



PROGRAMME OF
THE EUROPEAN UNION



Copernicus Land Monitoring Service – High Resolution Layer – Imperviousness 2021

PRODUCT USER MANUAL (PUM)



Date: 30.07.2025

Doc. Version: 1.3



Document history

Version	Date	Short description of changes
1.3	30.07.2025	Initial published issue



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1 Executive Summary

Copernicus is the Earth Observation component of the European Union's Space Programme. It offers space-based Earth observation and in situ (non-space) data as well as thematic data products. Copernicus data and products are freely and openly accessible to its users and six thematic Copernicus services (atmosphere monitoring, marine environment monitoring, land monitoring, climate change, emergency management and security) offer various operational thematic data products and services.

The Copernicus Land Monitoring Service (CLMS) provides geographical information on land cover and its changes, land use, vegetation state, water cycle and earth surface energy variables to a broad range of users in Europe and across the world for various domains and applications. CLMS is jointly implemented by the European Environment Agency (EEA) and the European Commission's Directorate-General Joint Research Centre (JRC).

The High-Resolution Layer (HRL) Imperviousness is part of the pan-European CLMS portfolio that currently covers the EEA38+UK countries. It consists of two products: Imperviousness and Impervious Built-Up, along with their derived and supporting layers.

All layers contained here are derived from high-resolution optical satellite image time series (Sentinel-2) via automatic image processing methods and provide dedicated information on Impervious and Built-Up surfaces during the reference year 2021 (i.e. status) and detected dynamics between 2018 and 2021 (i.e. change). The aim of these layers is to provide reliable status and updates on artificial sealing characteristics across Europe to facilitate environmental monitoring applications, regional and transnational analyses and, generally, to support decision-making that is based on spatial evidence.

This Algorithm Theoretical Basis Document (ATBD) describes and justifies the algorithms used to generate the HRL Imperviousness 2021 by describing each element of the processing, allowing users to understand the details of the products.



2 Background of the document

2.1 Scope

The Product User Manual (PUM) is designed to serve a broad audience of users who seek to understand and utilize the product effectively. It is intended primarily for end-users who require an overview of the product's features, quality, and usage guidelines without needing deep technical expertise.

The PUM provides essential information on product characteristics and concepts, intended usage and application areas, as well as other information relevant to the use of the products (e.g. lineage, terms of use, and available technical support). However, it is not intended as a technical document. Users in need of in-depth technical insights and the methodologies used for production, such as data scientists, developers, and researchers, are advised to consult the Algorithm Theoretical Basis Document (ATBD).

2.2 Content and structure

The document is structured as follows:

- Chapter 3 summarizes the evolution of the product portfolio over time
- Chapter 4 recalls the user requirements
- Chapter 5 presents potential application areas and/or example use cases
- Chapter 6 presents the product description (product file naming convention and format(s), product content and characteristics)
- Chapter 7 provides information about terms of use as well as the technical product support
- Chapter 8 lists references to the cited literature
- Chapter 9 provides annexes

3 Lineage

The evolution of the HRL Imperviousness reflects advancements in satellite technology, data processing, and environmental policy. Since its initial release in 2006 starting from lower-resolution imagery, it has transformed into a high-resolution, regularly updated product that provides critical insights into urban expansion, impervious surface dynamics, and their environmental impacts. It now serves as an essential resource for sustainable urban planning, monitoring of sealed areas and climate resilience efforts across Europe.

Over the time, the key improvements included increased spatial resolution, integration of full Sentinel-2 image time series, introduction of Impervious Built-Up layers and advanced data processing techniques. This evolution is further elaborated in the following chapters.

3.1.1 Initial Release in 2006

The first HRL Imperviousness (back then named: Soil Sealing) product was launched in 2006 with a focus on detecting impervious surfaces to support land cover and land use analyses across Europe, especially for the monitoring of urban expansion. Although a 20m-resolution intermediate layer was produced for the 2006 reference year, the first release was published with a spatial resolution of 100m. This decision stemmed from the fact that the available input satellite data (see



Table 1) only allowed for lower accuracy mappings at 20m resolution.

The product was limited in detail due to its lower resolution, providing a broad but pioneering overview of impervious surfaces across 38 EEA member and cooperating countries, i.e. 27 EU Member States at the time, as well as Iceland, Liechtenstein, Norway, Switzerland, Türkiye and the Western Balkan countries at the time (Albania, Bosnia-Herzegovina, Croatia, Former Yugoslavian Republic of Macedonia, Montenegro and Serbia). The coverage was in line with the EU's initial efforts to monitor urbanization and land cover changes to support regional policy goals as well as cooperation efforts within the European Environment Information and Observation Network (Eionet).

3.1.2 Product update 2009 - Enhanced Methodology and Expanded Coverage

The 2009 update introduced improvements in the methodology for detecting imperviousness, aiming to reduce errors and increase accuracy.

This product update maintained the 100m resolution but applied enhanced classification techniques to better distinguish impervious surfaces from other land cover types. It also laid the groundwork for more detailed future releases by refining algorithms.

3.1.3 Product update 2012

The 2012 product update included primarily detailed change mapping, making it possible to track and quantify changes in impervious surfaces over time.

3.1.4 Product update 2015 - Sentinel Data Integration and 20-Meter Update

The 2015 update was the first to incorporate Sentinel-2 satellite imagery, which introduced a new era of higher spatial and radiometric detail as well as more frequent input imagery.

The product maintained a 20-meter resolution, but the use of Sentinel-2 data improved consistency, reliability, and data continuity across the region. The 2015 update offered more refined change detection capabilities, supporting more detailed trend analysis in urban growth and impervious surface dynamics.

3.1.5 Product update 2018 - Resolution Upgrade with Full EEA38+UK Coverage

In 2018-update, a new thematic layer was introduced into the portfolio - the Impervious Built-up. It was developed to differentiate built-up areas (those with physical structures such as larger buildings) from other impervious surfaces (e.g., paved surfaces or roads).

In 2018, the HRL Imperviousness product was upgraded to a 10-meter resolution for the first time due to the now full availability of Sentinel-2 time-series, enhancing detail and detection of smaller impervious features more accurately, such as narrow roads and scattered buildings. The product retained full EEA38+UK coverage, with high-resolution data available consistently across Europe, improving cross-border analysis capabilities.

3.1.6 Product update 2021 - Continued 10-Meter Resolution

The 2021 release continued at 10-meter resolution, further enhancing detail and enabling fine-scale environmental assessments. This product update also incorporated advanced machine learning techniques, further improving classification accuracy.

**Table 1: Main parameters of historical and current products**

Ref. year	Main input data source	Temporal coverage of input data	Product Res.
2006	IRS-P6/Resourcesat-2 LISS-III, SPOT 5, Landsat-8	Mono-/bi-temporal from 2005 to 2007	20m/100m
2009	IRS-P6/Resourcesat-2 LISS-III, SPOT 5, Landsat-8	Mono-/bi-temporal from 2008 to 2010	20m/100m
2012	IRS-P6/Resourcesat-2 LISS-III, SPOT 5, Landsat-8	Mono-/multi-temporal from 2011 to 2013	20m/100m
2015	IRS-P6/Resourcesat-2 LISS-III, SPOT 5, Landsat-8, Sentinel 2	Mono-/multi-temporal from 2011 to 2013	20m/100m
2018	Sentinel 2	Multi temporal coverage	10m/20m/100m
2021	Sentinel 2	Multi temporal coverage	10m/20m/100m

4 Review of user requirements

The CLMS High Resolution Layers (HRLs) provide harmonized and consistent spatial information based on operational Earth observation data and can support a wide range of policies that address e.g. environment, climate, agriculture, regional development, transport or energy. In this context, frequently updated and reliable data about land cover, its characteristics and the dynamics across Europe and other spatial levels are often the basis for so-called geospatial indicators.

Based on the European Commission's Staff Working Document 2019, its underlying NextSpace 2018 Database, the ECoLaSS survey [1][2][3] as well as a continuous exchange with key users, the following general user requirements for HRLs and HRL Imperviousness, as well as the specific user requirements associated with the derivation of established geospatial indicators guide the production and evolution of HRL Imperviousness and its contained layers:

4.1.1 General and Thematic Requirements

- **Improved Frequency and Timeliness:** HRLs should be updated more frequently and provided with better timeliness than currently available, ideally enhancing their utility for near-real-time monitoring.
- **EU-wide Continuity and Consistency:** products should ensure continuity in EU coverage, maintaining thematic content and detail consistently across the EU. This uniformity helps with pan-European analysis and supports European policy needs.
- **Enhanced HRL Specifications:** Clearer and more consistent specifications are required for HRL, ensuring that they meet accuracy standards and are delivered on time. This includes better accuracy assessments and transparent change detection methodologies.
- **High-Resolution for Urban and Spatial Planning:** Large cities' spatial planning requires a detailed understanding of land cover and land-use patterns at a high spatial resolution (suggested <20m). This level of detail aids in ensuring good-quality living conditions by monitoring urban expansion, land-use changes, and spatial patterns.
- **Application in Urban Sprawl and Tourism Impact:** Improved HRL imperviousness degree data is needed for areas with dispersed settlements. More detailed classes in imperviousness (e.g., distinguishing built-up areas, new driveways, parking spaces) would improve urban sprawl estimation and environmental impact monitoring. Tourism



impact, particularly in heavily visited areas, is also a priority for tracking built-up area changes and vegetation impacts.

4.1.2 Specific Requirements for Change Mapping

- **Meaningful Change Products:** Change products must be meaningful, which implies a need for consistent change layers that accurately reflect real-world changes in land cover and land use.
- **Consistent Time-Series Data:** Time-series data should be calibrated consistently, maintaining the same areal extents and methodologies over time. This consistency allows for effective comparisons across different time periods, enhancing the ability to track trends and changes accurately. For example, the relationship $status(n0) + change(n0-1) = status(n1)$ should hold true across datasets.
- **Balanced Error Metrics:** The datasets should exhibit a balance of omission and commission errors. In change detection, omission errors (missed changes) and commission errors (false changes) should be minimized and balanced, enhancing the reliability of detected changes.

4.1.3 General Requirements for Indicator Development

- **Areal Statistics Applicability:** Indicators should be designed with a focus on areal (or spatial) statistics, thereby emphasizing change mapping. This implies that the data should provide insights into geographic areas rather than point data, supporting comprehensive regional or spatial assessments.
- **Continuity and Timeliness:** Data should be updated frequently, ideally available within one year after the end of the reference year. This ensures the indicators remain relevant for ongoing monitoring and decision-making processes.
- **Transparency:** Full transparency in methodology, workflow, and documentation is required. Users need to understand how data is processed and validated, promoting reproducibility and trust in the indicators.
- **Accuracy and Reliability:** High accuracy and reliability are critical, especially for datasets intended to support decision-making in environmental and spatial planning.

4.1.4 Indicator Facilitation and Integration with Other Data Sources

- **Enhanced Land Take Indicators:** Indicators for land take (e.g., conversion of natural land to built-up areas) should be refined. These indicators should also integrate with demographic and socio-economic data (e.g., land consumption rate relative to population growth) to provide a more comprehensive understanding of urbanization pressures.
- **Biodiversity and Sealed Surface Indicators:** Indicators for biodiversity applications should focus on area-based statistics, especially those related to sealed surfaces (i.e., areas covered by impervious materials). These indicators help assess the impact of land sealing on ecosystems and biodiversity, crucial for biodiversity conservation efforts.

It is the strength of the HRL products and HRL Imperviousness that a diverse range of requirements are considered for their implementation. Production continuously strives to ensure full compliance with user needs. As such, methodologies, accuracy and thematic extent are improved with every production.



5 Product application areas and exemplary use cases

HRL Imperviousness provides detailed information on a land cover that is often also indicative of a predominant land use and, as such, supporting various thematic analyses and applications. It offers a long and consistent time series that is updated every three years since 2006 and thus enabling the monitoring of land cover change. The product is particularly valuable for understanding the extent, spatial patterns, and dynamics of sealed surfaces, which are crucial for numerous domains.

Artificially sealed surfaces, such as sealed urban areas and roads, impact natural processes and functions, including hydrological cycles, soil functions, habitats, and biodiversity. Soil sealing also affects urban climate. HRL Imperviousness indicates the spatial patterns and development of these sealed areas which are essential for urban planning, environmental monitoring, and policy support, helping to mitigate the adverse effects of land cover changes.

5.1.1 Use case: Geospatial indicators for European policy information

Quality-controlled, Earth Observation-based data on built-up and sealed areas and their changes over time are crucial inputs for statistical applications and indicator frameworks supporting various environmental policies from national to global levels. These data are essential for reporting under frameworks such as the United Nations's Sustainable Development Goals (UN SDGs).

HRL Imperviousness supports SDG 11 (Sustainable Cities and Communities) by contributing to the European 'Soil Sealing Index' (SDG 11.3.1), which is based on HRL Imperviousness data [4].

The EEA's geospatial indicator 'Imperviousness and imperviousness change' provides harmonized and comparable data on the extent, degree, and trends of surface sealing across the EU, supporting spatial planning, environmental monitoring, and climate adaptation strategies. [5]

5.1.2 Use Case: Geospatial indicators for national policy information

EU Member States use and benefit from HRL Imperviousness to support national (and regional) indicators, specifically in countries where no or only outdated data is available.

For example, in Austria, monitoring and managing land take requires a multifaceted approach, integrating data from diverse sectors such as agriculture, settlement development, traffic, mobility, and forestry. A central component of this approach is the use of datasets provided by HRL Imperviousness, which offers precise, high-resolution information on the extent and intensity of surface sealing. This data is crucial for Austria's Soil Strategy for Austria [6] a national initiative aimed at minimizing land consumption by settlements and transportation infrastructure, as well as reducing soil sealing to preserve natural landscapes and arable land.

The Imperviousness Density (IMD) data allows Austria to quantify and map out where land take is most intense and how quickly it is progressing. This insight is invaluable for identifying hotspots of urban sprawl, assessing infrastructure impacts, and setting measurable targets for reducing impervious surfaces. This use case illustrates how IMD can serve as a core dataset in a comprehensive land monitoring system, enabling policymakers to address land use changes with data-driven strategies and policies.



Other countries could benefit from adopting comparable approaches, using IMD data alongside sector-specific datasets to develop targeted policies that balance urban development with ecological preservation. By applying high-resolution IMD data, countries can implement tailored soil protection measures, optimize land use, and foster sustainable urban planning practices that align with broader SDG goals.

5.1.3 Use case: Urban flood management

Predicting urban floods is crucial for authorities and emergency management as these events are often sudden, brief, and highly damaging. Flood modelling is a key tool for assessing flood extent, depth, duration, and frequency, supporting effective preparation and response.

Urban flooding typically results from inadequate drainage relative to rainfall intensity, river overflows, rising groundwater, or coastal surges. Drainage depends on both man-made systems and natural soil absorption. Climate change is amplifying heavy rainfall events, and with urban populations in Europe projected to grow by 6.8% by 2050, flood risks are likely to intensify [7].

Developing accurate, local-scale flood models is particularly challenging in cities, where dense impervious surfaces and high population densities increase flood susceptibility. Detailed understanding of these surfaces is essential for calculating runoff and modelling flood impacts accurately.

In urban flood management, understanding Imperviousness Density (IMD) and Impervious Built-Up (IBU) datasets is critical as sealed areas significantly influence flood dynamics within urban environments. Find below a summary of how sealed areas influence key processes and how IMD and IBU data can contribute to flood management:

- Reduced Infiltration and Higher/Faster Runoff:

IMD provides data on the extent of impervious surfaces (e.g., roads, pavements, parking lots) within a given area. High IMD values indicate that a large portion of the surface is unable to absorb water, leading to reduced infiltration into the soil. As a result, areas with high IMD values experience faster and more intense surface runoff during rainfall events, contributing to a greater risk of flooding. Flood simulation models use IMD data to estimate how much rainfall converts into runoff, helping simulate both the volume and speed of water flow, which are critical for understanding flood dynamics in densely built urban zones.

- Buildings as Blocking Features:

IBU data provides information on the physical footprint of buildings, enabling flood models to account for buildings as obstacles in water flow pathways. Buildings act as barriers, altering the natural runoff paths and potentially creating water flow bottlenecks or redirection points. Knowing the specific location and density of buildings through IBU data is essential for accurately simulating water flow routes and understanding areas at higher risk of water accumulation. In flood-prone areas, buildings can exacerbate flood conditions by channelling water in unintended directions, which is vital for designing effective flood response strategies.

- Susceptibility Monitoring and Simulation:

Both IMD and IBU datasets are essential inputs for susceptibility analysis and flood simulations. High IMD levels correlate with greater flood susceptibility due to increased runoff, while IBU data helps identify specific locations where water could back up or create high-pressure areas due to buildings. Using these metrics allows urban planners and flood management authorities to pinpoint areas of high flood risk and prioritize those that may need infrastructural adjustments, such as adding permeable surfaces or enhancing drainage networks.



5.1.4 Use Case: Biodiversity and Ecosystems

The issue of land take, the process of converting natural land into urban or developed space, is a growing concern across Europe, particularly in relation to its impact on biodiversity and ecosystem services. As urban areas expand to accommodate increasing populations and economic growth, natural landscapes are increasingly fragmented, with critical habitats for wildlife and green spaces for human recreation being lost or isolated. This fragmentation disrupts the flow of ecosystem services, such as pollination, water filtration, and carbon sequestration, which are essential for both human and environmental health.

In response to these challenges, European Union and national policies, including directives on Biodiversity and Habitats, have emphasized the need for maintaining ecological connectivity and minimizing the impact of land take on the environment. Strategies such as the EU Green Infrastructure Strategy, which aims to integrate natural systems into urban development, and the Alpine Convention, which focuses on preserving biodiversity in mountainous regions, call for more strategic planning to protect and enhance ecological corridors. These corridors serve as vital pathways that connect fragmented habitats, allowing for wildlife movement and preserving ecosystem functions across larger landscapes.

Furthermore, the Natura 2000 network, Europe's largest coordinated network of protected areas, plays a crucial role in safeguarding biodiversity. However, even within these protected sites, the effects of land take, urban sprawl, and infrastructure development can pose significant risks [8].

In the context of Natura 2000 areas and addressing landscape fragmentation, the integration of IBU and IMD layers play an essential role in understanding the spatial dynamics of urbanization and its impact on ecological connectivity. Both IMD and IBU, provide essential information that allows urban planners, conservationists, and policymakers to more accurately assess how land take and infrastructure development affect biodiversity and the functionality of ecological corridors. Here's how these datasets can be leveraged in this use case:

- Assessing Landscape Fragmentation

IMD data helps identify the extent of impervious surfaces within a given area, such as roads, pavements, and buildings. High IMD values indicate areas where a significant portion of the land is covered by impermeable surfaces, which are major contributors to habitat fragmentation. By mapping IMD across regions, particularly in proximity to Natura 2000 areas, it is possible to assess how fragmented the surrounding landscape is and identify critical areas where natural habitats are being disrupted.

IBU data is especially useful for highlighting specific infrastructures (e.g. urban developments or industrial zones) that encroach upon natural habitats. This data provides more granular insights into how built environments disrupt the flow of ecological corridors and the movement of wildlife. IBU helps to identify not only where urban development is occurring but also the specific structures that are contributing to the isolation of protected areas.

- Identifying Critical Zones for Ecological Corridors

The identification of ecological corridors is one of the most effective ways to mitigate the impacts of fragmentation. IMD data can be used to map areas of increased sealing that pose the greatest threat to the establishment of functional ecological corridors. For example, an area with high IMD values near a Natura 2000 site may indicate a need for creating green infrastructure solutions, such as wildlife bridges, restored wetlands, permeable pavements, or green roofs, to reconnect fragmented habitats and facilitate wildlife movement.



IBU data can further refine these assessments by identifying clusters of buildings or infrastructure that pose additional barriers to connectivity. For instance, transport networks like highways or railways can act as physical obstacles for wildlife migration. By analysing IBU in conjunction with IMD, planners can determine where these infrastructure elements intersect with potential ecological corridors and prioritize areas for mitigation or restoration efforts.

- Monitoring and Managing Habitat Connectivity Over Time

IMD and IBU data can be used not only to identify current threats to habitat connectivity but also to monitor changes over time. Urbanization and infrastructure development are dynamic processes, and high-resolution spatial data allows for ongoing monitoring of how these affect the landscape. Being provided with regular updated IMD and IBU and corresponding change datasets, conservationists can assess whether urban expansion is increasing impervious surfaces and reducing connectivity in critical areas. This enables proactive management of ecological corridors, such as by proposing modifications to urban planning policies or implementing land-use restrictions to preserve or enhance connectivity. [9]

For example, IMD data showing a significant increase in impervious surfaces around a Natura 2000 site could stimulate a re-evaluation of the area's management plan, leading to the creation of new green corridors or the expansion of existing ones. Similarly, IBU data can help to track the growth of urban areas and the potential need for new mitigation measures.

- Guiding Habitat Restoration and Mitigation Measures

When dealing with land take, IMD and IBU data are critical for identifying areas where habitat restoration efforts should be prioritized. If IMD data indicates a significant presence of impervious surfaces in an area, planners can target these regions for habitat restoration, focusing on the removal or reduction of impervious materials and introducing more permeable surfaces (e.g., green roofs, permeable pavements, or the restoration of wetlands). This process would not only reduce the area's impermeability but also improve its suitability for biodiversity by enhancing soil infiltration, reducing runoff, and restoring local water cycles.

IBU data helps planners identify locations where dense built-up environments obstruct wildlife movement. If a particular area with high IBU values cuts across an important habitat or corridor, strategies such as green bridges, wildlife tunnels, or overpasses can be designed to ensure species can safely cross urban barriers. The IBU dataset's spatial precision allows for the identification of optimal locations for such interventions, ensuring that they are effective in reconnecting fragmented habitats.

5.1.5 Use Case: Spatial / Urban planning for climate change adaptation

Responding to global warming and adapting to climate change effects such as heat waves and droughts are key priorities in European and national Climate Change Adaptation strategies. [10] Regional and urban governments aim to prevent heat-related health issues and stress on both humans and animals through measures like establishing green and blue infrastructure. In this context, IMD and IBU can be a significant support to better understand and address the challenges imposed by climate change, particularly with combating the Urban Heat Island (UHI) effect and generally enhancing urban resilience. The following indicate the relevance of HRL Imperviousness for key processes in this use case:

- Urban Heat Island Effect and Temperature Regulation

IMD data indicates the extent of impervious surfaces (such as concrete, asphalt, and other building materials) within an urban area. High IMD values are directly linked to the Urban Heat Island (UHI) effect because impervious surfaces absorb and retain heat, leading to higher land



surface and near-surface temperatures, especially during heat waves. These surfaces contribute to increased daytime temperatures and slower night-time cooling. Flood and heat stress models use IMD data to identify areas with high heat retention, guiding the implementation of climate adaptation strategies such as increasing greenery or improving cooling infrastructure in areas with a high density of impervious surfaces.

- Buildings and Heat Accumulation

IBU data provides insights into the physical layout and density of buildings within an urban area. Buildings, along with other impervious surfaces, can trap heat and block airflow, exacerbating the UHI effect. High IBU values indicate areas with a high potential of limited green space, reducing opportunities for natural cooling. Integrating IBU data into climate models helps identify heat-prone areas where interventions like urban greening (e.g., installing green roofs or creating green spaces) can significantly reduce local temperatures and improve urban climate resilience.

- Identifying Vulnerable Areas and Adaptation Planning

The combination of IMD, IBU, and other environmental datasets, such as vegetation cover and water surfaces, is essential for identifying areas most susceptible to heat stress. Urban planners can use this information to prioritize areas for interventions like creating green corridors, increasing tree cover, and improving access to cooling spaces like ponds or canals, which can mitigate the impacts of heat waves and droughts. IMD and IBU data also helps pinpoint areas where infrastructure changes are needed to reduce heat vulnerability, contributing to more effective urban planning and climate change adaptation strategies.

6 Product Description

The HRL Imperviousness comprises spatial datasets of entire Europe (i.e. 38 EEA member and cooperating countries as well as the United Kingdom) that currently address artificial sealed and built-up land surfaces at spatial resolutions of 10m, 20m and 100m. This release of HRL Imperviousness is compliant with the established specifications of previous productions and updates, extends, and complements these with additional products for the reference year 2021. HRL Imperviousness is part of a Non-Vegetated Land Cover Characteristics (NVLCC) product suite that intends to offer dedicated products for the entire complex of non-vegetated surfaces. Currently, NVLCC offers the two main products contained by HRL Imperviousness that address major aspects of man-made sealed surfaces:

- the Imperviousness product including change and auxiliary layers, and
- the Impervious Built-Up product, which is a harmonized sub-class of Imperviousness, including change and auxiliary layers.

HRL Imperviousness 2021 is generated using state-of-the-art automated image processing methods that are applied to systematically acquired, high-resolution satellite image time series from the Copernicus space segment (i.e. Sentinel-2). The products aim at providing a continental perspective and frequent updates on artificially sealed land cover characteristics (status and change). HRL Imperviousness focuses on impervious areas that are characterized by the substitution of the original (semi-) natural cover or water surface with an artificial, often impervious cover. These artificial surfaces are usually characterized by long cover duration, with serious implications for soil degradation, biodiversity, and flooding risk - among others. Other non-vegetated land covers, such as non-sealed artificial or bare surfaces of natural origin are currently not covered within HRL Imperviousness.

Since 2018, HRL Imperviousness includes the Impervious Built-Up (IBU) product which is fully harmonized with the Imperviousness product and aligned with the EAGLE data model. Built-up areas are a sub-class of impervious areas and generally cover above-ground building constructions without the 'flat' impervious areas such as roads or parking lots. In contrast to the Imperviousness Density (IMD) product that is characterized by a continuous range of density values [1-100%], IBU is expressed as either built-up or non-built-up [0;1].

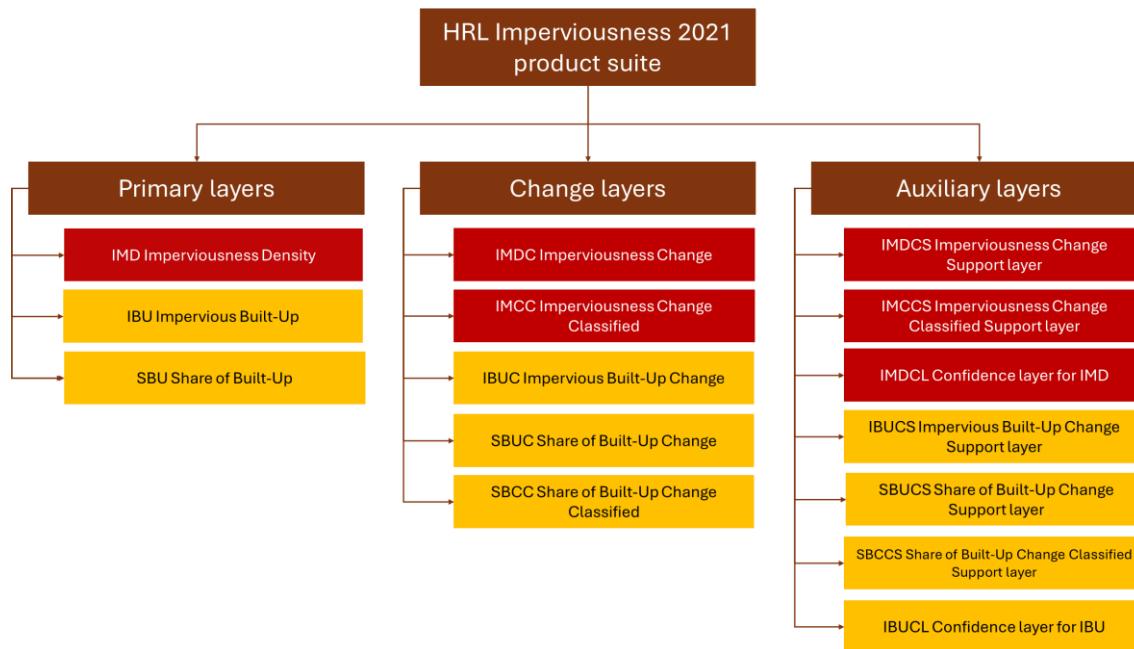
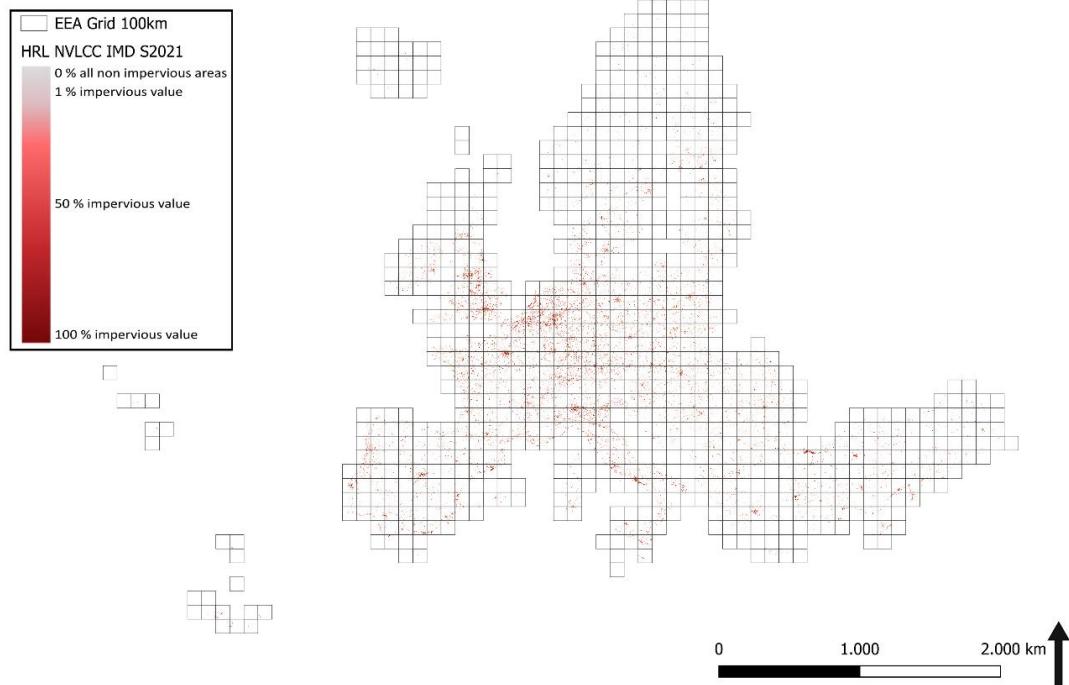


Figure 1: Overview of the HRL Imperviousness 2021 and contained layers

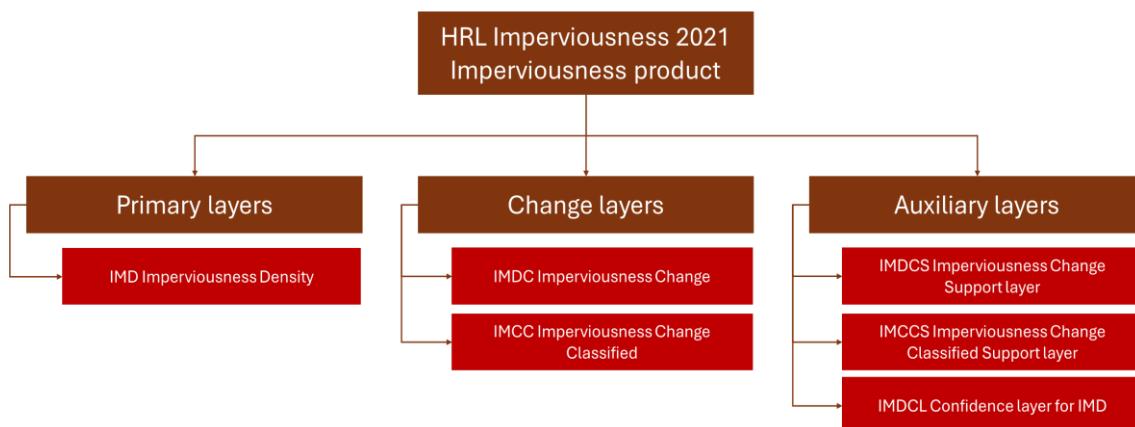
6.1 Product overview

All products and layers are provided in 100km tiles that are aligned with the EEA reference grid and Lambert Azimuthal Equal Area (LAEA, EPSG: 3035) projection as shown in Figure 3. The five contained French Oversea Territories (DOM; i.e. Martinique, Guadeloupe, French Guiana, Reunion Island, Mayotte) are provided in UTM projection with the layout of the respective territory. Each tile is available as raster file, i.e. Cloud-Optimized GeoTIFF (COG), and accompanied by a Persistent Auxiliary metadata (PAM) XML and an INSPIRE XML.

EEA 38 area + UK

Figure 2: The EEA tiling grid overlaying the IMD dataset (10m)

6.2 Imperviousness product

The Imperviousness Density (IMD) comprises the product's main layer and gives the mapped percentage of artificial sealing per pixel at 10m and 100m resolutions for the reference year 2021. The IMD 2021 is comparable and consistent with the previous IMD 2018 layer.


Figure 3: The Imperviousness product and contained layers

Impervious surfaces are considered here respect to their impermeability by water from above and are mapped from an Earth observation approach. Therefore, the concept followed, i.e. the surfaces and thematic elements considered, clearly relate to the extent and detectability of such properties and features "from above". For instance, the concept considers larger solar parks and permanent greenhouses as sealed, whereas certain soil functionalities could still be maintained for such areas (e.g. grass and crops could grow underneath). Table 2 and Table 3 show the



elements that are in-/excluded for the mapping of IMD and attempts to link these to the EAGLE nomenclature [11].

Table 2: Elements to be included in the Imperviousness Density (IMD) and derived layers

Included elements	Corresponding EAGLE codes
Housing areas (even with scattered houses)	LCC-1_1_1_1_1 LUA-5_1
Built-up traffic areas (airports, harbours, railway yards)	LCC-1_1_1_1_1 LUA-4_1
Non-built-up, sealed traffic areas (airport runways, non-built-up harbour areas, railway yards, parking lots)	LCC-1_1_1_3 LUA-4_1
Sealed roads	LCC-1_1_1_3 LUA-4_1_1
Railway tracks associated with other impervious surfaces (i.e. inside built-up areas)	LCC-1_1_2 LUA-4_1
Industrial, commercial areas, factories, energy production and distribution facilities	LCC-1_1_1_1_1 LUA-3
Non-built-up sealed surfaces, which are part of categories, such as e.g. allotment gardens, cemeteries, sport and recreation areas, camp sites, excluding green areas associated with them	LCC-1_1_1_1_2 LUA-3
Artificial grass-covered sport pitches	LCC-1_1_2_1 LUA-3_4_3
Construction sites with discernible evolving built-up structures	LCC-1_1_1_1_1 LUA-6_1
Single (farm) houses (where possible to identify from satellite imagery)	LCC-1_1_1_1_1 LUA-1_1_2
Paved borders of water edges	LCC-1_1_1_3 LUA-4_1
Permanent greenhouses covered through the year (including foil tunnels)	LCC-1_1_1_1_2 LUA-1_1_2
Solar panel parks	LCC-1_1_1_2 LUA-2_2_4_2

Table 3: Elements to be excluded from the Imperviousness Density (IMD) and derived layers

Excluded elements	Corresponding EAGLE codes
Railway tracks not associated with other impervious surfaces (i.e. outside built-up areas)	LCC-1_1_2_1 LUA-4_1
Construction sites without discernible evolving built-up structures	LCC: LCC-1_1_1_3 LUA-6_1
Non-permanent greenhouses (temporal plastic coverage)	LCC-1_1_1_1_2 LUA-1_1_2
Mines, quarries, peat extraction areas	LCC-1_1_2_1 LUA-1_3
Sand, sand pits	LCC-1_2_2_1_3 LUA-6_3
Dump sites	LCC-1_1_2_2 LUA-4_3_3_1



Natural, artificial, and cultivated vegetated areas	LCC-2 LUA-6_3
Unvegetated or sparsely vegetated areas	LCC-1_2 LUA-6_3
Unvegetated agricultural fields, arable land	LCC-1_2 LUA-1_1_2
Vineyards, fruit plantations	LCC-2_1 LUA-1_1_2
Grass surfaces used for sports of any kind	LCC-2_2_1_1 LUA-3_4_3
Glaciers, snow, water	LCC-3 LUA-6_3
Green roofs	LCC-1_1_1_1_1 LCC-2_2_1

Imperviousness Change layers

Imperviousness change layers for the reference period 2018-2021 include the Imperviousness Change (IMDC), the Imperviousness Change Classified (IMCC), the Imperviousness Change Support (IMDCS) and the Imperviousness Change Classified Support (IMCCS) in 20m resolution. The change layers depict imperviousness changes between the reference years on a continuous range -100% to +100% as well as thematically classified (new/loss of sealed cover, in-/decreased imperviousness density, unchanged areas). All layers are provided at 20m and 100m resolution to ensure consistency with the previous time series.

IMDCS and IMCCS provide decreased and increased imperviousness density between the reference years 2018 and 2021 due to technical change (as opposed to real change given by IMDC and IMCC). Technical change results from methodological advancements between the previous and the status layer, such as the transition from a Random Forest classifier to a Convolutional Neural Network (U-Net architecture), which allows for more accurate spatial pattern recognition. Additionally, the training data has been enhanced by incorporating information from the CLCplus Backbone 2018, which provides a more robust foundation for model calibration and improves classification consistency across diverse landscapes. The differentiation between technical and real change is done with an interim change-indication layer, which describes the probability of change occurrence on a continuous scale. In brief, the pixel values outlined by this interim change-indication layer indicate the amount real change between 2018 and 2021. Please refer to Chapter 7.2 for interpretation and to the ATBD for technical details of the change support layers.

To obtain meaningful change results at 20m level, the coarser resolution of 20m for both time periods is used for the change layers. Therefore, the IMD 2021 product will be aggregated from 10m spatial resolution to 20m in a first step to an intermediate aggregated 20m status layer. This aggregated layer is then combined with an independently derived change indicator, also at 20 m resolution and filtered to reduce noise, to distinguish between technical and real changes (See ATBD, chapter 4.5.1 - Generation of continuous change layers). The derived continuous change layer (IMDC) is finally converted into the classified change layer (IMCC). For this purpose, the continuous change values are thematically aggregated into the categorical classes and to the rulesets given in Table 4.

**Table 4: Rule base to create the Imperviousness Change Classified (IMCC), Impervious Built-Up Change (IBUC) and Share of Built-Bp Change Classified (SBCC) layers**

Code	Class name	IMCC	IBUC	SBCC
0	Unchanged areas	Unchanged non-impervious areas	Unchanged non-built-up areas	Unchanged non-built-up areas
		IMD(n-1) = 0, IMD(n) = 0	IBU(n-1) = 0, IBU(n) = 0	SBU(n-1) = 0, SBU(n) = 0
1	New cover	Increased imperviousness density, no imperviousness at first reference date	Increased built-up density, no built-up at first reference date	Increased built-up density, no share of built-up at first reference date
		IMD(n-1) = 0, IMD(n) > 0	IBU(n-1) = 0, IBU(n) > 0	SBU(n-1) = 0, SBU(n) > 0
2	Loss of cover	Decreasing imperviousness density, no imperviousness at second reference date	Decreased built-up density, no built-up at second reference date	Decreased built-up density, no share of built-up at second reference date
		IMD(n-1) > 0, IMD(n) = 0	IBU(n-1) > 0, IBU(n) = 0	SBU(n-1) > 0, SBU(n) = 0
10	Unchanged cover	Unchanged impervious areas, imperviousness > 0 at both reference dates	Unchanged built-up area, built-up > 0 at both reference dates	Unchanged built-up areas, share of built-up > 0 at both reference dates
		IMD(n-1) > 0, IMD(n) > 0	IBU(n-1) > 0, IBU(n) > 0	SBU(n-1) > 0, SBU(n) > 0
11	Increased cover	Increased imperviousness density, imperviousness > 0 at both reference dates	Increased built-up density, built-up > 0 at both reference dates	Increased share of built-up share of built-up > 0 at both reference dates
		IMD(n-1) > 0, IMD(n) > 0 & IMD(n) > IMD(n-1)	IBU(n-1) > 0, IBU(n) > 0 & IBU(n) > IBU(n-1)	SBU(n-1) > 0, SBU(n) > 0 & SBU(n) > SBU(n-1)
12	Decreased cover	Decreased imperviousness density, imperviousness > 0 at both reference dates	Decreased built-up density, built-up > 0 at both reference dates	Decreased share of built-up, share of built-up > 0 at both reference dates
		IMD(n-1) > 0, IMD(n) > 0 & IMD(n) < IMD(n-1)	IBU(n-1) > 0, IBU(n) > 0 & IBU(n) < IBU(n-1)	SBU(n-1) > 0, SBU(n) > 0 & SBU(n) < SBU(n-1)
255	Outside area			

6.2.1 Download content, file naming convention and file format(s)

Table 5: Download content, file naming convention and file format(s) for Imperviousness Density layers

Name of layer	Acronym	Abbreviation	Delivery format	Metadata
Imperviousness Density	IMD	IMD_S2021_R10m	Tiles of Cloud-Optimized GeoTIFF aligned with the 100km LAEA grid and with embedded colormaps	XML metadata files according to INSPIRE metadata standards and GDAL-style Permanent Auxiliary Metadata (PAM)*.aux.xml including statistics and Raster Attribute Table
Imperviousness Density	IMD	IMD_S2021_R100m		
Imperviousness Change	IMDC	IMDC_C2018-2021_R20m		
Imperviousness Change	IMDC	IMDC_C2018-2021_R100m		
Imperviousness Change Classified	IMCC	IMCC_C2018-2021_R20m		
Imperviousness Change Support layer	IMDCS	IMDCS_C2018-2021_R20m		
Imperviousness Change Support layer	IMDCS	IMDCS_2018-2021_R100m		
Imperviousness Change Classified Support layer	IMCCS	IMCCS_2018-2021_R20m		



Name of layer	Acronym	Abbreviation	Delivery format	Metadata
Confidence layer for Imperviousness Density (10m)	IMDCL	IMDCL_S2021_R10m		

6.2.2 Projection and spatial coverage

Table 6: Projection and spatial coverage for Imperviousness layers

Name of layer	Acronym	Spatial coverage	Coordinate reference system
Imperviousness Density	IMD	6.002.167 km ² (covering the full EEA38+UK)	European ETRS89 LAEA projection / for French DOMs WGS84 and the respective UTM zone
Imperviousness Change	IMDC		
Imperviousness Change Classified	IMCC		
Imperviousness Change Support layer	IMDCS		
Imperviousness Change Classified Support layer	IMCCS		
Confidence layer for Imperviousness Density (10m)	IMDCL		

6.2.3 Spatial resolution

Table 7: Spatial resolution for Imperviousness layers

Name of layer	Acronym	Pixel size
Imperviousness Density	IMD	10m
	IMD	100m
Imperviousness Change	IMDC	20m
	IMDC	100m
Imperviousness Change Classified	IMCC	20m
Imperviousness Change Support layer	IMDCS	20m
	IMDCS	100m
Imperviousness Change Classified Support layer	IMCCS	20m
Confidence layer for Imperviousness Density (10m)	IMDCL	10m

6.2.4 Temporal information

Table 8: Temporal information for Imperviousness layers

Name of layer	Acronym	Reference year
Imperviousness Density	IMD	2021
Imperviousness Change	IMDC	2018-2021
Imperviousness Change Classified	IMCC	2018-2021
Imperviousness Change Support layer	IMDCS	2018-2021
Imperviousness Change Classified Support layer	IMCCS	2018-2021
Confidence layer for Imperviousness Density (10m)	IMDCL	2021



Product characteristics

Table 9: Characteristics of Imperviousness layers

Name of layer	Acronym	Classified feature	Class coding	Target Accuracy
Imperviousness Density	IMD	Degree of imperviousness density 1-100%	0: All non-impervious areas 1-100: 1-100% imperviousness 255: Outside area	90% user's accuracy 90% producer's accuracy
Imperviousness Change	IMDC	Degree of imperviousness change (decrease of degree of imperviousness: 0 to 99%, increase of degree of imperviousness: 101-200%)	0 to 99: 0-100% imperviousness decrease 100: Unchanged impervious areas 101-200: 0-100% imperviousness increase 201: Unchanged non-impervious areas 255: Outside area	n/a
Imperviousness Change Classified	IMCC	Degree of imperviousness classified change (i.e. new/removal of imperviousness density, increased/decreased imperviousness density)	0: Unchanged non-impervious areas 1: New cover 2: Loss of cover 10: Unchanged impervious areas 11: Increased imperviousness density 12: Decreased imperviousness density 255: Outside area	90% user's accuracy 90% producer's accuracy
Imperviousness Change Support layer	IMDCS	Shows decreased and increased imperviousness density due to technical change (as opposed to real change)	0 to 99: 0-100% imperviousness decrease 100: Unchanged impervious areas 101-200: 0-100% imperviousness increase 201: Unchanged non-impervious areas 255: Outside area	n/a
Imperviousness Change Classified Support layer	IMCCS	Shows classified degree of imperviousness change due to technical change (as opposed to real change)	0: Unchanged non-impervious areas 1: New cover 2: Loss of cover 10: Unchanged impervious areas 11: Increased imperviousness density 12: Decreased imperviousness density 255: Outside area	n/a
Confidence layer for Imperviousness Density (10m)	IMDCL	Measure of confidence for Imperviousness Density (10m)	0-100: 0-100% confidence 255: Outside area	n/a

6.3 Impervious Built-Up product

The Impervious Built-up (IBU) layers as well as their aggregated Share of Built-up (SBU) layers were first included in the production of 2018 and hence change layers are introduced with the current 2021 reference year. All layers are fully harmonized with the Imperviousness product-meaning that they are conceptually and spatially a sub-class of Imperviousness.

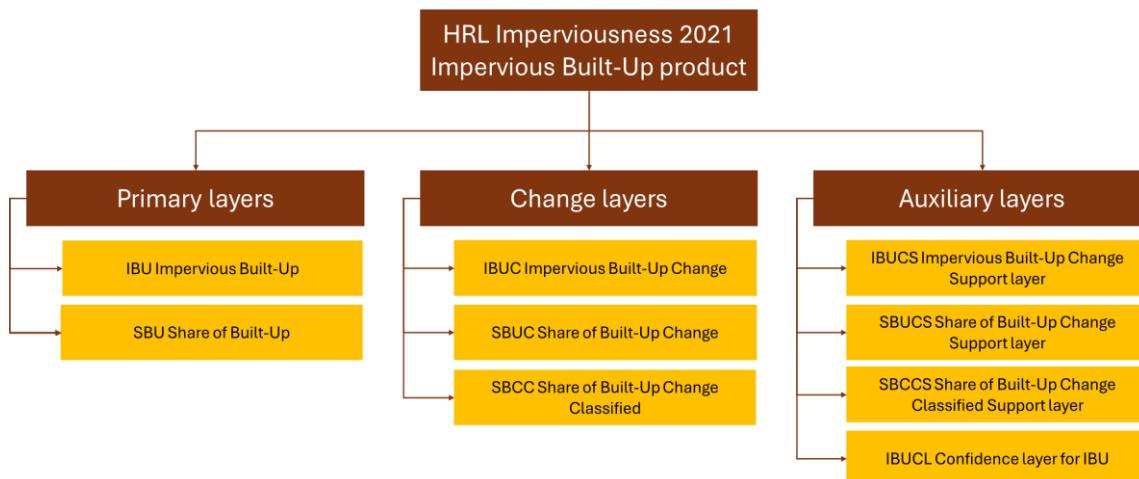


Figure 4: The Impervious Built-Up product and contained layers

The IBU maps built-up areas at high-resolution across Europe. It distinguishes between built-up (impervious) and natural (permeable) surfaces, accurately reflecting the extent of human development. IBU visualizes built-up patterns and urban sprawl, offering valuable insights into the distribution and intensity of human-modified landscapes across the region. The detailed summary of which elements are considered as built-up, and which not, can be found in the Table 10 and Table 11 together with their corresponding EAGLE nomenclature codes [11].

Table 10: Elements to be included in the Impervious Built-up (IBU) layer and derived layers

Included elements	Corresponding EAGLE codes
Housing areas (even with scattered houses)	LCC-1_1_1_1_1 LUA-5_1
Built-up traffic areas (airports, harbours, railway yards)	LCC-1_1_1_1_1 LUA-4_1
Industrial, commercial areas, factories, energy production and distribution facilities	LCC-1_1_1_1_1 LUA-3
Construction sites with discernible evolving built-up structures	LCC-1_1_1_1_1 LUA-6_1
Single (farm) houses (where possible to identify from satellite imagery)	LCC-1_1_1_1_1 LUA-1_1_2
Permanent greenhouses covered through the year (including foil tunnels)	LCC-1_1_1_1_2 LUA-1_1_2

**Table 11: Elements to be excluded from the Impervious Built-up (IBU) layer and derived layers**

Excluded elements	Corresponding EAGLE codes
Non-built-up traffic areas (e.g. airport runways, non-built-up harbor areas, rail yards, open parking lots)	LCC-1_1_1_3 LUA-4_1
Railway tracks associated with other impervious surfaces (i.e. inside built-up areas)	LCC-1_1_2 LUA-4_1
Non-built-up (sealed or unsealed) surfaces associated with diverse and often small-scale thematic elements, e.g. allotment gardens, sport and recreation areas, camp sites or similar	LCC-1_1_2_1 LUA-3_4
Artificial grass-covered sport pitches	LCC-1_1_2_1 LUA-3_4_3
Paved borders of water edges	LCC-1_1_1_3 LUA-4_1
Solar panel parks	LCC-1_1_1_2 LUA-2_2_4_2
Green roofs	LCC-1_1_1_1_1 LCC-2_2_1

Impervious Built-up Change layers

The Impervious Built-up change (IBUC) layer in 20m resolution as well as a layer indicating the changes of the Share of Built-Up (SBU) in 100m resolution are provided for the first time, indicating increases and decreases of built-up (and share of built-up) as well as stable (unchanged) built-up and non-built-up area.

The IBUC including the Impervious Built-Up Change Support (IBUCS) are also produced in 20m resolution. Therefore, firstly the IBU 10m is aggregated to 20m resolution by using a touching rule, i.e., every pixel containing at least one 10m IBU pixel is classified as built-up in the 20m aggregated layer. This rule is in line with the definition of the IBU described in the 2018 key technical specification document. After aggregation, the IBUC is created in a similar manner as the IMCC with the difference that no increase/decrease classes are provided due to the binary inputs (i.e. IBU 2018 and IBU 2021). The distinction of “real changes” vs. “technical changes” requires an additional source of information that enables the detection of changes between 2018 and 2021 from the underlying satellite-based image time series. The integration applied here uses the Root Mean Squared Deviation (RMSD) which is calculated from the parametrized Normalized Difference Vegetation Index (NDVI) time series of both involved years. If RMSD exceeds a certain threshold, the corresponding pixels are marked as change candidates and are further analysed using both status layers (see ATBD, 4.2.5 - Intermediate layer: Change mask (CHM)). Only if a pixel has both, a classification change between 2018 and 2021 (i.e. non-built-up to built-up or vice versa) and a high RMSD in the NDVI signal, it is considered a “real change”. For the Share of Built-Up Change, two layers are provided: a Share Built-Up Change Classified (SBCC) and a Share of Built-Up Continuous (SBUC) also including the accompanying change support layers (SBCCS, SBUCS).

6.3.1 Download content, file naming convention and file format(s)

Table 12: Download content, file naming convention and file format(s) for Impervious Built-Up layers

Name of layer	Acronym	Abbreviation	Delivery format	Metadata
Impervious Built-up	IBU	IBU_S2021_R10m		



Name of layer	Acronym	Abbreviation	Delivery format	Metadata
Share of Built-Up	SBU	SBU_S2021_R100m	Tiles of Cloud-Optimized GeoTIFF aligned with the 100km LAEA grid and with embedded colormaps	XML metadata files according to INSPIRE metadata standards and GDAL-style Permanent Auxiliary Metadata (PAM)*.aux.xml including statistics and Raster Attribute Table
Impervious Built-Up Change	IBUC	IBUC_C2018-2021_R20m		
Impervious Built-Up Change Support layer	IBUCS	IBUCS_C2018-2021_R20m		
Share of Built-Up Change	SBUC	SBUC_C2018-2021_R100m		
Share of Built-Up Change Support layer	SBUCS	SBUCS_C2018-2021_R100m		
Share of Built-Up Change Classified	SBCC	SBCC_C2018-2021_R100m		
Share of Built-Up Change Classified Support layer	SBCCS	SBCCS_C2018-2021_R100m		
Confidence layer for Impervious Built-Up (10m)	IBUCL	IBUCL_S2021_R10m		

6.3.2 Projection and spatial coverage

Table 13: Projection and spatial coverage for Impervious Built-Up layers

Name of layer	Acronym	Spatial coverage	Coordinate reference system
Impervious Built-Up	IBU		
Share of Built-Up	SBU		
Impervious Built-Up Change	IBUC		
Impervious Built-Up Change Support layer	IBUCS		
Share of Built-Up Change	SBUC		
Share of Built-Up Change Support layer	SBUCS		
Share of Built-Up Change Classified	SBCC		
Share of Built-Up Change Classified Support layer	SBCCS		
Confidence layer for Impervious Built-Up (10m)	IBUCL		

6.3.3 Spatial resolution

Table 14: Spatial resolution for Impervious Built-Up layers

Name of layer	Acronym	Pixel size
Impervious Built-Up	IBU	10m
Share of Built-Up	SBU	100m
Impervious Built-Up Change	IBUC	20m
Impervious Built-Up Change Support layer	IBUCS	20m
Share of Built-Up Change	SBUC	100m
Share of Built-Up Change Support layer	SBUCS	100m
Share of Built-Up Change Classified	SBCC	100m
Share of Built-Up Change Classified Support layer	SBCCS	100m
Confidence layer for Impervious Built-Up (10m)	IBUCL	10m



6.3.4 Temporal information

Table 15: Temporal information for Impervious Built-Up layers

Name of layer	Acronym	Reference year
Impervious Built-Up	IBU	2021
Share of Built-Up	SBU	2021
Impervious Built-Up Change	IBUC	2018-2021
Impervious Built-Up Change Support layer	IBUCS	2018-2021
Share of Built-Up Change	SBUC	2018-2021
Share of Built-Up Change Support layer	SBUCS	2018-2021
Share of Built-Up Change Classified	SBCC	2018-2021
Share of Built-Up Change Classified Support layer	SBCCS	2018-2021
Confidence layer for Impervious Built-Up (10m)	IBUCL	2021

6.3.5 Product characteristics

Table 16: Characteristics of Impervious Built-Up layers

Name of layer	Acronym	Classified feature	Class coding	Target Accuracy
Impervious Built-Up	IBU	Binary impervious built-up presence	0: Non-built-up 1: Built-up 255: Outside area	90% user's accuracy 90% producer's accuracy
Share of Built-Up	SBU	Share of built-up areas 1-100%	0: All non-built-up areas 1-100: 1-100% built-up 255: Outside area	n/a
Impervious Built-Up Change	IBUC	Impervious built-up change (i.e. new/removal of impervious built-up)	0: Unchanged non-built-up areas 1: New cover 2: Loss of cover 10: Unchanged built-up areas 11: Increased built-up density 12: Decreased built-up density 255: Outside area	90% user's accuracy 90% producer's accuracy
Impervious Built-Up Change Support layer	IBUCS	Shows loss and gain of impervious built-up due to technical change (as opposed to real change)	0: Unchanged non-built-up area 1: New cover 2: Loss of cover 10: Unchanged built-up areas 11: Increased built-up density 12: Decreased built-up density 255: Outside area	n/a
Share of Built-Up Change	SBUC	Share of built-up change (i.e. negative change 0 to 99%, positive change 101-200%)	0 to 99: 1-100% built-up decrease 100: Unchanged built-up areas 101-200: 1-100% built-up increase 201: Unchanged non-built-up areas 255: Outside area	n/a
Share of Built-Up Change Support layer	SBUCS	Shows loss and gain of share of built-up due to technical change (as opposed to real change)	0 to 99: 1-100% built-up decrease 100: Unchanged built-up areas 101-200: 1-100% built-up increase	n/a



Name of layer	Acronym	Classified feature	Class coding	Target Accuracy
			201: Unchanged non-built-up areas 255: Outside area	
Share of Built-Up Change Classified	SBCC	Classified share of built-up change (i.e. new/removal of share of built-up, increased/decreased share of built-up)	0: Unchanged non-built-up area 1: New cover 2: Loss of cover 10: Unchanged built-up areas 11: Increased built-up density 12: Decreased built-up density 255: Outside area	n/a
Share of Built-Up Change Classified Support layer	SBCCS	Shows loss and gain of classified share of built-up due to technical change (as opposed to real change)	0: Unchanged non-built-up area 1: New cover 2: Loss of cover 10: Unchanged built-up areas 11: Increased built-up density 12: Decreased built-up density 255: Outside area	n/a
Confidence layer for Impervious Built-Up (10m)	IBUCL	Measure of confidence for Impervious Built-Up (10m)	0-100: 0-100% confidence 255: Outside area	n/a

7 Interpretation of auxiliary layers

7.1 Confidence layers (IMDCL, IBUCL)

The confidence layers provide a nuanced view of the classification results, offering insights into the probability of correct prediction and helping to ensure that decisions based on IMD and IBU products are well-informed and reliable.

The confidence values range from 0 to 100. However, only values from 50 to 100 are practically used, as a value below 50 would indicate higher confidence in the opposite class. In a theoretical example, if a pixel in the IMD layer has a confidence value of 40, this suggests a higher likelihood that the pixel is not impervious, corresponding to a confidence of 60 for the non-impervious class. Conversely, a confidence value of 90 would indicate strong certainty that the pixel is indeed impervious.

The confidence layers shall be interpreted in the following way:

- **High Confidence (75-100):** Pixels with confidence values in this range are considered highly reliable. The model has a strong agreement across different runs, indicating that the classification is very likely to be accurate.
- **Moderate Confidence (50-75):** Pixels in this range are less certain, suggesting some variability in the model predictions. These areas might require further inspection or could be areas of transitional land cover where classification is naturally more challenging.
- **Low Confidence (<50):** As mentioned, these values suggest higher confidence for the opposite class and are therefore not used in this context. Values below 50 are only theoretical and do not occur in the confidence layers.



Additional considerations and recommended usage:

- **Interpretation in Analysis:** Confidence layers can be critical in post-processing and analysis, allowing users to focus on areas with high confidence for more accurate assessments. Conversely, regions with lower confidence can be flagged for further investigation or excluded from certain analyses.
- **Data Quality Improvement:** By examining areas with lower confidence, it might be possible to identify specific regions where the model struggles, potentially guiding efforts to improve the training data or model parameters.
- **Integration with Other Layers:** Confidence layers can be used alongside the main classification outputs to refine decision-making processes, such as prioritizing areas for ground truth validation or tailoring intervention strategies based on the reliability of the data.

7.2 Change support layers (IMDCS, IMCCS, IBUCS, SBUCS, SBCCS)

The status layers represent the landscape at a given point in time, such as in 2018 (year1) or 2021 (year2). The change layers capture the differences between two status layers, calculated as: Status (Year 2) - Status (Year 1) = Total Change

The total change consists of two components that needs to be understood, to use the change layers and change support layers effectively. Those are:

- **Technical Changes** - These arise from differences in the classification process between the two years and are captured in the support layers. Since classification methods are continually refined, the technical changes are often improvements over earlier productions. However, these changes do not reflect actual landscape modifications but rather adjustments to better match reality. Examples of technical changes include minor percentage shifts (due to heterogeneity/noise in the EO data, atmospheric effects, meteorological conditions etc.), calibration differences, adjustments in the classification scheme and corrections of omission/commission errors in the previous production.
- **Real Changes** - these correspond to actual modifications in the landscape and are captured in the change layers. Unlike technical changes, real changes represent genuine dynamics between the two status years. Examples of real changes include, for example, new construction sites.

The relationship between these components can be summarized by the following formula:

$$\text{IMD18} + \text{IMDC18-21} + \text{IMDCS18-21} = \text{IMD21}$$

This formula shows that the 2021 status (IMD21) is built by combining the 2018 status layer (IMD18), the detected real changes (IMDC18-21), and the accounted technical adjustments (IMDCS18-21). The formula can be applied in a similar way to the other change products. However, it is only mathematically accurate for continuous change layers that use mean aggregation (IMDC, SBUC). For the IBUC layers and the classified versions of the change, the formula should be understood as a conceptual illustration rather than a strict calculation.

Table 17 summarizes the concept of change and change support layers. Examples of important combinations of change categories in the two different layers are further explained together with illustrations.

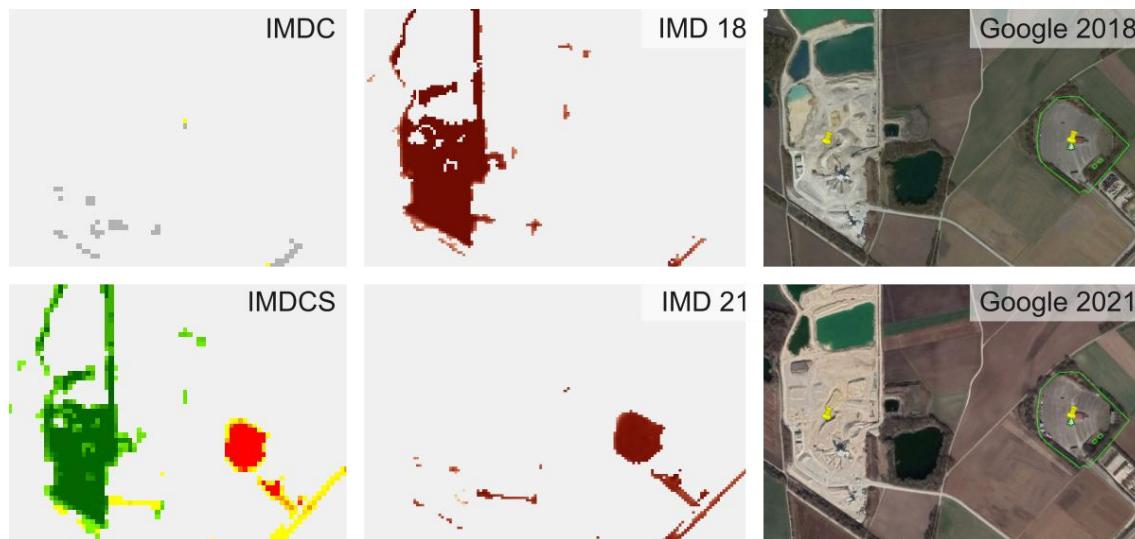
Table 17: Concept of change and change support layers

Change	Change support	Description
0	Gain	Incorrect classification in 2018: The pixel was not detected in 2018 (i.e. IMD=0; IBU=0) but is detected in 2021 status layers (i.e. IMD>0; IBU=1) and there is no indication* for real change between 2018 and 2021
0	Loss	Incorrect classification in 2018: The pixel was not detected in 2021 (i.e. IMD=0; IBU=0) but is detected in 2018 status layers (i.e. IMD>0; IBU=1) and there is no indication* for real change between 2018 and 2021.
Loss	0	A real change: Both the 2018 and 2021 status layers are correct and indicate* a loss of imperviousness/built-up.
Gain	0	A real change: Both the 2018 and 2021 status layers are correct and indicate* an imperviousness/built-up gain.

*as indicated by the change detection, see ATBD chapter 4.2.5 for details.

Partial gains and losses, as well as partial increases and decreases, are inherent features of the change and change support layers. This means a pixel may appear “active” in both layers. This behaviour is intentional and reflects the nature of the data: improvements in calibration typically introduce technical changes, while real-world changes overlay these adjustments. As a result, both technical and real changes can occur within the same pixel, capturing the complexity of transitions in the data.

Figure 5 below shows an example of both a technical gain and loss between 2018 and 2021 in an example from an area close to Munich, Germany (48.165N, 11.694E). The Google satellite images on the right-hand side show that no change was present between 2018 and 2021. Both areas are incorrectly detected in IMD 2018. The classification was fixed in the IMD 2021 and as such, the areas are correctly marked as technical change in the IMDC and IMDCS 2018-2021 layers. Please note that most areas are classified as "unchanged non-impervious" (class 201 in IMDC). This follows the rule that an area is only marked as "unchanged impervious" if it shows a value greater than 0 in both the 2018 and 2021 status layers.


Figure 5: Example of a technical change between 2018 and 2021

In contrast, real changes should appear in the corresponding change layers (e.g. IMDC, IBUC). An example of increased IMD between 2018 and 2021 (area close to Munich, 48.190N, 11.863E) is shown in Figure 6 below, the change support layer (IMDCS) shows slight changes in the

calibration of densities (shadings of green/yellow) but no significant imperviousness gain in the change support layer.

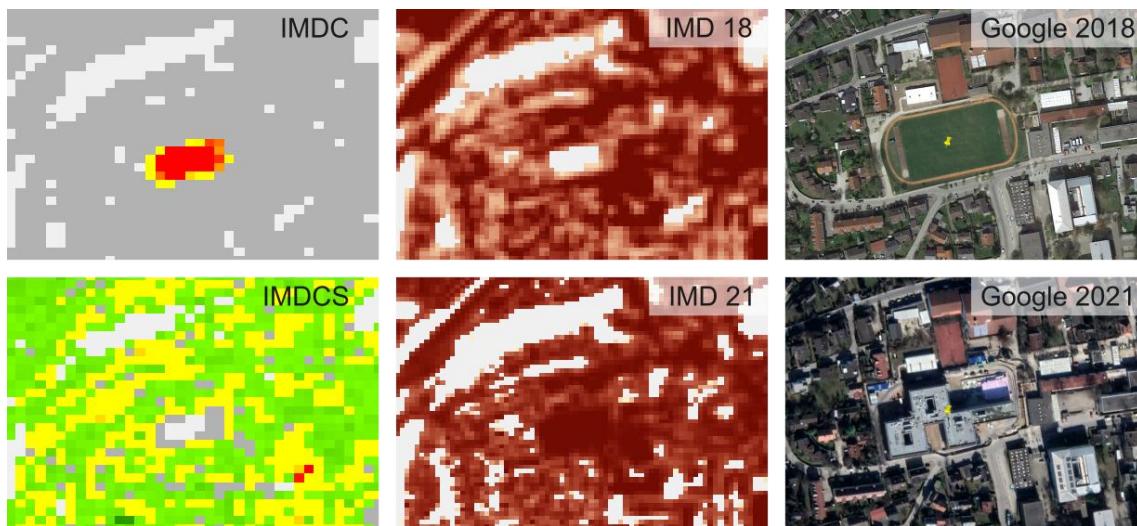


Figure 6: Example of a real change of IMD between 2018 and 2021

Additional Considerations:

- For analyzing the changes, the continuous change layers should be used instead of the classified versions, if available (i.e. IMDC, SBUC). These continuous change layers provide percentage-based differences, which are crucial for capturing nuanced variations in imperviousness or other attributes. Classified versions, on the other hand, only indicate broad categories of change and do not differentiate between subtle differences in percentages, which can lead to less precise interpretations.
- Direct subtraction of status layers (e.g. IMD 2021 - IMD 2018) is not recommended. This calculation aggregates both technical and real changes, leading to a total, that does not differentiate between methodological refinements and actual environmental modifications. Consequently, it can obscure meaningful insights and produce misleading results.

8 Terms of use and product technical support

8.1 Terms of use

The Terms of Use for the product(s) described in this document, acknowledge that:

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**“Generated using European Union's Copernicus Land Monitoring Service information;
<insert all relevant DOI links here, if applicable>”**

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8.3 Product technical support

Product technical support is provided by the product custodian through Copernicus Land Monitoring Service desk [13]. Product technical support does not include software specific user support or general GIS or remote sensing support.

More information on the products can be found on the Copernicus Land Monitoring Service website [14].



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List of abbreviations

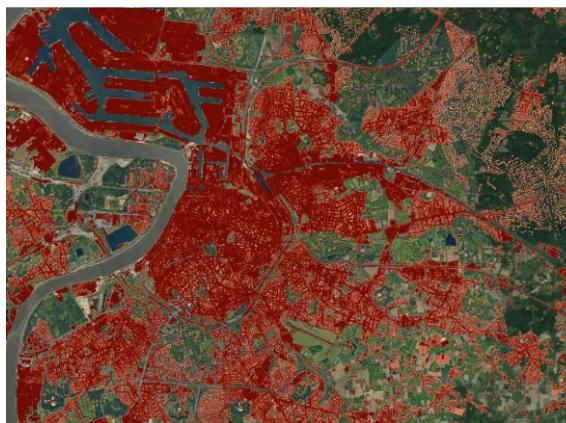
Abbreviation	Name
AD	Applicable Document
ATBD	Algorithm Theoretical Basis Document
CLMS	Copernicus Land Monitoring Service
CNN	Convolutional Neural Network
CHM	Change mask
COG	Cloud-Optimized GeoTIFFs
DOMs	Overseas Departments and Regions of France
EEA38	The 32 member and 6 cooperating countries of the EEA
EEA38+UK	The 32 member and 6 cooperating countries of the EEA, and UK
EAGLE	Action Group on Land monitoring in Europe
EU	European Union
FWC	Framework Contract
GDAL	Geospatial Data Abstraction Library
HRL	High Resolution Layer
IBU	Impervious Built-Up
IBUC	Impervious Built-Up Change
IBUCL	Confidence layer for Impervious Built-Up (10m)
IBUCS	Impervious Built-Up Change Support layer
IBUMD	Metadata information on input satellite imagery and training data for Impervious Built-Up (10m)
IMCC	Imperviousness Change Classified
IMCS	Imperviousness Change Support layer
IMCCS	Imperviousness Change Classified Support layer
IMD	Imperviousness Density
IMDC	Imperviousness Change
IMDCL	Confidence layer for Imperviousness Density (10m)
IMDCS	Imperviousness Change Support layer
IMDMD	Metadata information on input satellite imagery and training data for Imperviousness Density (10m)
INSPIRE	Infrastructure for Spatial Information in Europe
JRC	Joint Research Centre
LAEA	Lambert azimuthal equal area
NDVI	Normalized Difference Vegetation Index
NVLCC	Non-Vegetated Land Cover Characteristics
PAM	Persistent Auxiliary metadata
PUM	Product User Manual
RMSD	Root Mean Squared Deviation
SBCC	Share of Built-Up Change Classified
SBCCS	Share of Built-Up Change Classified Support layer
SBU	Share of Built-Up
SBUC	Share of Built-Up Change



SBUCS	Share of Built-Up Change Support layer
SDG	Sustainable Development Goals
TIFF	Tagged Image File Format
UHI	Urban Heat Island
UN	United Nations
UTM	Universal Transverse Mercator
VLCC	Vegetated Land Cover Characteristics
XML	Extensible Markup Language

Annex 1 - Product examples

Imperviousness Density (IMD)

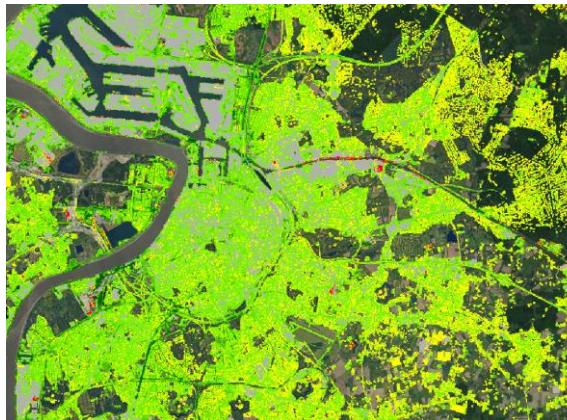


All non-impervious areas	
1% imperviousness	
2% to 49% imperviousness	colour shades in between
50% imperviousness	
51% to 99% imperviousness	colour shades in between
100% imperviousness	
Outside area	

Imperviousness Change (IMDC)



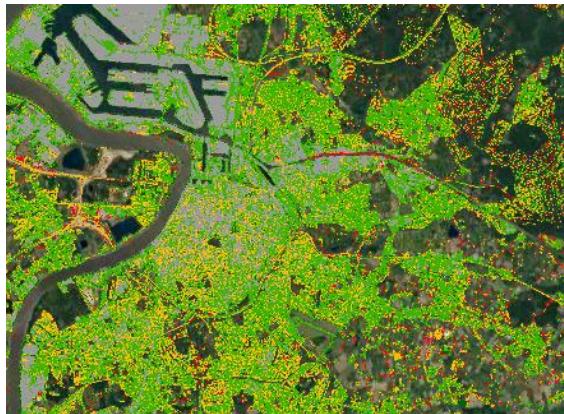
100% imperviousness decrease	
51-99% imperviousness decrease	colour shades in between
50% imperviousness decrease	
2-49% imperviousness decrease	colour shades in between
1% imperviousness decrease	
Unchanged impervious areas	
1% imperviousness increase	
2-49% imperviousness increase	colour shades in between
50% imperviousness increase	
51-99% imperviousness increase	colour shades in between
100% imperviousness increase	
Unchanged non-impervious areas	
Outside area	

Imperviousness Change Support (IMDCS)

100% imperviousness decrease	
51-99% imperviousness decrease	colour shades in between
50% imperviousness decrease	
2-49% imperviousness decrease	colour shades in between
1% imperviousness decrease	
Unchanged impervious areas	
1% imperviousness increase	
2-49% imperviousness increase	colour shades in between
50% imperviousness increase	
51-99% imperviousness increase	colour shades in between
100% imperviousness increase	
Unchanged non-impervious areas	
Outside area	

Imperviousness Change Classified (IMCC)

Unchanged non-impervious areas		
New cover		
Loss of cover		
Unchanged impervious areas		
Increased imperviousness density		
Decreased imperviousness density		
Outside area		

Imperviousness Change Classified Support layer (IMCCS)

Unchanged non-impervious areas	
New cover	
Loss of cover	
Unchanged impervious areas	
Increased imperviousness density	
Decreased imperviousness density	
Outside area	

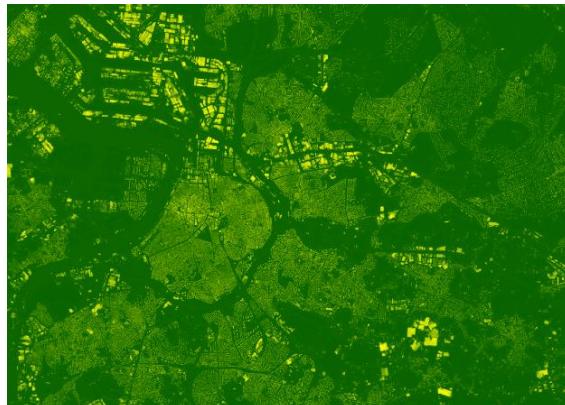
Confidence Layer for Imperviousness Density (IMDCL)

0% confidence	
1-49% confidence	colour shades in between
50% confidence	
51-99% confidence	colour shades in between
100% confidence	
Outside area	

Impervious Built-Up (IBU)

Non-built-up	
Built-up	
Outside area	

Confidence Layer for Impervious Built-Up (IBUCL)



0% confidence	
1-49% confidence	colour shades in between
50% confidence	
51-99% confidence	colour shades in between
100% confidence	
Outside area	

Share of Built-Up (SBU)

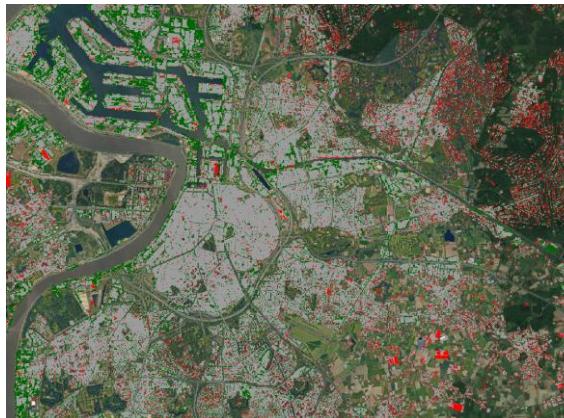


All non-built-up areas	
1% built-up	
2% to 29% built-up	colour shades in between
30% built-up	
31-69% built-up	colour shades in between
70% built-up	
71-99% built-up	colour shades in between
100% built-up	
Outside area	

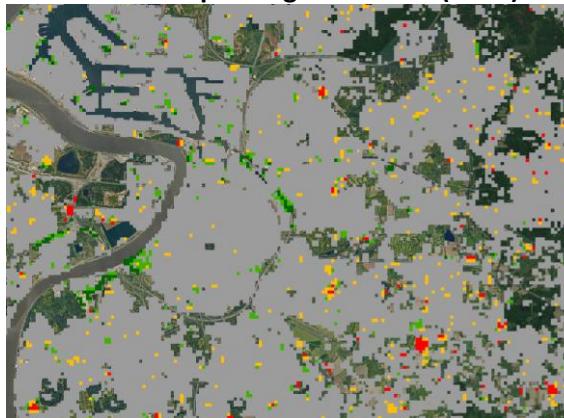
Impervious Built-Up Change (IBUC)



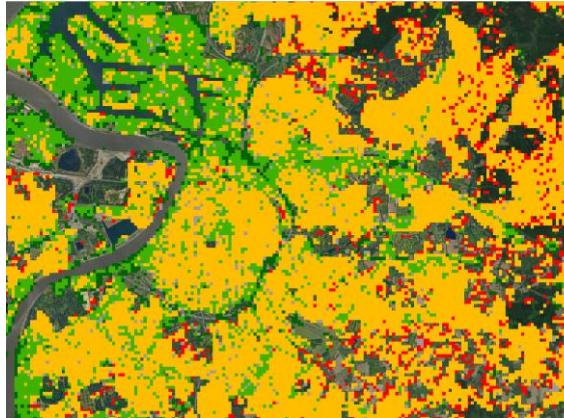
Unchanged non-built-up areas	
New cover	
Loss of cover	
Unchanged built-up areas	
Increased built-up density	
Decreased built-up density	
Outside area	

Impervious Built-Up Change Support (IBUCS)

Unchanged non-built-up areas	
New cover	
Loss of cover	
Unchanged built-up areas	
Increased built-up density	
Decreased built-up density	
Outside area	

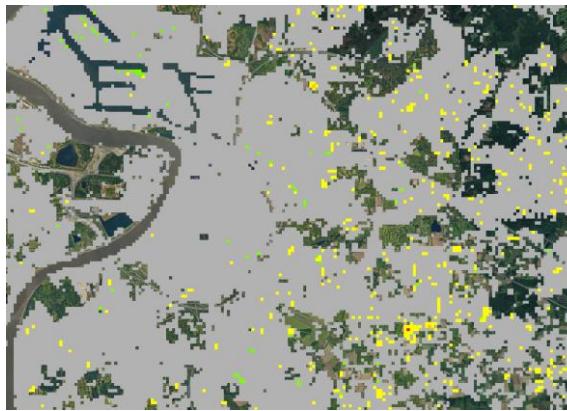
Share of Built-Up Change Classified (SBCC)

Unchanged non-built-up areas	
New cover	
Loss of cover	
Unchanged built-up areas	
Increased built-up density	
Decreased built-up density	
Outside area	

Share of Built-Up Change Classified Support layer (SBCCS)

Unchanged non-built-up areas	
New cover	
Loss of cover	
Unchanged built-up areas	
Increased built-up density	
Decreased built-up density	
Outside area	

Share of Built-Up Change (SBUC)



100% built-up decrease	
51-99% built-up decrease	colour shades in between
50% built-up decrease	
2-49% built-up decrease	colour shades in between
1% built-up decrease	
Unchanged built-up areas	
1% built-up increase	
2-49% built-up increase	colour shades in between
50% built-up increase	
51-99% built-up increase	colour shades in between
100% built-up increase	
Unchanged non-built-up areas	
Outside area	

Share of Built-Up Change Support layer (SBUCS)



100% built-up decrease	
51-99% built-up decrease	colour shades in between
50% built-up decrease	
2-49% built-up decrease	colour shades in between
1% built-up decrease	
Unchanged built-up areas	
1% built-up increase	
2-49% built-up increase	colour shades in between
50% built-up increase	
51-99% built-up increase	colour shades in between
100% built-up increase	
Unchanged non-built-up areas	
Outside area	