Belgium. The explanation for this cannot be reconstructed for the base data in the context of this study. It is conceivable, however, that the inclusion of planned building zones in the monitoring systems of the Swiss *Arealstatistik* and larger, previously non-built area designations from the 1960s and 1970s in Belgium play a role. In Germany, such planned construction zones are not included in the monitoring; the land-registry-based data contains only use types reflecting actual use, i.e. the current, not the planned status of surfaces.

Regardless of these possible explanations, the land take figures reconstructed here are often taken up in the political discourse without reflection, with a need to distinguish between monitoring methods seldom communicated. Our example thus shows that, without in-depth consideration of the monitoring method, all that is revealed is the inconsistency between national land use statistics and the CLC data.

Figure 6: Annual land take in the three countries comparing national land use statistics and CORINE Land Cover



Source: Statistisches Bundesamt, Arealstatistik Schweiz, land use statistics Belgium, own design.
Graphic: J. Rönsch

3.3 Comparison of industrial and commercial land take

In a second comparison, statements from the ESPON SUPER report and the EEA's SOER on the increase in industrial surfaces ("industrial land take") for the whole of Europe constitute a reason for reconstructing the figures for the selected countries. As stated in the report interpretations in Section 2.2, the CLC-based ESPON report concludes that Germany experienced the highest industrial land take per capita in Europe between 2000 and 2018. The following quote from the ESPON SUPER report echoes this finding:

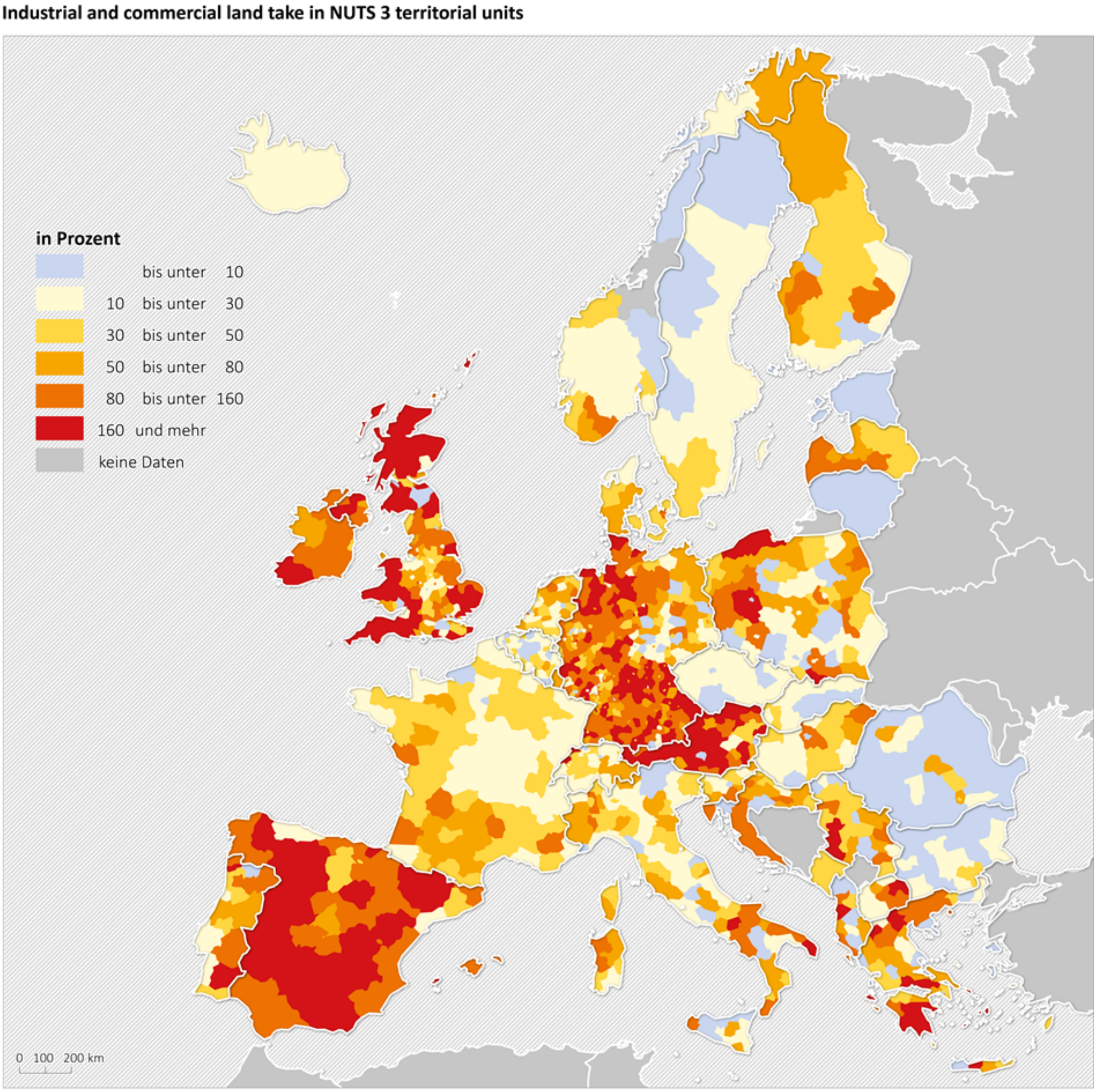
"Overall, the period 2000-2018 has seen the largest increase in industrial areas per capita in the UK, Spain, Germany, Austria, Western Poland, the Western Balkans, Greece and Turkey; and a decrease in only a few regions but including most of Lithuania and Romania" (ESPON 2020a: 23).

The following section reconstructs the base figures to verify these two statements in more detail, using CLC data for the period 2000-2018. Due to the lack of population reference figures, this comparison is not possible for the increase in industrial areas per capita as presented in the report. The evaluation refers to the increase in industrial and commercial areas[5] in percent, without population-related effects being taken into account. This limitation is justifiable, since

[5] The dataset describes the land cover class as "industrial and commercial units", while we just use the term "industrial areas".

the epistemic interest of this analysis is to compare industrial land take with national land use statistics. The results are revealing despite the lacking population reference.

Figure 7: Industrial and commercial land take in NUTS 3 territorial units



Source: Data: Copernicus CLC, own design. Graphic: J. Rönsch

For this purpose, the data on the increase in industrial areas was first obtained from CLC and visualised in the map in Figure 7 for the third spatial hierarchy of EU member states (NUTS-3 classification system of 2016)[6]. The map in Figure 7 confirms that German NUTS-3 regions are among the countries with the highest percentage increases in industrial areas in Europe.

In the following, these figures are contrasted with the industrial land take figures recorded in national land use statistics, followed by a critical reflection on the plausibility of this comparison.

[6] NUTS - *Nomenclature des unités territoriales statistiques* is the European Union's classification system of statistical spatial reference units.

3.3.1 Germany - Comparison of industrial land take

According to CLC data, industrial areas in Germany increased by 152.5% from 2000 to 2018. This period also saw the changeover from ALB/ALK to ALKIS, with specific changes in the use types for industrial areas. The problem here is that the land-register-based view of the use types considers industrial and commercial areas together; it is thus not possible to look solely at purely industrial areas. Before the changeover, the land use statistics included the use types *commercial and industrial buildings and open space*, as well as *operating areas* which needed to be added. After the changeover, industrial areas covered the use types *industrial and commercial areas*, together with *operating areas*, i.e. the latter were no longer separate. However, reports from the field suggest that this reclassification was not carried out systematically and uniformly (see also Georg 2016). For example, commercial areas may also have been reclassified as *areas of mixed use,* or industrial operating areas may have been transferred to the use type groups *mining operations* or *open-cast mine, quarry*.

In addition to these uncertainties, the German land use statistics for the states of Saxony, Schleswig-Holstein and Thuringia lack data for the year 2000. Thus, for Germany, a comparison with CLC data can only be made for selected federal states, as shown in Table 5. It is noticeable that the differences in percentage land take rates between DESTATIS and CLC are very irregular. There are no systematic deviations: depending on the state, DESTATIS or CLC is higher. The negative DESTATIS figures for the eastern German states of Brandenburg (-36.0%), Mecklenburg-Vorpommern (-27.6%) and Saxony (-30.6%) are particularly striking. CLC shows no such decreases, with all three states instead featuring increases.

For the interpretation of these irregularities, an observation addressed in Section 2.2. discussing the figures found in the EEA's SOER is instructive. Indeed, a comparison of CLC data on industrial areas between the 2000-2012 and 2012-2018 periods shows that a decline in the share of land take accounted for by industrial areas in the later period came at the expense of construction areas. It can therefore be assumed that changing classifications play a role in identifying industrial land cover in CLC, so that a transition from industrial areas to construction areas cannot be ruled out. In this data analysis, this methodological explanation encounters a difficulty in the time series of German area statistics, again due to methodological reasons.

In the interaction of these two effects, it is difficult to assess the plausibility of the base data in the field of industrial land take in Germany.

Table 5: Industrial and commercial land take in German federal states from 2000-2018

Federal state	Percentage change in industrial and commercial space (DESTATIS)*	Percentage change in industrial areas (CLC)
Baden-Württemberg	44.5%	126.7%
Bavaria	48.1%	249.2%
Berlin	49.6%	46.6%
Brandenburg	-36.0%	70.0%

Federal state	Percentage change in industrial and commercial space (DESTATIS)*	Percentage change in industrial areas (CLC)
Bremen	70.0%	95.0%
Hamburg	58.3%	19.0%
Hesse	44.9%	142.3%
Mecklenburg-Vorpommern	-27.6%	48.0%
Lower Saxony	3.1%	259.8%
North Rhine-Westphalia	12.5%	109.0%
Rhineland-Palatinate	28.2%	114.9%
Saarland	17.8%	64.6%
Saxony	-30.6%	38.0%

*2000: Commercial and industrial buildings and associated open spaces + Operating areas / 2018: Industrial and commercial areas

Source: Federal Statistical Office (https://www-genesis.destatis.de/genesis/online?operation=statistic&levelindex=0&levelid=1635686202992&code=33111#abreadcrumb)

3.3.2 Switzerland - Comparison of industrial land take

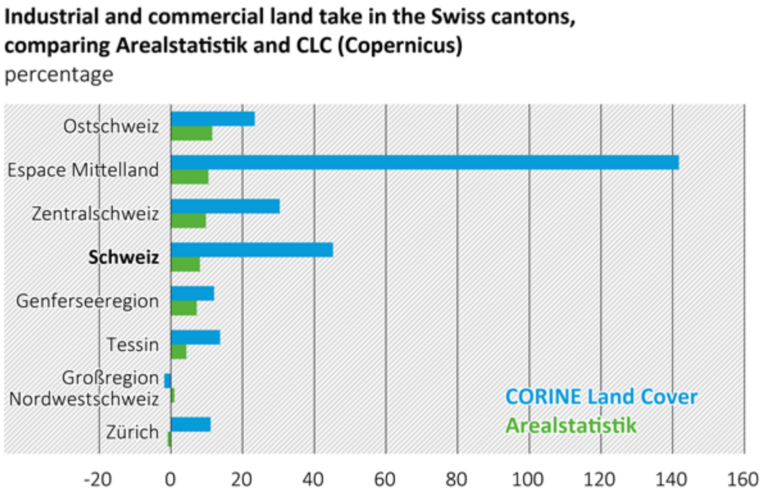
For Switzerland, mean growth in industrial areas between 2000 and 2018 was 45.2% according to data in the EEA's SOER. The comparison with Swiss *Arealstatistik* is based on the data available for the time periods 2004/2009 and 2013/2018 (see also 3.1.1). Here again, commercial areas are part of the overall industrial and commercial land use type and thus cannot be separated from purely industrial areas. Due to a lack of data in the *Arealstatistik*, land take for three of the seven cantons in Eastern Switzerland (Glarus, St. Gallen and Graubünden) is not included, meaning that total land take is likely to have actually been higher. The base data is the total area for industrial and commercial areas as the sum of the two basic categories "Industrial and commercial buildings" (1) and "Surroundings of industrial and commercial buildings"[7] (2) (see Appendix C).

The chart in Figure 8 shows that the *Arealstatistik* features lower industrial land take than the CLC data; mean growth in industrial areas across Switzerland's 23 cantons is 8.1% (CLC: 45.2%). For the seven major regions, this difference varies greatly. The deviation is most pronounced in the greater Espace Mittelland region, with 10.5% in the *Arealstatistik* against 141.7% in CLC. This is due to extreme percentage increases in the cantons of Jura (391.2%) and Neuchâtel (206.7 %).

[7] The Swiss-German term "Umschwung" means the associated land around the buildings, analogous to the area of buildings and open space in German land use statistics.

The explanations for these differences considered in the last section for the deviations in Germany also apply to Switzerland. First, it cannot be assumed with certainty that the national land use statistics accurately reflect developments. Second, reclassifications from industrial to construction land likely played a role in the CLC figures from 2012 to 2018. However, the exact effect cannot be quantified.

Figure 8: Industrial and commercial land take in the Swiss cantons, comparing *Arealstatistik* and CLC (Copernicus)



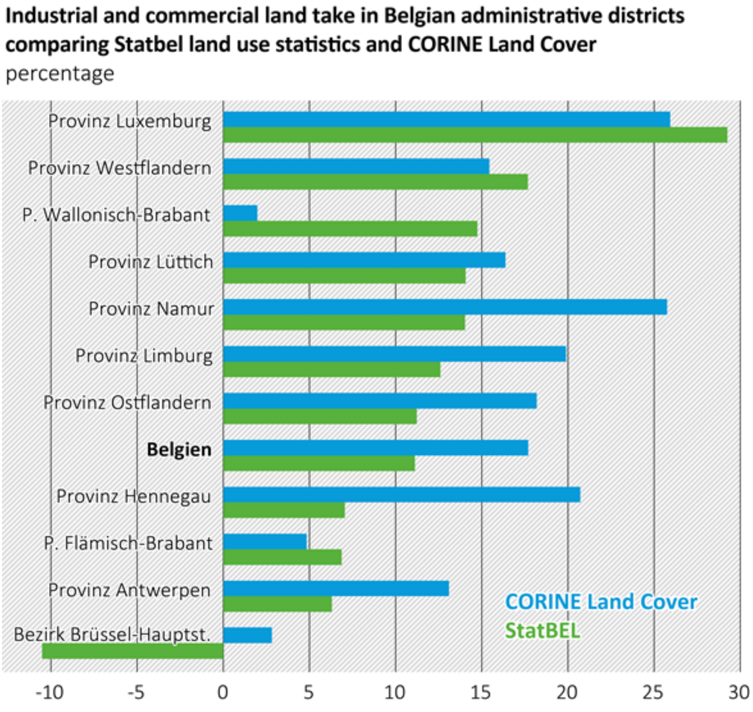
Source: Data: Arealstatistik Schweiz, Copernicus CLC, own draft. Graphics: J. Rönsch

3.3.3 Belgium - Comparison of industrial and commercial land take

Belgium's national land use statistics similarly make no distinction between industrial and commercial land. Therefore, to calculate industrial land take, the use types *workshops and industrial buildings*, *warehouses* and *commercial buildings* must be combined (see the categories of the Belgian land register in Appendix E). In 2000, the total of these uses was 54,405 hectares. By 2018, this had risen to 60,448 hectares, corresponding to an increase of eleven percent.

The comparison with the CLC data shows that the deviation from the Belgian land use statistics is not as pronounced as in Germany or Switzerland. Mean industrial and commercial land take across Belgium's 44 administrative districts is 17.7%, 6.6 percentage points higher than CLC's industrial land take (11.1%). However, the deviations in individual administrative districts such as the province of Walloon Brabant or the capital district of Brussels are so considerable that a supposed approximation between national land use statistics and CLC does not allow any further conclusions to be drawn. In Belgium, there are thus also major uncertainties regarding the comparability of national land use statistics and CLC.

Figure 9: Industrial and commercial land take in Belgian administrative districts comparing Statbel land use statistics and CORINE Land Cover



Source: Data: Land use statistics Belgium, Copernicus CLC, own design. Graphics: J. Rönsch

3.3.4 England - Comparison of industrial and commercial land take

In contrast to the land take rates described above, industrial and commercial land take can be considered separately for England. The official 2018 English land use statistics indicate an area of 48,551 ha for the “Industry and Commerce” land use type. This use type is made up of the categories “Industry”, “Offices”, “Retail” and “Storage and Warehouse”. Valid comparative values for older years stem from the *Land use change statistic* (LUCS), from which industrial and commercial land take can be reconstructed from 2013 onwards (see Table 6). While only the values for the whole of England are available from this source, they do however contain additional information important for the English land-saving target (see 3.1.3.), i.e., the proportion of industrial and commercial land take implemented on “previously developed land” (brownfield land), and that for “new developed use”.

Overall, the amount of new land designated for “Industry and Commerce” each year between 2013 and 2018 is 7,704 hectares, i.e., an increase of 18.9%. To enable a comparison with CLC despite the different time periods, annual land take can be determined and compared. For the period 2000 to 2018, CLC shows mean annual land take of 16.3% for English NUTS 3 regions (total from 2000-2018: 292.85%). This compares to a much smaller figure from national land use statistics of 3.77%.

Table 6: Industrial and commercial land take in England in data comparison

Years	“Industry and Commerce” on previously developed use (ha)	New developed use (ha)	Land changing from non-developed use to “Industry and Commerce” (ha)
2013/14	5,380	7,114	1,734

Years	"Industry and Commerce" on previously developed use (ha)	New developed use (ha)	Land changing from non-developed use to "Industry and Commerce" (ha)
2014/15	5,381	8,264	2,883
2015/16	5,288	5,767	479
2016/17	4,291	5,164	873
2017/18	4,811	6,546	1,735
Total	25,151	32,855	7,704

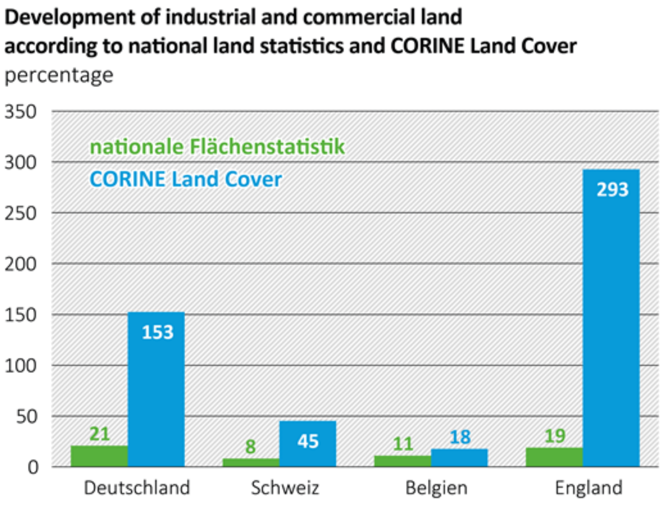
Source: Land Use Change Statistics in England: 2017-18 (https://www.gov.uk/government/statistical-data-sets/live-tables-on-land-use-change-statistics)

CLC thus again shows a much higher industrial land take in England, similar to Germany and Switzerland than that registered by national land use statistics. Again, two major differences can be cited as explanations: (1) uncertainty regarding the types of uses in the national statistics that are counted as industrial and commercial areas, and (2) the possible classification of construction land as industrial land in previous CLC datasets that were reclassified as construction land in 2018.

3.3.5 Interim conclusion II - Development of industrial land take

Comparison of CLC data with the data available at national level and used for monitoring national industrial land take reveals significant differences. The summary chart in Figure 10 illustrates that CLC lists higher land take for all countries considered. This difference is most pronounced in England, where land take according to CLC is 15.5 times higher than national land use statistics. The difference is least pronounced in Belgium (CLC 1.6 times higher). Germany (CLC 7.3 times higher) and Switzerland (CLC 5.6 times higher) are in between (see Figure 10).

Figure 10: Development of industrial and commercial land according to national land statistics and CORINE Land Cover



Source: Data: Statistisches Bundesamt Deutschland, Arealstatistik Schweiz, land use statistics Belgium, LUCS land use change statistics England, Copernicus CLC, own draft. Graphics: J. Rönsch

It can be surmised that, between 2000 and 2012, CLC detected many areas with spectral signatures assigning them to the industrial land class, but which were classified as construction land in the subsequent period up to 2018. This explanation is derived from the high shares of these two classes in total land take in the periods under consideration (cf. also Figure 1). In addition, it is unclear to what extent CLC is able to distinguish between industrial and commercial land take. While the land use view used in national land statistics groups these two classes together, the remotely sensed CLC view, with its minimum mapping unit of five hectares, is likely to have difficulty distinguishing small-scale commercial areas from surrounding uses.

3.4 Aerial photography-based checks of anomalous changes in industrial and commercial sites in two case studies

The following section examines the land take rates for municipalities featuring anomalous changes in North Rhine-Westphalia using aerial photo comparisons. The anomaly also relates to the ESPON SUPER project base data which shows a 1,668% increase in industrial surfaces in Solingen and a 24.1% decrease in Bottrop, two industrial cities in North Rhine-Westphalia.

3.4.1 Development of industrial and commercial areas in Bottrop

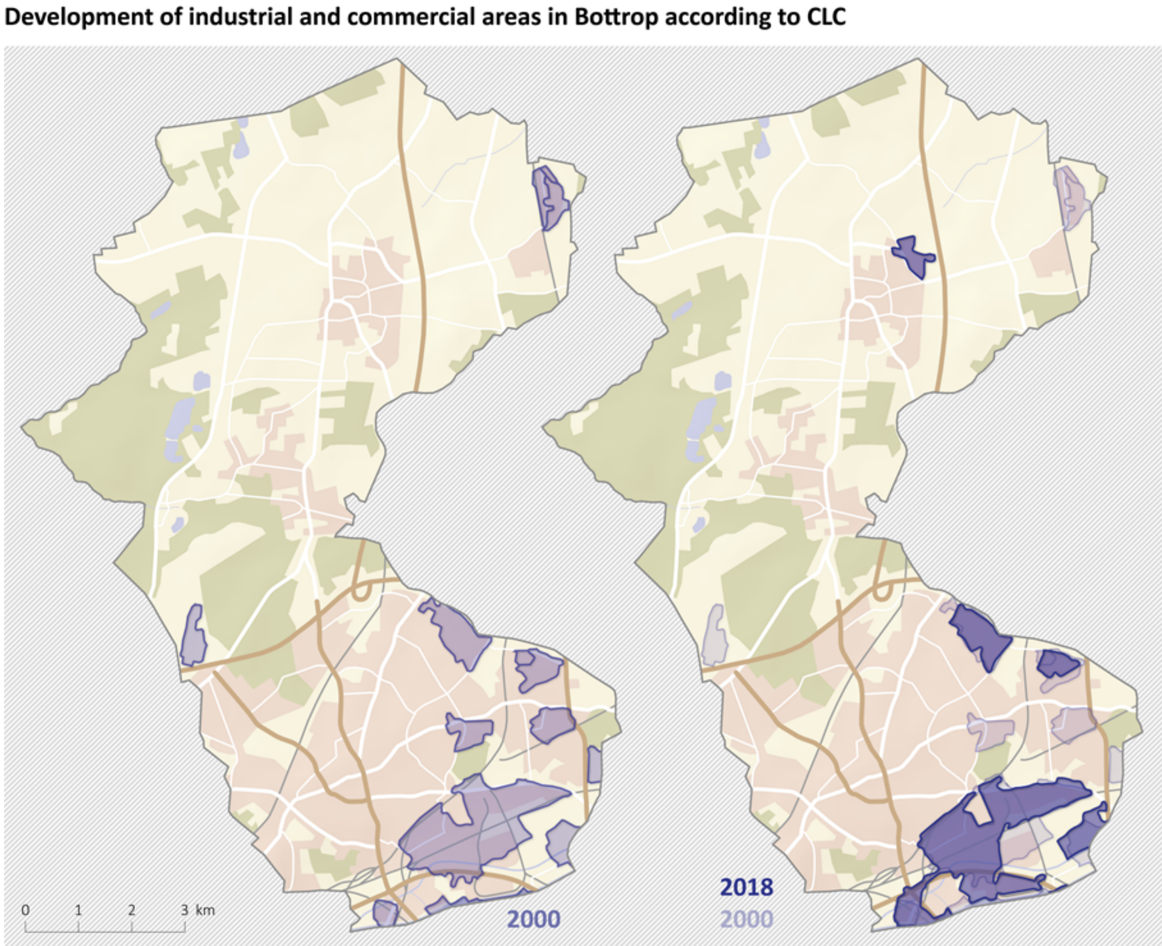
The decrease in industrial and commercial land in Bottrop according to CLC data is 24.1%, from 671 to 511 hectares. Reconstructing this figure using data from the German land use statistics for Bottrop shows a decrease of 15.7%, from 683 hectares in 2000, which, in line with the use types at the time, consisted of buildings and open space for industry and commerce as well as operating areas, to 576 hectares of industrial and commercial land in 2018. In the CLC geodata in Figure 11, we see that some areas are no longer present, while others have been added. The left part in Table 7 shows the areas included in CLC in 2000. The figure on the right shows the situation in 2018 with a darker shading for remaining industrial areas and lighter shading for areas no longer captured in 2018.

For five selected areas, Table 7 traces, as far as possible, how actual land development appears in historical and current aerial photographs of Bottrop (https://gis.bottrop.de)[8]. The first thing that becomes clear is that assignment to CLC use types does not always reflect actual developments. For areas such as the Zeche Haniel colliery, the Movie Park Germany, or the industrial estates in Kirchhellen and South Bottrop, CLC Change Detection registers changes in the surface texture, which are interpreted as a decrease of industrial surfaces. However, it is actually a different classification according to the CLC land cover classes in 2018 compared to 2000. New industrial areas such as the Kirchhellen or Horster Strasse industrial estates already existed in the 1998 aerial photograph, though at the time they were still under construction. Again, the new classification in CLC 2018 as industrial surfaces is not however due to an actual change in use.

These examples highlight the difficulties experienced by CLC in monitoring spectral signature changes from satellite imagery to classify land cover over several years without inconsistencies, particularly in the field of industrial areas.

[8] The following aerial photographs are released for reprint according to the data license Germany - Zero - Version 2.0. https://gis.bottrop.de/mapapps/resources/apps/Stadtplan_Luftbilder/index.html?lang=de, last visited 11.06.2021.

Figure 11: Development of industrial and commercial areas in Bottrop according to CLC



Source: Geodata: Geobasis-DE/BKG2018, Own design. Graphics: J. Rönsch

Table 7: Changes in large industrial areas in CLC, city of Bottrop, 2000-2018

Area	Area in aerial photo 2000	Area in aerial photo 2018
The **Zeche Haniel** is a disused **colliery.** The buildings still exist, but are no longer used industrially. The area formerly classified as an industrial unit in CLC is now listed as a mineral extraction site and is thus no longer a settlement area.		
The **Movie Park Germany** was opened in 1996. The amusement park is still there today. In the CLC 2000 dataset, the area was classified as an industrial unit, while in that of 2018 it is listed as a sports and leisure facility.		

Area	Area in aerial photo 2000	Area in aerial photo 2018
The **Kirchhellen industrial estate** was already partially present on aerial photographs in 1998. It was not identified as an industrial unit in the CLC 2000 dataset, but is grouped into the categories “discontinuous urban fabric” and “pastures”. In the CLC 2018 dataset, it appears as a new industrial area.		
The **industrial estate in the south of Bottrop** has been in existence since 1998. In the 2018 CLC dataset, the area is no longer designated as industrial, but is listed as discontinuous urban fabric.		

Area	Area in aerial photo 2000	Area in aerial photo 2018
In 1998, the **Horster Straße** industrial estate was still a construction site. It developed into a trading park in the following years and has been classified as an industrial unit in CLC ever since.		

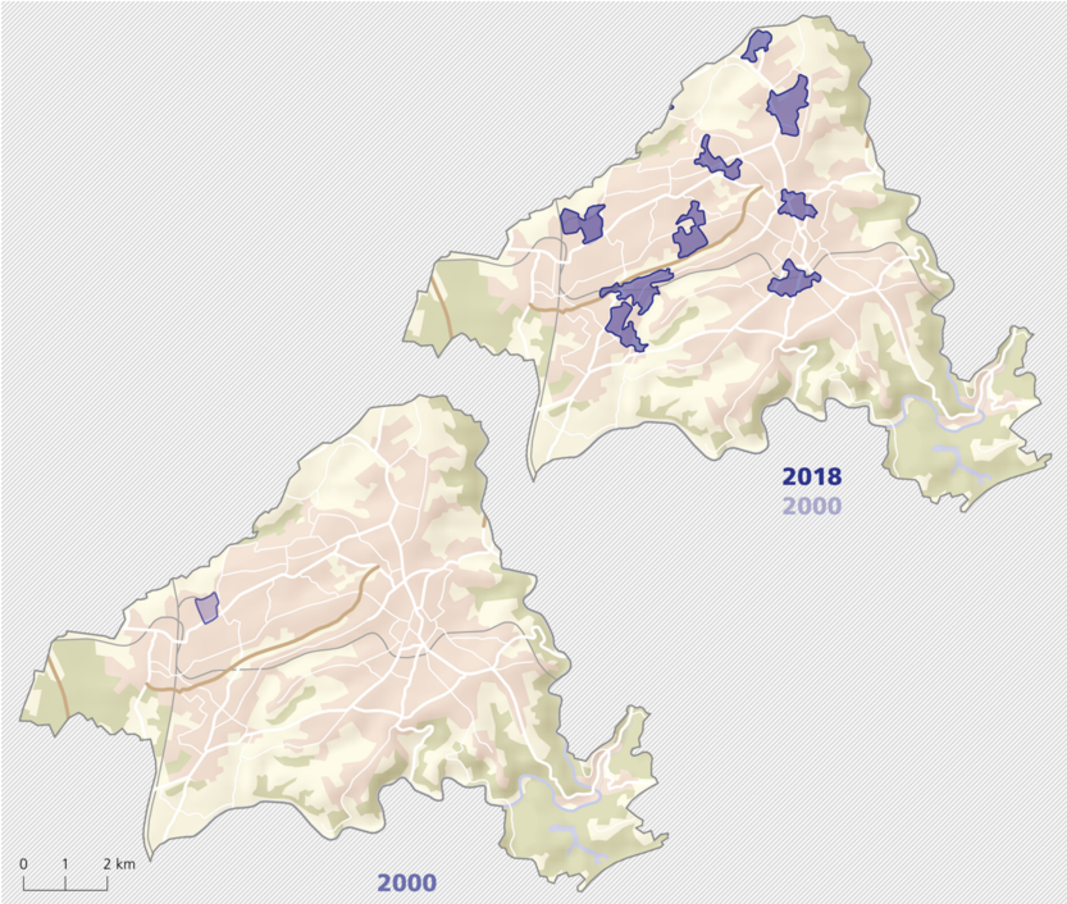
Source: Own research, aerial photographs: https://gis.bottrop.de, last visited on 11.06.2021

3.4.2 Development of industrial and commercial areas in Solingen

A similar analysis was conducted for Solingen, a city featuring growth of 1,668% in industrial and commercial space between 2000 and 2018. According to the 2000 CLC data, there was only one industrial estate in the city, with a total surface area of 25.4 hectares (see Figure 12, left). This value cannot be reconstructed from the German land statistics for 2000, which list the total area used for commercial and industrial purposes as 442 hectares (commercial and industrial buildings and open space plus operating areas), while in 2018 the figure had dropped to 407 hectares (industrial and commercial), a 7.9% decline.

Figure 12: Development of the largest industrial and commercial areas in Solingen according to CLC

Development of the largest industrial and commercial areas in Solingen according to CLC



Source: Geodata: Geobasis-DE/BKG2018, Own design. Graphics: J. Rönsch

Source: Own design. Graphics: J. Rönsch

The strong growth in industrial areas in Solingen according to CLC can be attributed to nine new areas identified in the 2018 geodataset (see Figure 12, right). These have a total area of 448.7 ha. Due to the low starting value in 2000, this explains the calculated strong increase of 1,667 %.

Most of the newly classified industrial land was classified as discontinuous urban fabric in the 2000 data set. Solingen's historical atlas (https://geoportal.solingen.de/buergerservice1/ol3/sg_layout.html?gui=histo)[9] offers the possibility to verify the classification by historical aerial photographs. Due to the similarity of the problems, the Schmalzgrube industrial and commercial area is used as the sole example (cf Fig. 13).

[9] Reprinted with the kind permission of the city of Solingen.

Figure 13: The Schmalzgrube commercial and industrial area in Solingen

Aerial photos of the Schmalzgrube commercial and industrial area in Solingen from 1998 (left) and 2018 (right).
Source: https://geoportal.solingen.de/buergerservice1/ol3/sg_layout.html?gui=histo, last visited on 11.06.2021

According to this, the Schmalzgrube commercial and industrial area already existed in 1998 and has changed only slightly since. Accordingly, the example points to the area having been classified as discontinuous urban fabric in CLC 2000, but as an industrial or commercial unit in the 2018 dataset. No actual development meriting a reclassification occurred.

3.4.3 Interim Conclusion III - Aerial Photo Matching for Anomalous Changes in Industrial and Commercial Sites

The individual case analyses of the CLC data using the example of industrial areas in Bottrop and Solingen make it clear that numerous classification inconsistencies can occur in CLC datasets over time series. These inconsistencies can have various causes and lead to incorrect conclusions regarding land use developments:

- Existing industrial areas present in the 2000 dataset may have disappeared through being assigned to other CLC land cover types. Comparing 2000 to 2018, this led to a decrease in industrial areas which did not occur in reality (e.g. Bottrop South industrial estate).
- A decrease in industrial areas may also be the result of corrections. In these cases, areas previously designated as industrial were assigned to their correct class without any change to the area or land cover (e.g., Movie Park Deutschland, Zeche Haniel).
- Conversely, industrial estates that already existed in reality but were not declared as such in the CLC 2000 dataset may result in a very high percentage increase when subsequently added to the 2018 CLC dataset (e.g. Solingen, the Bottrop-Kirchhellen industrial estate).

Overall, a direct comparison over time for individual areas using CLC geospatial data for different years thus yields results that pose problems for monitoring land take. The case studies show that, due to different classification results between CLC 2000 and CLC 2018, a comparison over time is only possible to a limited extent. At European level, the information from Change Detection is nevertheless taken up in reports such as ESPON Super or the EEA's SOER.

Technical alternatives to improve the information value of time series are being researched, for example in projects using the Sentinel II series of the Copernicus programme. However, monitoring improvements through emerging technologies cannot always be used retrospectively, meaning that the time series remain susceptible to breaks. These are not directly recognisable, especially in land development reporting, since only the land use attribute of object-based data is further processed in the aggregation procedures used to determine the status. The results in the form of tables, graphs and maps do not allow any conclusions to be drawn about the classification quality of the underlying objects, as exemplified by the aerial photograph matching shown above.

The sometimes high discrepancies between selected national statistics and CLC results impressively demonstrate this problem. It must however also be clearly stated that land use statistics in Germany are also susceptible to breaks in time series due to changes in use type catalogues, new measurements of objects, and not always uniform handling of recording systems between individual authorities and the aggregating agency.

4 Summary

This report analysed the comparability of cadastre-based versus satellite-based figures and statements on land take. The aim was to find out whether internationally cited land consumption rates based on satellite image analysis match with e.g. German figures based on official land use statistics.

Figures from Germany, Switzerland, Belgium and the United Kingdom show that deviations between land use change records based on satellite images and the ones from cadastral data can be substantial. Reports like the State of the Environment. Reports such as the EEA's State of the Environmental Report (SOER) make quantitative statements on land take in Germany which differ significantly from nationally published figures. Without further guidance and interpretations from this report, they are hardly comprehensible.

The 2015 scientific paper by Decoville and Schneider concludes that the mostly varying base data in EU countries hardly allows for an internationally comparable assessment and progress monitoring of the European Union's land take target ("no net land take by 2050") by member state.

Countries use several approaches to monitoring sustainable land development at national level. The Swiss Arealstatistik is based on time-stable point surveys from aerial photo interpretations, meaning that the results are closer to the CLC land development figures than in the other countries considered. However, the data collection method remains very costly.

Land use statistics in Belgium are cadastre-based and comparably up to date. 2020 data was already available online in April 2021.

England, on the other hand, has a spatial monitoring approach that uses data to support action-oriented land-saving policies. The political objectives are linked to the recycling of brownfields, to be seen as an important building block for achieving the circular land economy also envisaged by the German government in the German Sustainable Development Strategy for 2050.

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A Further reading

Authors/ Title	**Gardi, C. et al./ *Land take and food security: assessment of land take on the agricultural production in Europe (2014)***
Data sources used	CORINE Land Cover 1990, 2000 and 2006
Spatial reference	21 countries in Europe
Assessment	The study seeks to assess the potential productivity losses in European agriculture due to land use processes between 1990 and 2006. For this purpose, land cover maps for the years 1990, 2000 and 2006 were calculated using Corine data. The quality of the data used is mentioned in the methods section, but is not an explicit subject of the study.

Authors/ Title	**Inostroza, L.; de la Barrera, F./ *Ecosystem Services and Urbanisation. A Spatially Explicit Assessment in Upper Silesia, Central Europe (2019)***
Data sources used	CORINE land cover data set (Copernicus 2018)
Spatial reference	Upper Silesia, Central Europe
Assessment	In this paper, a spatial analysis was conducted to examine the provision of ecosystem services (ES) and the degree of urbanisation to drive the use of ES in planning. Potential ES provision was evaluated using a land use-based approach. The CORINE land cover dataset (Copernicus 2018) was used here to determine the potential. However, the article does not address the quality of the base data.

Authors/ Title	**Gibas, P.; Majorek, A./ *Analysis of Land-Use Change between 2012-2018 in Europe in Terms of Sustainable Development (2020)***
Data sources used	Corine Land Cover, DEGURBA
Spatial reference	Europe
Assessment	This article presents methods for assessing land use changes in the context of sustainable development and the results of their application based on the transformations that took place in individual regions of Europe in 2012-2018. The data used comes from the CORINE land cover programme and municipal authorities representing the degree of urbanisation (DEGURBA). In particular, the use of municipal-level spatial data is interesting and could be relevant for the project.

Authors/ Title	**Früh-Müller, A. et al./ *Regional Patterns of Ecosystem Services in Cultural Landscapes (2016)***
Data sources used	ALKIS
Spatial reference	Germany (selected counties in Hesse)
Assessment	This article focuses on the spatial distribution of ecosystem services in agriculturally dominated districts. The study is very specific to the agricultural sector and uses ALKIS data as the basis for building models. However, there is no discussion of data quality.

Authors/ Title	**Masini, E. et al./ *Urban Growth, Land-use Efficiency and Local Socioeconomic Context: A Comparative Analysis of 417 Metropolitan Regions in Europe (2019)***
Data sources used	Urban Atlas
Spatial reference	Europe (417 metropolitan regions in 27 European countries)
Assessment	The study presents a multidimensional analysis of land use efficiency in terms of per capita artificial surface in 417 metropolitan regions from 27 European countries. The study period covers two urban phases: economic expansion (2000-2007) and crisis (2008-2015). Unlike the other studies, the authors draw on digital, high-resolution maps from the Urban Atlas, supplementing them with statistical information from Eurostat's Urban Audit initiative. Methodologically, this study thus provides an interesting starting point for improving the information content of existing datasets.

Authors/ Title	**EEA/ *Urban Sprawl in Europe (2016)***
Data sources used	Corine Land Cover
Spatial reference	Europe (32 countries)
Assessment	Assessment: This report provides a comparable measure of urban sprawl for 32 European countries at three levels (country level, NUTS 2 region level, and 1 km2 cell level) and for two years (2006 and 2009). The analysis is based on the Copernicus system. The quality and suitability of data for measuring sprawl is addressed.

B Arealstatistik Schweiz land cover categories

10	Hauptkategorie: Künstlich angelegte Flächen	Main area: Artificially created areas
11	Befestigte Flächen	Paved surfaces
12	Gebäude	Buildings
13	Treibhäuser	Greenhouses
14	Beetstrukturen	Bed structures
15	Rasen	Lawns
16	Bäume auf künstlich angelegten Flächen	Trees on artificially created areas
17	Gemischte Kleinstrukturen	Mixed small structures

20	Hauptkategorie: Gras-, Krautvegetation	Main area: Grass, herbaceous vegetation
21	Gras-, Krautvegetation	Grass, herbaceous vegetation

30	Hauptkategorie: Gebüschvegetation	Main area: Scrub vegetation
31	Gebüsch	Bushes
32	Verbuschte Flächen	Overgrown areas
33	Niederstammobst	Low-stem orchards
34	Reben	Vines
35	Gärtnerische Dauerkulturen	Horticultural permanent crops

40	Hauptkategorie: Baumvegetation	Main area: Tree vegetation
41	Geschlossene Baumbestände	Continuous wooded areas
42	Waldecken	Small groups of trees
43	Waldstreifen	Strip of wooded land
44	Aufgelöste Baumbestände	Discontinuous wooded areas
45	Gebüschwaldbestände	Scrub
46	Lineare Baumbestände	Linear wooded areas
47	Baumgruppen	Groups of trees

50	**Hauptkategorie: Vegetationslose Flächen**	**Main area: Areas without vegetation**
51	Anstehender Fels	Rocks
52	Lockergestein	Scree
53	Versteinte Flächen	Surfaces covered with stones

60	**Hauptkategorie: Wasser und Feuchtflächen**	**Main area: Water and wetlands**
61	Wasser	Water
62	Gletscher, Firn	Glacier, firn
63	Nassstandorte	Wetlands
64	Schilfbestände	Reeds

Source: https://www.bfs.admin.ch/bfs/de/home/statistiken/raum-umwelt/nomenklaturen/arealstatistik/nolc2004/27-grundkategorien.html

C Settlement areas in Switzerland (excerpt from the 72 categories)

	Siedlungsflächen	Settlement areas
1	Industrie- und Gewerbegebäude	Industrial and commercial buildings
2	Umschwung von Industrie- und Gewerbegebäuden	Surroundings of industrial and commercial buildings
3	Ein- und Zweifamilienhäuser	One- and two-family houses
4	Umschwung von Ein- und Zweifamilienhäusern	Surroundings of one and two-family houses
5	Reihen- und Terrassenhäuser	Terraced houses
6	Umschwung von Reihen- und Terrassenhäusern	Surroundings of terraced houses
7	Mehrfamilienhäuser	Apartment buildings
8	Umschwung von Mehrfamilienhäusern	Surroundings of apartment buildings
9	Öffentliche Gebäude	Public buildings
10	Umschwung von öffentlichen Gebäuden	Surroundings of public buildings
11	Landwirtschaftliche Gebäude	Agricultural buildings
12	Umschwung von landwirtschaftlichen Gebäuden	Surroundings of agricultural buildings
13	Nicht spezifizierte Gebäude	Unspecified buildings
14	Umschwung von nicht spezifizierten Gebäuden	Surroundings of unspecified buildings

Source: https://www.bfs.admin.ch/bfs/de/home/statistiken/raum-umwelt/bodennutzung-bedeckung/gesamtspektrum-regionalen-stufen/Kantone.assetdetail.11007189.html

D Categories of land use statistics in Belgium

	Rubrique	Heading
1.	Terres agricoles totales (excl. serres)	Total agricultural land (excluding greenhouses)
1.1	Terres laborables	Arable land
1.2	Terres consacrées à des cultures permanentes	Land dedicated to permanent cultures
1.3	Terres consacrées aux prairies et pâturages permanents	Grasslands and pastures
2.	Total des forêts et autres terres boisées	Total wooded areas
3.	Terrains bâtis et terrains connexes	Developed land (buildings and their surroundings)
3.1	**Terrains résidentiels**	**Housing areas**
3.2	**Terrains industriels (autres que 3.3 ci-dessous)**	**Industrial areas (other then 3.3 below)**
3.3	Terrains utilisés pour les carrières, puits, mines, etc.	Land used for quarries, pits, mines, etc.
3.4	**Terrains commerciaux**	**Commercial areas**
3.5	Terrains utilisés pour des services publics, excepté les infrastructures de transport, de communication et techniques	Land used for public services, except transport, communication and technical infrastructures
3.6	Terrains à usage mixte	Mixed-use land
3.7	**Terrains utilisés pour les transports et les communications**	**Land used for transport and communication**
3.8	Terrains occupés par les infrastructures techniques	Land used for technical infrastructures
3.9	Terrains à usage de loisirs et autres espaces ouverts	Land used for leisure and other open spaces
7.	Eaux	Water
7.1	Eaux intérieures	Inland water
7.2	Eaux côtières	Coastal water
8.	Zone marine	Marine zone
9.	Autres terrains	Other land
10.	Superficie continentale	Continental surface
11.	Superficie de sols	Soil surface
12.	Superficie totale (y compris zone marine)	Total surface (including the marine zone)

Source: https://statbel.fgov.be/en/themes/environment/land-cover-and-use/land-use#figures

E Categories of the Belgian land register

1TOT	total des parcelles non bâties	Total undeveloped land
1AE	terres agricoles nda	agricultural land
1BC	pâtures, prés	pastures, grasslands
1DI	jardins et parcs	gardens and parks
1F	vergers	orchards
1G	bois	woods
1H	terres vaines et vagues	unused land
1J	loisirs, sports	leisure, sports
1K	eaux cadastrées	cadastered water
1L	chemins cadastrés	cadastered paths
1MNOP	autres	others

2TOT	total des parcelles bâties	Total developed land
2A1A2	appartements	apartments
2B	immeubles à appartements	apartment buildings
2C	maisons, fermes	houses, farms
2DEF	annexes, y compris les serres	outbuildings, including greenhouses
2G	ateliers et bâtiments industriels	workshops and industrial buildings
2H	bâtiments de stockage	warehouses
2I	banques, bureaux	banks, offices
2JK	bâtiments commerciaux	commercial buildings
2L	bâtiments publics	public buildings
2M	equipements d’utilité publique	public facilities
2N	bâtiments destinés à l’aide sociale et aux soins de santé	social and healthcare buildings
2O	bâtiments destinés à l’enseignement, la recherche, la culture	teaching, research, culture buildings
2P	bâtiments destinés aux cultes	religious building
2Q	bâtiments destinés aux loisirs, aux sports	leisure and sports buildings

2TOT	**total des parcelles bâties**	**Total developed land**
2RST	autres	others

Source: https://statbel.fgov.be/en/land-use-according-land-register#figures