Final draft

Service Contract No 3506/R0-COPERNCA/EEA.59551

CLC2024 Technical Guidelines

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Based on
CLC2018 Technical guidelines (2017 - SC No3436/R0-Copernicus/EEA.56665)

22 May 2024

Version 1.0

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1 INTRODUCTION

1.1 ABOUT THE DOCUMENT

The European Environment Agency (EEA) is an agency of the European Union that delivers knowledge and data to support Europe's environment and climate goals. In collaboration with its partner network, Eionet, the EEA informs decision-makers and the public about the state of Europe's environment, climate change and wider sustainability issues.

Through a Contribution Agreement between the EU, represented by the European Commission and the EEA, the Agency, as Entrusted Entity, implements the Copernicus component of the space programme of the EU, namely, the Copernicus Land Monitoring Service (European and local components) and the Copernicus In-situ component.

The Copernicus Land Monitoring Service (CLMS) provides users in the field of environment and other terrestrial applications with high-quality information based on space data combined with other sources of in-situ and other ancillary data.

These Technical Guidelines provide support for the update of CORINE land cover (CLC) data for the reference year 2024, similarly to its predecessors for CLC1990 [1], CLC2000 [2], CLC2006 [3], CLC2012 [4] and CLC2018 [5]. According to the described standard methodology the CORINE Land Cover database for the year 2024 (CLC2024) will be derived by integrating the data of land cover changes between the years 2018–2024 (CLC-Change$_{2018\text{-}2024}$) - as primary product - with the revised land cover map of year 2018 (revised CLC2018) - as side product. Alternative, semiautomatic methodologies - if providing comparable results with the standard methodology - are allowed and welcome, but not discussed in this document. The enhanced version of CLC nomenclature is discussed in a separate document [6]. Ortho corrected satellite imagery called IMAGE2018 (taken mainly in 2017) and IMAGE2024 (taken mainly in 2024) should be used in deriving CLC-Change$_{2018\text{-}2024}$ and CLC2024.

CLC2024 is traditionally implemented or managed by national members of the Eionet Thematic Group Copernicus Land (former Eionet National Reference Centre (NRC) for land cover), where the best expertise as well as the ancillary data are available for mapping land cover changes. Verification of national products and integration of all national contributions will be provided by EEA, supported by the European Topic Centre Data integration and Digitalisation (ETC DI).

The structure and content of this document is similar to the CLC2018 Technical Guidelines [5]. The first three chapters describe the background, main technical parameters, organisation, and satellite image basics of CLC2024. Chapter 4 provides guidelines for mapping CLC-Changes (focusing on the "change mapping first" photointerpretation approach, applied by most of the participants). Chapter 5 is about ancillary data. Chapter 6 describes the automated generation of CLC2024. Chapters 4-6 have changed only modestly compared to the CLC2018 Technical Guidelines. Chapter 7 describes metadata requirements Chapters 8 is about the training of national teams and the verification procedure. Verification needs to be reorganised to keep track with the tight schedule of the project, while not losing the high quality of products. Chapter 9 replaced the former chapter about "Deliverables" and describes the guidelines for delivery of the products.

The intended readers of this document are the members of CLC national teams and other organisations involved in production. The primary aim is to provide guidance on practical issues of production, with a basic overview of the theoretical considerations.

1.2 Brief history of CORINE Land Cover

CLC2024 is the sixth CORINE Land Cover inventory (***Table 1***). A brief history of CLC is presented below.

1.2.1 CLC1990

From 1985 to 1990, the European Commission implemented the CORINE Programme (Co-ordination of Information on the Environment). During this period, an information system on the state of the European environment was created and nomenclatures and methodologies were developed and agreed at EU level [7]. Images acquired by earth observation satellites are used as the main source data to derive land cover information. Satellite images were visually interpreted by using plastic overlays on top of 1:100.000 scale hardcopies. The first CORINE Land Cover project (CLC1990) has been implemented in most of the (at that time) EU countries, as well as in the 10, so called, Phare partner countries in Central and Eastern Europe.

Table 1 CORINE Land Cover inventories in Europe

Name	Start year	End year
CLC1990	1986	1999
CLC2000	2001	2006
CLC2006	2007	2010
CLC2012	2013	2015
CLC2018	2017	2018
CLC2024	2025	2026 (planned)

1.2.2 CLC2000

Following the setting up of the European Environment Agency (EEA) and the establishment of the European Environment Information and Observation Network (Eionet), the responsibilities of the CORINE databases - including the updates - rely on the EEA.

As CLC1990 was completed and came to use, several users at national and European level expressed their need for an updated CLC database. Updating was implemented within the IMAGE&CLC2000 project [8], which consisted of two main components:

- IMAGE2000: covering activities related to satellite image acquisition, ortho-rectification and production of European and national mosaic;
- CLC2000 covering activities related to updating of CLC1990 based on IMAGE2000 (updated version is named CLC2000) and detection and interpretation of land cover changes (named CLC-Change$_{1990\text{-}2000}$) by using CLC1990, IMAGE1990 and IMAGE2000. In order to prevent propagating errors into CLC2000 – the geometric and thematic mistakes in CLC1990 have been corrected [8].

Improving the geometry of CLC layer and mapping CORINE land cover changes constituted the main novelties of CLC2000. The technology of drawing the interpretation on transparencies was discarded and replaced by CAPI (computer-assisted photo-interpretation).

1.2.3 CLC2006 under GMES FTSP

In 2005–2006, strategic discussions amongst member countries, the European Parliament and the main EU institutions responsible for environmental policy, reporting and assessment (DG ENV, DG AGRI, EEA, ESTAT and JRC) have underlined an increasing need for factual and quantitative information on the state of the environment to be based on timely, quality assured data, in particular in land cover and land use related issues. Based on requirements of DG ENV, DG AGRI and other users for the period 2006–2008, the EEA put forward a proposal to collaborate with the European Space Agency (ESA) and the European Commission (EC) on the implementation of a fast-track service precursor (FTSP) on land monitoring. The definition and implementation of the necessary satellite data procurement and processing was undertaken by ESA and JRC. CLC2006 was one of the components of Global Monitoring for Environment and Security (GMES) FTSP Land Monitoring [9], [10].

From a technical point of view, the main novelty of CLC2006 was the introduction of harmonised change mapping rules [11]. All changes exceeding 5 ha in size had to be mapped, not only those that were associated to existing polygons. CAPI was the prevailing method applied in interpreting of satellite images. Nevertheless, FI, IS, NO, SE and the UK applied a semiautomatic methodology. Concerning satellite imagery, the single date Landsat TM, used in CLC2000 was replaced by two types of satellite imagery (taken by IRS and SPOT-4) acquired in two different acquisition windows.

1.2.4 CLC2012 under GMES Initial Operations

The fourth CLC inventory (CLC2012) was implemented as part of the GMES Initial Operations (GIO) initiated by DG ENTR. The coordination of the GIO land monitoring was delegated to EEA for implementation [12]. With CLC2012 the CLC time series have become embedded in the Copernicus programme, thus ensuring sustainable funding for the future.

The ESA Data Warehouse [13] has provided a satellite image catalogue and download system for all GMES-related activities, including CLC2012. Two satellite image coverages have been acquired (primarily IRS/ResourceSat and RapidEye and to a less extent SPOT-4 and SPOT-5) in 2011-2012. Gap filling in 2013 was targeting those areas which were not covered by imagery during the 2-year image acquisition period. The technical implementation of CLC2012 [4] was similar to the CLC2006 inventory. The majority of countries applied Computer Assisted Photointerpretation (CAPI) technology to map the CLC-Change layer first. Germany and Ireland joined the Scandinavian countries and UK by applying a semi-automatic methodology based on the integration of existing land use data, satellite image processing and generalization.

1.2.5 CLC2018 in the frame of Copernicus

CLC2018, the fifth CLC inventory was a continuation of previous CORINE Land Cover inventories. The project was coordinated by the EEA. Main highlights were:

- Sentinel-2 satellite imagery – the 1st European satellite dedicated to land monitoring – was provided as basic image data support representing land cover in 2017-2018. For gap-filling Landsat-8 data were used.
- Shorter production time (see Tables 1 and 2) compared to previous inventories to be harmonised with SoER[1] 2020.

Computer-assisted visual photointerpretation is still the dominating method used by the participating countries, but alternative solutions (bottom-up approach) were emerging.

1.2.6 CLC2024 in the frame of Copernicus 2.0

CLC2024, the sixth CLC inventory, is a continuation of previous CORINE Land Cover inventories under the coordination of the EEA. Main highlights are:

- Sentinel-2 satellite imagery will be available for year 2018 as well as for year 2024. For the first time in the history of CLC this means the availability of the same type of high quality imagery as basic image data support. For gap-filling Landsat-8&9 data will be used.

1 The European environment — state and outlook 2020 — European Environment Agency (europa.eu)

- To keep on with the targeted one-and-a-quarter-year long production time to make available updated land cover information for the users.

1.3 MAIN TECHNICAL PARAMETERS OF CORINE LAND COVER

The choice of minimum mapping unit (MMU = 25 hectares) and minimum width of linear elements (MMW = 100 metres) in CLC mapping represent a trade-off between cost and detail of land cover information [1]. These two basic parameters are the same for all the five CLC inventories.

The standard CLC nomenclature includes 44 land cover classes. These are grouped in a three-level hierarchy. The five main (level-one) categories are: 1) artificial surfaces, 2) agricultural areas, 3) forests and semi-natural areas, 4) wetlands, 5) water bodies [1]. All national teams had to adopt this standard nomenclature according to their landscape conditions. Although the 44 categories have not changed since the implementation of the first CLC inventory (1986-1998), the definition of most of the nomenclature elements has been significantly improved [6].

Earth observation satellite imagery is the basis of CLC mapping, providing up-to-date information about the surface of the Earth in proper resolution. Raw satellite images first have to be pre-processed and enhanced to yield geometrically correct reference in national projection. In the CLC1990 inventory ortho-correction was usually not applied, and GCPs[2] were mostly selected from 1:100.000 scale maps. Therefore, the geometric accuracy of IMAGE1990 products and that of the derived CLC1990 did not fulfil the 50 geometric accuracy specification (Table 2). Starting from the CLC2000 project, satellite images are ortho-corrected by using a digital elevation model (DEM)[3]. The accuracy is characterised by an RMS error below 25 metres.

During the first CLC inventory the "traditional" photointerpretation method was used: an overlay was fixed on top of a satellite image hardcopy and the photo-interpreter drew polygons on it marking them with a CLC code. Later the overlay was digitised, topology was created and the CLC code entered. This procedure often resulted in several types of errors in geometry as well as in thematic content, which were mostly corrected later, within the frame of IMAGE&CLC2000.

In CLC2000 the method of drawing on transparencies was discarded, and the use of computer-assisted image interpretation (CAPI) was applied [2]. CAPI has become the main tool of producing all the subsequent CLC inventories, including CLC2024. The number of alternative solutions is growing slowly.

Main characteristics of subsequent CLC projects are summarised in Table 2.

1.4 CORINE LAND COVER CHANGES

CORINE Land Cover Changes (CLC-Changes) were first mapped in the 2nd CLC inventory, CLC2000. It was a policy requirement to map changes in finer resolution than the 25 ha MMU size of CLC status maps. The MMU of the CLC-Changes database was therefore set to 5 ha[4]. However, the 100-meter minimum width is also valid was kept for the CLC-Changes polygons for practical reasons. Changes should refer to real evolution processes. Starting from CLC2006, mapping CLC-Changes has been standardised: all CLC-changes larger than 5 ha have to be mapped [11]. See more details in Ch. 4.

2 Ground Control Points
3 Digital Terrain Model
4 In case of a complex change polygon, size less than 5 ha is also allowed (see Ch. 4.3.1 / Complex change, elementary changes)

Table 2 Evolution of CORINE Land Cover

	CLC1990	**CLC2000**	**CLC2006**	**CLC2012**	**CLC2018**	**CLC2024**
Satellite data used dominantly	Landsat-4/5 TM single date (in a few cases Landsat MSS)	Landsat-7 ETM single date	SPOT-4 and / or IRS LISS III dual date	IRS, SPOT-4/5 and RapidEye dual date	Sentinel-2 with Landsat-8 for gap filling dual date	Sentinel-2 with Landsat-8&9 for gap-filling dual date
Time consistency	1986-1998	2000 +/- 1 year	2006+/- 1 year	2011-2012	2017-2018	2023-2024
Geometric accuracy satellite images	≤ 50 m	≤ 25 m	≤ 25 m	≤ 25 m	≤ 10 m (Sentinel-2)	≤ 10 m (Sentinel-2)
CLC mapping MMU	25 ha	25 ha	25 ha	25 ha	25 ha	25 ha
CLC mapping minimum width	100 m	100 m	100 m	100 m	100 m	100 m
Geometric accuracy CLC data	100 m	better than 100 m	better than 100 m	better than 100 m	better than 100 m	better than 100 m
Thematic accuracy	≥ 85% (probably not achieved)	≥ 85% (achieved [14]	≥ 85%	≥ 85% (probably achieved)	≥ 85%	≥ 85%
Change mapping	_	boundary displacement min. 100 m; change area for existing polygons ≥ 5 ha; isolated changes ≥ 25 ha	boundary displacement min. 100 m; all changes > 5 ha must be mapped	boundary displacement min. 100 m; all changes > 5 ha must be mapped	boundary displacement min. 100 m; all changes > 5 ha must be mapped	boundary displacement min. 100 m; all changes > 5 ha must be mapped
Production time	13 years	5 years	4 years	3 years	1,5 years	1,25 years
Documentation	incomplete metadata	standard metadata	standard metadata	standard metadata	standard metadata	standard metadata
Access to the data	unclear dis-semination policy	dissemination policy agreed from the start	free access for all kind of users	free access for all kind of users	free access for all kind of users	free access for all kind of users
Number of European countries involved5	22 (28)	32 (39)	38 (39)	39	39	not yet known

5 During the official lifetime of the project (with additional countries joining later)

1.5 PREPARING FOR CLC2024

1.5.1 Participating countries

At the time of writing of this Manual, the final list of participating countries is not yet available. In order to continue the CLC time series, the products to be delivered shall cover all of the EEA 32 Member Countries and 6 Cooperating Countries, i.e., the full EEA38 and the UK (see ***Figure 1.*** and ***Table 3***) with total area of 5.85 Mkm^2.[6]

Table 3 CLC participating countries

Country	EEA status		Country	EEA status
Albania	Cooperating		Kosovo (under the UN Security Council Resolution 1244/99)	Cooperating
Austria	Member		Latvia	Member
Belgium	Member		Liechtenstein	Member
Bosnia and Herzegovina	Cooperating		Lithuania	Member
Bulgaria	Member		Luxemburg	Member
Croatia	Member		Malta	Member
Cyprus	Member		Montenegro	Cooperating
Czech Republic	Member		The Netherlands	Member
Denmark	Member		Norway	Member
Estonia	Member		Poland	Member
Finland	Member		Portugal	Member
North Macedonia	Cooperating		Romania	Member
France	Member		Serbia	Cooperating
Germany	Member		Slovakia	Member
Greece	Member		Slovenia	Member
Hungary	Member		Spain	Member
Iceland	Member		Sweden	Member
Ireland	Member		Switzerland	Member
Italy	Member		Türkiye	Member
			United Kingdom	Not member[7]

6 The total territory includes all integral parts of the respective national territories, such as overseas areas, as well as Andorra, Monaco, San Marino, and Vatican City should be fully embedded in the EEA39 coverage.

7 The UK will associate to Copernicus from 1 January 2024. The agreement with the EU secures UK participation in Copernicus through to 2027 when the multiannual financial framework finishes.

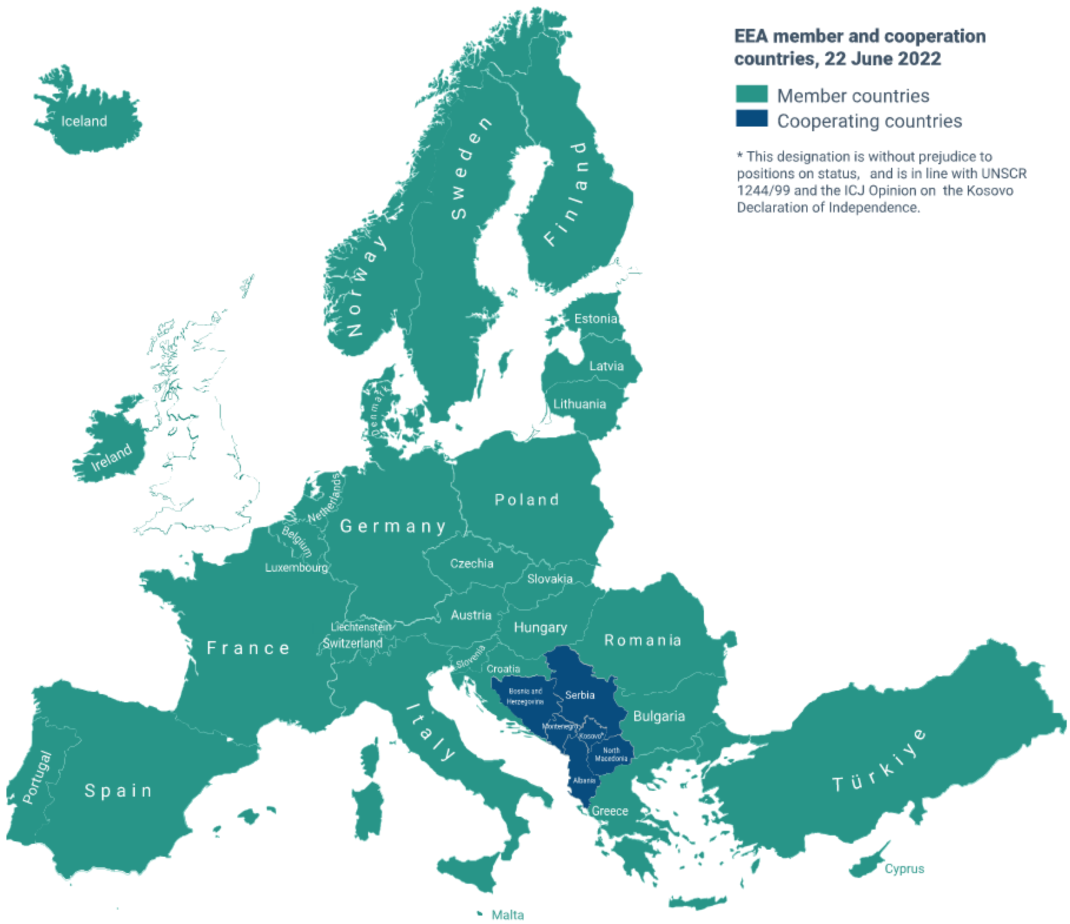

Figure 1 EEA member and cooperating countries (Status June 2022)[8]

1.5.2 Technical documents

Technical documents supporting the implementation of CLC2024 are presented below.

Table 4 List of technical documents supporting the implementation of CLC2024

Subject / Title	Status, reference
CLC2024 Technical guidelines	updated, this document
CORINE Land Cover illustrated nomenclature guidelines	updated for CLC2018, separate document and online version [6]
Manual of CORINE Land Cover changes	updated for CLC2018, separate document [17]
ArcGIS macro programme for generating CLC2024	minor update for CLC2024, not available yet
CLC QC Quick Guide - online manual	updated for CLC2018, separate document [19]
CLC2024 Support Package (software and user guide)	Updated for CLC2024, not available yet
Step-by-step guidelines for IMAGE2024 selection	new, separate document, not available yet

8 Source: https://www.eea.europa.eu/en/about/who-we-are/our-knowledge-network-eionet

2 COMPONENTS OF CLC2024

2.1 WORK PACKAGES

Like in the previous CLC inventories 7 work packages have been defined to implement CLC2024. Table 5 provides an overview of the role of contributing partners involved in the execution of each work package.

Table 5 Work packages and overview of the role of partners (NT=CLC National Team, ETC DI = European Topic Centre Data integration and digitalisation, ESA=European Space Agency)

Tasks	**NT**	**EEA/ ETC DI**	**ESA**	**Service provider**
WP 1.1 Satellite data acquisition (Sentinel-2 and Landsat 8&9)			**X**	
WP 1.2 Ortho-correction			**X**	
WP 1.3 Technical preparation of IMAGE2024 (Sentinel-2 and Landsat-8-9 (gap-filling) image provision)	x	**X**		
WP 2 In-situ and ancillary data collection	**X**	x		
WP 3.1 CLC change mapping 2018-2024	**X**	x		
WP 3.2 Generating CLC2024	**X**	x		
WP 4 Verification by Technical Team	x	**X**		
WP 5 Validation				**X**
WP 6 CLC data dissemination	**X**	**X**		
WP 7 Project management	x	**X**		x

X = leading organisation
x = organisation involved

This document describes in detail WP1.3, WP3 and WP4. Other WPs will be tackled only marginally.

2.2 PROJECT ORGANISATION AND GOVERNANCE

In accordance with Article 5 of the Regulation, the EEA may agree with the institutions or bodies which form part of Eionet (national environmental organisations, National Focal Points (NFPs), and European Topic Centres (ETCs)) upon the necessary arrangements, in particular contracts, for successfully carrying out the tasks which it may entrust to them. The EEA chooses to launch Negotiated Procedures under Article 5 when the specialised expertise, which Eionet members possess, is needed.

The Eionet members have successfully cooperated with the EEA under the framework of GMES and Copernicus and they enjoy thus a long-standing experience and know-how in land monitoring related activities (in particular CLC production). The continued/renewed involvement of local experts will warrant the success of the project with access to local knowledge and ancillary data necessary to support land cover change mapping.

As highlighted in Section 1, CLC is implemented by national teams under the management, guidance, and close quality control of EEA through the CLC Technical Team. It is financed through Copernicus budget (provided by EEA) through a selection of contracting procedures.

There will be two types of contracting procedures, depending on the beneficiary:

1. Direct service contracts established between EEA and a national institution represented in Eionet. It applies to all EEA member and cooperating countries.

2. Open Call for Tenders for those not interested in the co-creation of CLC 2024 and the UK (not a Eionet country).

CLC2024 implementation (change mapping and CLC2018 revision) is therefore executed by national organizations. EEA and ETC DI will provide administrative and technical support. Similarly to previous CLC inventories, the CLC Technical Team will provide training on CLC mapping, performs verifications, give helpdesk support on CLC production methodology and the photointerpretation software, and carry out the technical verification.

ETC DI will also provide support in image coverage pre-selection, re-projection to national projections, and provision of the input data to the countries.

3 SATELLITE IMAGE BASICS FOR CLC2024

The purpose of this chapter is to provide an overview of the satellite imagery provided by EEA to support the CLC2024 project. The satellite imagery referred to as IMAGE2024 and prepared to derive CLC2024 will be comprised of two data sources:

- Sentinel-2 imagery – Sentinel-2 imagery will be considered the main data source for IMAGE2024.
- Landsat 8-9 imagery – Landsat 8-9 imagery will be considered an alternative data source to fill gaps where Sentinel 2 imagery does not meet selection criteria.

Sentinel-2 and Landsat 8-9 imagery will be accessed from the European Space Agency's (ESA) Copernicus Data Space Ecosystem (CDSE). The CDSE provides access to a wide range of satellite data and processing capabilities such as processing APIs and infrastructure. It also provides the Copernicus Browser application commonly used for browsing images at full resolution. The Copernicus Data Space Ecosystem continues the legacy of open and free access to Copernicus data of the Copernicus Open Access Hub, which ceased its operations in November 2023.

The satellite imagery will be prepared and provided by the EEA to provide support to countries in pre-processing of the IMAGE2024 imagery.

IMAGE2024, together with IMAGE2018 are considered to be the official input reference data for CLC2024 inventory. This means that these image sets will be the basis of quality control, and in case of disagreement with other source of information (e.g. other images used as ancillary data), IMAGE2018 and IMAGE2024 will be considered as truth.

3.1 IMAGE2024 SATELLITE IMAGERY DATA SOURCES

3.1.1 Sentinel-2

Overview

Sentinel-2 mission is a European earth polar-orbiting satellite constellation (Sentinel-2A and 2B) designed to acquire continuous and operational high-resolution imagery for the global and sustained monitoring of Earth land and coastal areas[9]. The Sentinel-2 constellation is based on the concurrent operations of two identical satellites flying on a single orbit plane but phased at 180º, each hosting a **Multi-Spectral Instrument** (MSI) acquiring data in the **visible- NIR** to the **shortwave infrared** spectral range at 10m, 20m and 60m resolution (***Figure 2***).

Each satellite provides a global coverage of the Earth's land surface approximately every 10 days, resulting in a combined revisit frequency of 5 days since February 2018 (operational availability of Sentinel-2B). Due to an overlap between adjacent orbits, the coverage frequency increases towards the poles. ***Table 6*** shows the basic characteristics of the Sentinel 2 mission.

9 https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-2

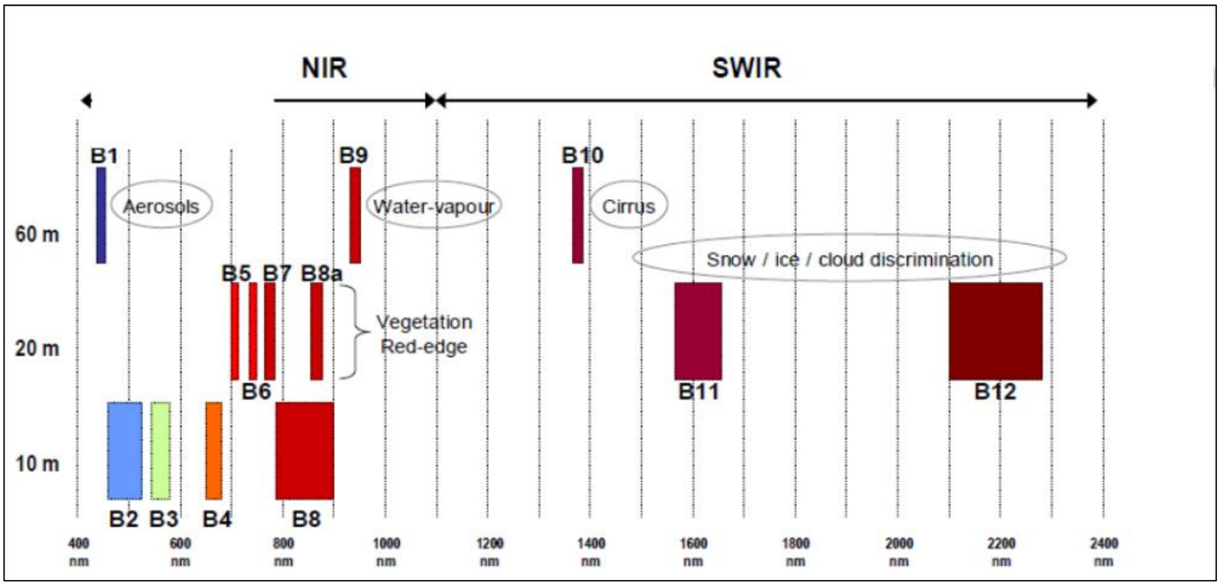

Figure 2 MSI spectral bands versus spatial resolution adapted from MSI product specification[10]

Table 6 Overview of the basic characteristics of Sentinel-2 mission

Property	**Description**	
Swath width (km)	290	
Number of bands	13 (altogether)	
	4	VIS
	6	NIR
	3	SWIR
Ground sampling distance (m)	10	bands 2,3,4 (VIS) and band 8 (NIR)
	20	bands 5,6,7,8a (NIR) and bands 11,12 (SWIR)
	60	band 1 (VIS), band 9 (NIR) and band 10 (SWIR)
Bit depth (recording)	12	
Repeat cycle at the Equator (days)	10 (with 1 satellite) 5 (with 2 satellites)	
Data access	free, full, and open access	
Delivered resolution (m)	10 / 20 /60 (depending on band)	

Data products

Sentinel-2 data are processed at levels: Level-0, level-1, and Level-2. **Level-0** and **Level-1A** contain raw data from the satellite not released to users.

- **Level-0**: Compressed raw image data in Instrument Source Packet (ISP) format. Contains all information required for processing to higher product levels.
- **Level-1A:** Obtained by decompressing level-0 raw image data and developing a geometric model to locate any pixel in the image.

The products available to users are **Level-1B, Level 1C** and **Level-2A** (***Table 7***)**.** Each Level-1C and Level-2A product is composed of 110x110 km^2 tiles in cartographic geometry (UTM/WGS84 projection).

10 https://sntinel.esa.int/documents/247904/349490/s2_msi_product_specification.pdf

Table 7 Overview of Sentinel user products[11]

Product type	Description	users	Data availability
Level-1B	Top-Of-Atmosphere (TOA) radiance in sensor geometry	Expert users	• July 2015 – present (Global)
Level-1C	Top-of-atmosphere (TOA)reflectance in cartographic geometry	All users	• July 2015 – present (Global)
Level -2A	Atmospherically corrected Surface Reflectance (SR) in cartographic geometry	All users	• March 2017 – present (Europe) • December 2021 – present (World with exception of Europe)

The European Space Agency is performing a reprocessing campaign for sentinel 2 data products to provide consistent Sentinel-2A and Sentinel-2B time series with a uniform processing baseline and optimized calibration to improve the products geometric performance.

The resulting products are published as **Sentinel-2 Collection 1**[12] which represents the products generated from the processing baseline 5 and above.

Since April 25th, 2022, all data acquired by the MSI instrument are systematically processed up to Level-2A with a fixed set of parameters, including the use of the Copernicus DEM, Global Reference Image and a single Sen2Cor[13] version.

All historical data in the period spanning from the Sentinel-2A satellite launch back in 2015 until December 2021 are planned to be reprocessed in reverse chronological order of sensing time. The availability status of the Sentinel-2 Collection 1 is published online[14].

Sentinel 2 spectral bands in comparison to other Earth Observation (EO) satellites

Sentinel-2's high-resolution Multi-spectral Instrument is based on well-established heritage from France's SPOT missions and the USGS Landsat satellites. The multispectral instrument is the most advanced of its kind – in fact it is the first optical Earth observation mission to include four bands in the 'red edge', which provide key information on vegetation state. ***Table*** shows spectral bands of Sentinel-2 in comparison with bands of main satellite sensors used in previous CLC projects.

11 https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/product-types
12 https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/processing-baseline
13 https://step.esa.int/main/snap-supported-plugins/sen2cor/
14 https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/copernicus-sentinel-2-collection-1-availability-status

Table 8 Comparison of spectral bands of Sentinel-2 with other EO satellites

S2 Band	Description	Spatial res (m)	Bandwidth: lower wavelength – upper wavelength [µm]				
			Sentinel-2 MSI	Landsat 8-9 OLI	Landsat ETM+, TM	IRS (Resource-sat) LISS-III	SPOT-4 HRVIR
B01	Coastal aerosol: Main use - atmospheric correction (aerosols)	60	0.433-0.453	0.43-0.45	-	-	-
B02	Blue	10	0.458-0.523	0.45 - 0.51	0.45-0.52	-	-
B03	Green	10	0.543-0.578	0.53 - 0.59	0.52-0.60	0.52–0.59	0.50–0.59
B04	Red	10	0.650-0.681	0.64 – 0.67	0.63-0.69	0.62–0.68	0.61–0.68
B05	Vegetation Red Edge	20	0.698-0.713	-	-	-	-
B06	Vegetation Red Edge	20	0.733-0.748	-	-	-	-
B07	Vegetation Red Edge	20	0.773-0.793	-	-	-	-
B08	NIR	10	0.735-0.950	0.85-0.88	0.76-0.90	0.77–0.86	0.78–0.89
B8A	Vegetation Red Edge	20	0.855-0.875	-	-	-	
B09	Water Vapour: Main use - atmospheric correction	60	0.935-0.955	-	-	-	
B10	SWIR - Cirrus Main use: atmospheric correction	60	1.365-1.395	-	-	-	
B11	SWIR	20	1.565-1.655	1.57-1.65	1.55-1.75	1.55–1.70	1.53–1.75
B12	SWIR	20	2.100-2.280	2.11 – 2.29	2.08-2.35		

3.1.2 Landsat 8&9

Landsat 8 (launched in 2013) and Landsat 9 (launched in 2021) are part of the Landsat program running since 1972 led by the partnership of NASA and USGS. Main mission characteristics are summarized in ***Table 9***. They both carry on board two instruments: the

Operational Land Imager (OLI for Landsat 8 and OLI-2 for Landsat 9) and the **Thermal Infrared Sensor** (TIRS for Landsat 8 and TIRS-2 for Landsat 9) (***Table 10***).

Table 9 Overview of the basic characteristics of Landsat 8-9 mission

Property	**Description**
Swath width (km)	185
Number of bands	11
Repeat cycle at the Equator (days)	8 days (16 days for each of the two sensors)
Data access	free, full, and open access
Delivered resolution (m)	30m – multi-spectral bands (TIRS band 10 & 11 are resampled from 100m to 30m) 15m – Panchromatic band
Common usage	Vegetation monitoring, land use, land cover maps and monitoring of changes.

Table 10 Landsat 8-9 Operational Land Imager OLI and Thermal Infrared Sensor TIRS spectral bands[15]

Band name	**Description**	**Lower-Upper Wavelength (µm)**	**Ground Sampling Distance (m)**
B01	Ultra Blue - Coastal aerosol	0.43-0.45	30
B02	Blue	0.45-0.51	30
B03	Green	0.53-0.59	30
B04	Red	0.64-0.67	30
B05	NIR	0.85-0.88	30
B06	SWIR 1	1.57-1.65	30
B07	SWIR 2	2.11-2.29	30
B08	Panchromatic	0.50-0.68	15
B09	Cirrus	1.36-1.38	30
B10	Thermal Infrared TIRS1	10.6-11.19	100 * resampled to 30m
B11	Thermal Infrared TIRS2	11.50-12.51	100 * resampled to 30m

Landsat 8&9 continue the legacy of the Landsat program with improved radiometric & geometric capabilities while keeping consistency with earlier Landsat satellites.

The **OLI** captures observations of the Earth's surface in **9 spectral bands (band 1-9)** in the visible, near-infrared, and shortwave-infrared while **TIRS** measures thermal infrared radiation (heat), emitted from the Earth's surface in **2 spectral bands (band 10-11)**.

Seven of the nine bands are consistent with the Thematic Mapper (**TM**) and Enhanced Thematic Mapper Plus (**ETM**+) sensors found on earlier Landsat satellites, providing for compatibility with the historical Landsat data, while also improving measurement capabilities. **Band 1 - deep blue coastal / aerosol band** and **band 9- shortwave-infrared cirrus band**, are new bands that allow scientists to measure water quality and improve detection of high, thin clouds.

See ***Table 8*** above, for a comparison of spectral bands from Landsat satellites & Sentinel-2 satellites.

15 https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites

Data products

The Landsat data archive is organized into a tiered collection management structure based on data quality and level of processing. **Landsat collection 2**[16] is the second major reprocessing effort on the Landsat archive, which resulted in substantial processing, geometric and radiometric improvements including improved data access and distribution capabilities. Landsat Collection 2 contains the following products:

- **Level-1** data from **Landsat 1-9**,
- **Level-2** and **Level-3** science products from **Landsat 4-9**.

Table 11 Overview of Landsat 8-9 collection 2 products

Product type	Description	Data availability	Tiers[17]
Level-1[18]	Calibrated scaled Digital Numbers (DN) in an unsigned 16-bit integer format. Can be converted to TOA Reflectance and TOA Brightness Temperature using radiometric scaling factors provided in each scene metadata file	Landsat 8 since February 2013, Landsat 9 since November 2021.	• Real-Time • Tier 1 • Tier 2
Level-2[19]	Surface Reflectance (unitless) and Surface Temperature (Kelvin) products	Landsat 8 since March 2013, Landsat 9 since January 2022.	• Tier 1 • Tier 2

16 https://www.usgs.gov/landsat-missions/landsat-collection-2

17 Landsat uses tiers to show the quality and level of processing of products. Tier 1 is preferred, as it is of the highest quality, but there could be a chance that only tier 2 is available for a specific scene.

18 https://www.usgs.gov/landsat-missions/landsat-collection-2-level-1-data

19 https://www.usgs.gov/landsat-missions/landsat-collection-2-level-2-science-products

3.2 PROVISION OF IMAGE2024 TO COUNTRIES

IMAGE2024 will be provided to CLC national teams by ETC DI. The imagery will be comprised of Sentinel-2 images acquired in 2024 (covering only a single year instead of 2 or 3 years of previous CLCs). In the event of lack of suitable Sentinel-2 images, Landsat 8&9 imagery will be provided as an alternative.

Sentinel-2 with its frequent and systematic coverage and high spatial resolution provide input data for both land cover and land cover change mapping, bringing significant improvements to previous CLC production campaigns.

The following are the main highlights regarding the use of Sentinel 2 imagery in IMAGE 2024:

1. ***Large number of acquisitions***: With a high repeat cycle of 5 days and up to 2 days at higher latitudes, a large number of Sentinel- 2 scenes are expected to be available across e.g. a 5-month acquisition window.
2. **Automated image pre-selection and image selection through a web browser**: Images will be optimally selected from the image catalogue by use of python scripts considering cloud clover & seasonality. The selected scenes will be viewed in full resolution and natural colour using ESA's Copernicus Browser[20].
3. **Sentinel 2 products[21]:** the service provider will provide both ***Sentinel-2 full, raw products*** and a **visual product** (*Sentinel 2 false colour composite)* to support workflows that utilize visual interpretation. (The same applies to Landsat 8&9 products).
4. ***Cartographic projection:***
    - ***Sentinel 2 false colour composite*** will be provided in national cartographic projection to allow seamless integration of the products to existing workflows at national level. (The same applies to Landsat 8&9 products).
    - ***Sentinel-2 full products*** will be provided in the original UTM/WGS84 cartographic projection as provided by ESA. (The same applies to Landsat 8&9 products).

3.2.1 Image Selection

The aim is to optimally provide two full image coverages for each country, with at least a six-week period between the two coverages per reference tile. The two coverages are selected within the acquisition window specified by the CLC national teams (e.g. from mid -spring to mid-autumn).

An image taken in full vegetation cover (summer) and another one taken in partial vegetation cover (spring or autumn) are usually considered as optimal (see also Ch. 4.1).

In addition to these two coverages, the CLC national teams can select additional images to meet specific needs based on a selection criterion agreed upon with the service provider.

3.2.1.1 Image Selection Workflow

1. The CLC national teams provide the required inputs to the service provider: acquisition window, pre-selection criteria and specifications, and a list of specifications for the outputs.
2. The service provider based on the acquisition window and pre-selection criteria prepares a Python script that pre-selects 2 coverages of Sentinel-2 imagery (or

20 https://browser.dataspace.copernicus.eu/

Landsat 8-9 gap filler), using the Catalog API[22] and Statistical API[23] of the Copernicus Data Space Ecosystem.

3. The service provider provides the CLC national teams with the following:
    i. An excel table (one per national team), containing the list of pre-selected scenes & Copernicus Browser links to visualize the pre-selected scenes in natural colour and additional columns to indicate the approve/reject decision and alternative proposed scenes by the CLC national teams,
    ii. Guide on how to navigate the Copernicus Browser (change dates, compare scenes, etc.),
    iii. The Python script to be kept for future use.
4. CLC national teams analyse the pre-selected scenes at full resolution using the Copernicus Browser and make a decision to approve or reject or propose additional scenes.
5. CLC national teams provide a final list of selected scenes of (usually) two coverages.
6. The service provider proceeds to the production of the imagery.

Next steps 7-10 described in Chapter 3.2.2.1 below.

3.2.2 Product Types

Based on the imagery needs specified by the CLC national teams, the service provider will deliver the following product types (***Table 13***):

i. The visual product, re-projected to national projections based on Sentinel-2 imagery (or Landsat 8-9 for gap filling). The recommended standard colour composite for photointerpretation is false colour composite using NIR, SWIR & Red bands combination. False colour composites allow to visualize wavelengths outside of the visible spectrum that cannot be seen by the human eye. ***Table 12*** shows the false colour band combinations for Sentinel-2 and Landsat 8-9.

Table 12 False colour composite band combination for Sentinel-2 and Landsat 8-9

RGB channels	Sentinel-2 bands	Landsat 8-9 bands
Red	Band 8 (NIR)	Band 5 (NIR)
Green	Band 11 (SWIR)	Band 6 (SWIR)
Blue	Band 4 (Red)	Band 4 (Red)

ii. Full original products with all bands & original projections as provided by ESA (Sentinel-2) and NASA/USGS (Landsat 8-9).

Table 13 Overview of IMAGE2024 product types

Data Source	Characteristic	Visual product	Full product
Sentinel 2	Processing level	Level -1C or Level-2A*	Level -1C or Level-2A*
	Units	Top of Atmosphere Reflectance or Surface Reflectance	Top of Atmosphere Reflectance or Surface Reflectance
	Formats	Cloud Optimized GeoTIFF (COG**)	• Sentinel -SAFE format • JPEG2000 image data format

22 https://documentation.dataspace.copernicus.eu/APIs/SentinelHub/Catalog.html
23 https://documentation.dataspace.copernicus.eu/APIs/SentinelHub/Statistical.html

	Spatial resolution	10m	10m,20m,60m depending on the band
	Bit depth	16 bit	16 bit
	Bands	3-bands 8, 11 and 4 (NIR, SWIR, Red) false colour composite	All bands
	Projection	National CRS	UTM/WGS84 Projection
	Resampling	Band 11 resampled to 10 m	No resampling
	Improvements	No geometric/ radiometric improvements	No geometric/ radiometric improvements
	Naming convention	Custom	Original
Landsat 8&9	Processing level	Level-1 or Level-2*	Level-1 or Level-2*
	Units	**Level -1** Top of Atmosphere Reflectance or **Level-2** Surface Reflectance	**Level -1** Top of Atmosphere Reflectance/Brightness Temperature or **Level-2** Surface Reflectance(optical)/ Surface Temperature (TIRS)
	Formats	Cloud Optimized GeoTIFF (COG**)	Cloud Optimized GeoTIFF (COG**)
	Spatial resolution	15m – Pan-sharpened	10m,20m,60m depending on the band
	Bit depth	16 bit	16 bit
	Bands	3-bands 5, 6 and 4 (NIR, SWIR, Red) false colour composite	All bands
	Projection	National CRS	UTM/WGS84 Projection
	Pan - sharpening	Band 5,6,4 pansharpened to 15 m with panchormatic band	No pan-sharpening /resampling
	Improvements	No geometric/ radiometric improvements	No geometric/ radiometric improvements
	Naming convention	custom	original

***Sentinel -2 Level -2A and Landsat 8-9 level -2** products provide atmospherically corrected Surface Reflectance images derived from the associated Level-1 products enabling further analysis without applying additional atmospheric corrections.*
****Cloud Optimized GeoTIFF** data format is a GeoTIFF file with an internal organization that enables more efficient imagery data access on the cloud.*

3.2.2.1 Product Delivery Workflow

Continuation of steps 1-6 listed in Chapter 3.2.1.1 above.

7. The Service provider prepares a Python script to fetch full (raw) products and perform batch processing of selected scenes using batch processing API[24] to produce the 3-band visual product in COG format in the national CRS. The script is also part of the deliverables, for future use.

8. The service provider stores the output results (full product and COG products) in a ZIP format (one per country) and makes it available for download via HTTP to CLC national teams.

24 https://documentation.dataspace.copernicus.eu/APIs/SentinelHub/Batch.html

9. Optional: The service provider additionally prepares WMS layers of the visual products for interested countries, to allow the CLC national teams to use interactive access to the data, rather than download.

10. CLC national teams download the provided products and/or use the WMS layers provided.

3.2.3 IMAGE2024 Provision Workflow and Timing

Table 14 summarizes IMAGE2024 provision steps and foreseen timing of their execution-

Table 14 Summary workflow and timing for the provision of IMAGE2024

Step	Activity	Responsible	Timing
1	Inputs specifications	CLC National Teams	Up to 4 weeks after the start of the contract
2	Pre-selection of scenes	Service Provider	Up to 4 weeks after closure of extended windows (with first deliveries starting 1st October)
3.	Provision of Copernicus Browser links to the pre-selected scenes	Service Provider	
4.	Selection of scenes. • Approval & rejection of the pre-selected scenes • Propose additional images	CLC National Teams	Up to 2 weeks (total of 6 weeks after end of extended window, considering first delivery date)
5.	Provision of final list of the selected scenes,	CLC National Teams	
6 & 7	Production of imagery; full product & visual product & WMS layers.	Service Provider	Up to 4 weeks (total of up to 10 weeks after end of extended window, considering first delivery date)
8 & 9	Provision of imagery for download or interactive access	Service Provider	
10	Download provided products/ use of the WMS layers	CLC National Teams	Up to 4 weeks (total of up to 14 weeks after end of extended window, considering first delivery date)

3.3 IMAGE2018

To map CLC changes between 2018 and 2024 two sets of satellite images should be used: the IMAGE2018 and IMAGE2024.

CLC2018 was the first CLC production to make use of Sentinel-2 and Landsat 8 imagery which was processed & provided by a consortium of organizations contracted by EEA to support the CLC2018 campaign. IMAGE2024 consists of the same data sources, hence providing compatibility.

3.3.1 IMAGE2018 Satellite Imagery

IMAGE2018 comprised of Sentinel-2 and Landsat 8 Imagery (for gap filling) with the characteristics shown in ***Table 15*** below:

Table 15 IMAGE2018 product types

Data Source	Visual product	Full product
Sentinel 2 A/B	• GeoTIFF, 16bit, 3 bands, no compression, ToA reflectance • False colour composite using S2 bands 8, 11 and 4 (NIR, SWIR, red) • 10-meter spatial resolution • Re-projection to national projection as specified by EEA with EPSG codes. • No geometric improvements • No radiometric improvements • Band 11 brought to 10 m by HPF sharpening	• No modification of projection, format, naming convention, radiometry, meta data • All bands in original resolution
Landsat 8	• Re-projection to national projection as specified by EEA with EPSG codes. • False colour composite using L8 bands 5, 6, 4 (NIR, SWIR, red) • 15-meter spatial resolution • No geometric improvements • DN to ToA reflectance conversion, followed by HPF sharpening	• No modification of projection, format, naming convention, radiometry, meta data • All bands in original resolution

3.3.2 IMAGE2018 Data Access

Normally, IMAGE2018 data (provided by EEA for CLC2018 inventory) are available for the participating national teams in their own archives. If this is not the case, access to IMAGE2018 is going to be provided (for download) via the same channels as IMAGE2024, upon request by the National Team.

4 Production of CLC-Change$_{2018-2024}$

4.1 Interpretation strategy in CLC2024

Chapter 4.1 is specific because of the use of Sentinel-2 data and valid for any methodology of deriving CLC-change$_{2018-2024}$.

During the S2 image acquisition campaign in 2023-2024 (like in 2017-18) we can expect several images acquired for any area. Even if some of these images will be cloudy / partially cloudy, we can expect a number of useful or partially useful images, more in number than was available for former European CLC inventories. There are three main issues to be considered for proper satellite image selection:

1. <u>Vegetation phenology</u> (see also in Ch. 4.2.2.2.3): it is important to have at least one image taken in the peak of vegetation development.
    a. Forests: Broadleaved forests are leafless in May in Scandinavia and some species (e.g. *Robinia pseudoacacia*) can be leafless even in Central Europe in that period. The leaf development status depends on elevation also. Mapping forests is optimal by using images taken between June and August.
    b. Natural grassland and sparse vegetation: green vegetation should be visible to map these classes properly. As grass becomes yellow in summer under warm climate (Mediterranean, Iberian Peninsula, Türkiye), images taken in spring (even May can be too late in some regions) are needed to map these classes.
    c. Non-irrigated arable land: like in b) spring images are needed to distinguish rain-fed crops (class 211) from abandoned arable land (class 231) in the Mediterranean, Iberian Peninsula and Türkiye.
    d. In image selection take into account yearly changes in climate. For example in large parts of Central Europe spring 2024 was much warmer than average, causing a considerable shift in start of season (deciduous trees in leaves three weeks earlier than usual). Meanwhile spring in Western Europe was unusually cold.
2. <u>Water</u>: proper mapping of water coverage in CLC often requires two satellite images, taken in different seasons. This way, short term phenomena (e.g. flooding) will not result in misclassifications. Spring and summer imagery will help avoiding erroneous mapping of seasonal changes of water coverage of lakes and reservoirs (e.g. due to water abstraction for irrigation during summer).
3. <u>Glaciers and permanent snow</u>: images of not exactly the same date (optimally the date of smallest snow extent: late August or early September) are not comparable, thus using them leads to mapping false changes.
4. <u>Fast-changing phenomena</u>: especially construction sites and mineral extraction sites, clearcutting of forest and burnt forests and shrubs. These phenomena can develop fast relative to the length of the S2 image acquisition period in 2017 and 2024. As the aim is to map the land cover status and land cover change which is closest to the year of 2018 and 2024 (nominal reference years of CLC2018 and CLC2024), the **latest acquired useful (cloud free) images should be considered**. However, as late season images can suffer from low Sun illumination angle, the practical end of the image acquisition period should be determined according the (extended) time window set by each country.

5. General advice regarding timing of coverages:

- An **S2 image taken in the peak vegetation** period (e.g. July) is considered as the main coverage (coverage-1) for photointerpretation / thematic processing.
- It is obligatory to use also the **latest[25] acquired useful S2 image** (e.g. early September, mid-October, depending on latitude). This is considered coverage-2 for photointerpretation / thematic processing. This image **will be used primarily in verification by the CLC Technical Team** when checking fast-changing phenomena.
- The time difference between coverage-1 and coverage-2 should be at least 6 weeks.
- **Use both coverage-1 and coverage-2 in photointerpretation / thematic processing.** Otherwise, there is a risk that the interpretation will be incomplete.
- Moreover, an image taken in May or early June can be proposed as coverage-3 for areas with warm climate (the Mediterranean, Iberian Peninsula, Türkiye) for improved mapping of semi-natural vegetation as well as agriculture. The time difference between coverage-3 and coverage-1 is preferably also at least 6 weeks.

4.1.1 Subdivision of the 121 class (Industrial or commercial units and public facilities)

A novelty of CLC2024 inventory is the voluntary mapping of photovoltaic power stations (solar parks, solar power plants) newly established between 2018 and 2024 on formerly non-built-up ground.

These power systems - designed to supply usable solar power to households and industry – are made up of solar arrays comprising of multiple solar panels. Majority of solar arrays are free-field systems mounted on support structures (***Figure 3***), however, systems mounted on building rooftops also occur. Free-field structures often allow parallel uses of these areas, e.g. as grazing ground for sheep. Mapping will focus solely on solar parks established on formerly non-sealed areas, such as agricultural fields, (semi-)natural areas, non-sealed dump sites etc. Solar panels mounted on rooftops or as (for example) shading structures over sealed parking lots are not mapped[26].

The mapping – as it requires extra effort – is voluntary, however recommended as results will give information not only on the increase of renewable energy production, but also on the extent and type of land occupied by these structures. Photovoltaic power stations occupy at least one hectare for each megawatt of rated output, therefore require a substantial land area[27] and compete for land with other uses, such as agriculture.

In practice, solar parks will be mapped as level-4 subclass of CLC class 121 – Industrial or commercial units and public facilities, as follows:

- 1211 – Industrial, commercial or public units other than free-field solar parks
- 1212 – Solar parks mounted on formerly non-sealed ground (free-field solar parks)

Voluntary mapping includes only mapping of changes, using the same technical parameters as other changes (see Chapter 4.2.2.2 for more detail). The use of level-4 classes is also supported by the CLC2024 Support Package photointerpretation software (see Chapter 4.4). Resulting polygons will be extracted and delivered as a separate layer for exploring further use, while in official European delivery they will be generalized into level-3 class 121.

25 according to the image acquisition window defined for the region
26 Because mounting solar panel on buildings does not cause additional land take (its already sealed / taken from agriculture/nature).
27 https://en.wikipedia.org/wiki/Photovoltaic_power_station#cite_note-110

Figure 3 Free-field solar park (photovoltaic power plant) (Source: By JUWI Group - Photo courtesy of JUWI Group, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4957243)

4.2 CHANGE MAPPING

CLC-Change$_{2018-2024}$ is the primary product of the CLC2024 project. CLC-Change$_{2018-2024}$ is a "stand-alone" product (i.e. not derived by intersecting CLC2018 and CLC2024) and has a smaller MMU (5 ha) than the CLC status layers (25 ha).

The aim is to produce European coverage of **real land cover changes** (see details in *Text box 1*) that:

- are larger than 5 ha;
- wider than 100 m,
- occurred between 2018 and 2024;
- are detectable on satellite images[28]; regardless of their position (i.e. connected to an existing CLC2018 polygon or being "island"-like).

Because most of the participating countries still apply photointerpretation (CAPI) the previously standardised **"change mapping first" methodology** (*Text box 2*) is promoted, like in the three latest inventories (CLC2006, CLC2012 and CLC2018). Obviously, like before, any alternative solutions capable of providing equivalent results are encouraged.

28 with support of dedicated in-situ data

Text box 1:

What does "real land cover change" mean?

Change codes should always represent the change process that happened in reality. When giving the codes, interpreter always must be able to answer the questions: what is the process described by the codes I gave? Is this process the same what I see on the image pair? Is this really a CLC change?

Example:

211-112 change means extension of built-up area (112) on non-irrigated arable land (211). The interpreter should see the irrigated arable land on the 2018 image and should be convinced that this is not a long-time abandoned area (231) or area under construction (133). Moreover, he/she should be convinced that in 2024 the area is built-up (112) and not yet under construction (133).

This way interpreter can avoid mapping seasonal differences as change or giving attributes that are meaningless on the field. See more details in Ch. 4.2.1/Real change.

The proposed "change mapping first" approach (see *Text box 2*) provides a good means to answer these questions and map real land cover changes with MMU = 5 ha.

On the contrary, the "update first" approach followed by intersecting CLC2018 and CLC2024 would provide differences of two datasets with 25 ha MMU. These differences should be edited to get the real changes. Moreover, isolated changes in the 5 ha – 25 ha size range will be neglected.

Text box 2:

What does "Change mapping first" method mean?

"Change mapping first" means that changes are interpreted directly, based on comparison of reference images. Visual comparison of IMAGE2018 with IMAGE2024 satellite imagery (with CLC2018 vector data overlaid for spatial reference) is followed by direct delineation of change polygons.

Practically, if change occurred to a CLC2018 polygon, it should be transferred to the database of CLC changes, where the changed part will be delineated and kept as polygon (***Figure 4***).

At the end of process CLC-Change$_{2018\text{-}2024}$ polygons will be combined with CLC2018 polygons in GIS to obtain the CLC2024 database.

Necessary thematic/geometric correction (revision) of CLC2018 data must precede the delineation of change polygons to avoid error propagation from CLC2018 to CLC2024. See proposed correction of CLC2018 in Ch. 4.2.2.1.

Consequently, change mapping consists of two steps, namely:

- **CLC2018 correction (revision) and**
- **interpretation of changes that occurred between 2018 and 2024.**

The two processes can be carried out consecutively or in parallel, but on the level of individual polygons correction (revision) must always precede change delineation (see Ch. 4.2.2.1).

The basis of identification of changes is the interpretation of visually detectable land cover differences on satellite images taken in 2018 and 2024. Ancillary data, such as topographic maps, orthophotos, HR layers (derived from satellite imagery), LPIS data, Google Earth imagery etc. are highly recommended to use (see Ch. 5).

Delineation of changes must be based on CLC2018 polygons to avoid creation of sliver polygons and false changes when producing the CLC2024 database. This means that during interpretation of changes CLC2018 polygons must be visualised and used by the interpreter so that outlines of CLC-Change$_{2018-2024}$ polygons exactly fit CLC2018 boundaries (***Figure 4***).

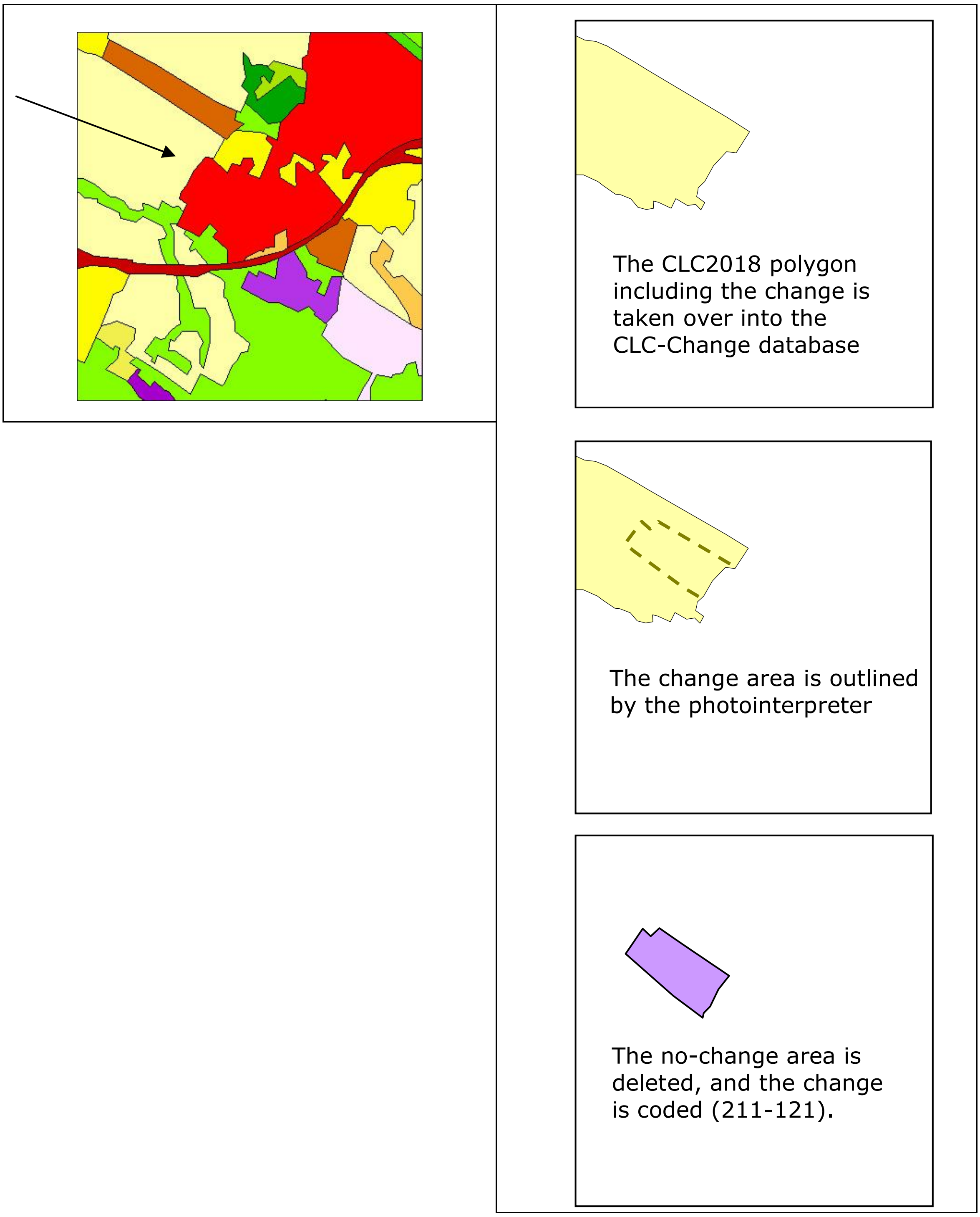

Figure 4 Realisation of the change mapping first approach (see also *Text box 2*) - the polygons of the old status layer used as basis for change delineation (as also applied by the InterChange software [16], [17]).

Interpreter must give two CLC codes to each change polygon: $code_{2018}$ and $code_{2024}$, both included as separate attributes. These codes must represent the land cover status of the given polygon in the two dates respectively. **Change code pair thus shows the process that occurred in reality** and may be different from the codes occurring in the parent layer and / or in new CLC databases (due to generalisation applied in producing CLC2018 and CLC2024). See *Text box 3*.

Text box 3:

What does it mean: Change code pair should show the process that occurred in reality and may be different from the codes occurring in the parent layer and / or in new CLC database?

Example:

Think about a 243 polygon in CLC2024 including small (<25 ha but > 5 ha) agriculture land and small patches of forest.

One of the forest patches (>5 ha) inside the polygon has been cut between 2018 and 2024.

The real change that has to be mapped is: 311-324, and not 243-324 (being a false change). Note, that the CLC2018 code should not be taken over automatically into CLC2024!

In CLC2024 the small (<25 ha) 324 polygon will be generalised to yield a 243 polygon.

In this example both attributes of the CLC-change polygon are different from $code_{2018}$ as well as from $code_{2024}$. Moreover, if we compare CLC codes in CLC2018 (243) and CLC2024 (243) no change will be seen.

See more in Ch. 4.3.1 /Real change

4.2.1 Input vector data

There are two input vector layers to be used in implementation of CLC2024 change mapping. The first and most important of these is the CLC2018 database. Like in previous CLC exercises, a border-matched version of CLC2018 data has been produced by EEA to eliminate inconsistencies along state boundaries. As most of the borders were already matched during the CLC2000 and CLC2006 projects, only a limited level of border matching took place this time.

For consistency reasons, all countries participating in CLC2024 update are expected to start the work with CLC2018 data extracted from the latest version of integrated European CLC2018 dataset.

In order to support this, border-matched CLC2018 and CLC-$Change_{2012-2018}$ data (vector format, national projection) for all participating countries will be available for download from a link to be provided to CLC2024 implementing organizations/entities.

4.2.2 Particular requirements concerning CLC2024 mapping

There are particular requirements of change mapping that might be mentioned in previous technical guidelines, but (as shown by experience gathered during the CLC2018 verification process) probably not emphasised enough. These are gathered below. Additional requirements related to the subdivision of 121 class are described in Chapter 4.1.1 above.

4.2.2.1 CLC2018 revision

Occurrence of interpretation mistakes is an inherent characteristic of visual interpretation of remote sensing data, coming not necessarily from negligence, but from insufficient information. During the update process, by examining newly available satellite images or ancillary data, usually a number of thematic mistakes are discovered in the database to be updated. To avoid error propagation into CLC2024, mistakes discovered in CLC2018 should– in locations of changes absolutely necessary to - be corrected.

These are:

1. Systematic mistakes known from the previous inventory but not yet corrected and the ones discovered during the recent change mapping (or verification). These are relatively easy to find by searching for the codes that show systematic mistakes. Systematic improvement of geometry can also be included here.
2. Random mistakes. These are usually ad-hoc mistakes discovered during change mapping or can be systematically searched for by visually browsing the CLC2018 map in scale 1:30.000-40.000.

In case national team decides not to modify previously submitted CLC2018 data, the tool of technical change can be used for revision. Technical changes are polygons in the change database having identical codes for 2018 and 2024. If used for revision, technical changes can be larger than 25 ha. E.g. if a 50 ha polygon is coded as technical change (121-121) (see Ch. 4.3.1/ Technical change), it means that 50 ha industrial area was not mapped in CLC2018. By means of using technical change CLC2024 will include this 50 ha industry as correction.

The process of CLC2018 revision can be done either before starting change mapping or in parallel with change mapping (depending on the software used). However, interpreter must make sure that revision (correction) of an individual CLC2018 polygon is always done before a change is mapped in the same location.

In CLC2024 – due to financial limitations and to speed up the photointerpretation phase - the revision process (i.e. correction of CLC2018) has been simplified.

The following mistake types **will be ignored** during verification:

- Random interpretation mistakes not associated to a CLC change.
- Residual mistakes in geometry (< 5 ha) due to the CLC mapping rules (i.e. change areas <5 ha were not mapped in CLC2018), if not associated to a change between 2018 and 2024.

However, **corrections are strictly expected** in the following cases:

- Mistakes in CLC2018 discovered in location of changes.
- Systematic mistakes (mistake type having 10 or more occurrences in a WU of 2500 km2), especially the ones coming from wrong understanding and application of specific CLC class(es).
- A few cases of significant mistakes in CLC2018 reported by users (following a specific request by EEA

The following mistakes **are recommended to be corrected**:

- Mistakes of delineation among level-1 classes (e.g. artificial-agriculture border, water-land border, >25 ha missing artificial area misclassified as agriculture), as these significantly spoil the credibility of the product among users

4.2.2.2 CLC change interpretation

4.2.2.2.1 Geometry

The mapping of CLC changes must be done using the geometrical basis of CLC2018 polygon layer. The outline of change polygons must therefore match CLC2018 polygon border, otherwise false changes and geometric mistakes occur. This means that firstly, there should not be any narrow channels between or slivers around change polygon outlines and CLC2018 polygon outlines (***Figure 5***); secondly, change polygon outlines should not criss-cross over CLC2018 outlines (***Figure 6***). These mistakes can be most easily avoided by applying the recommended method of change mapping: taking over polygons from CLC2018 to change database, then drawing changes, then discarding not changed parts (***Figure 4*** above).

Topological consistency must be kept. Change polygons should not overlap each other.

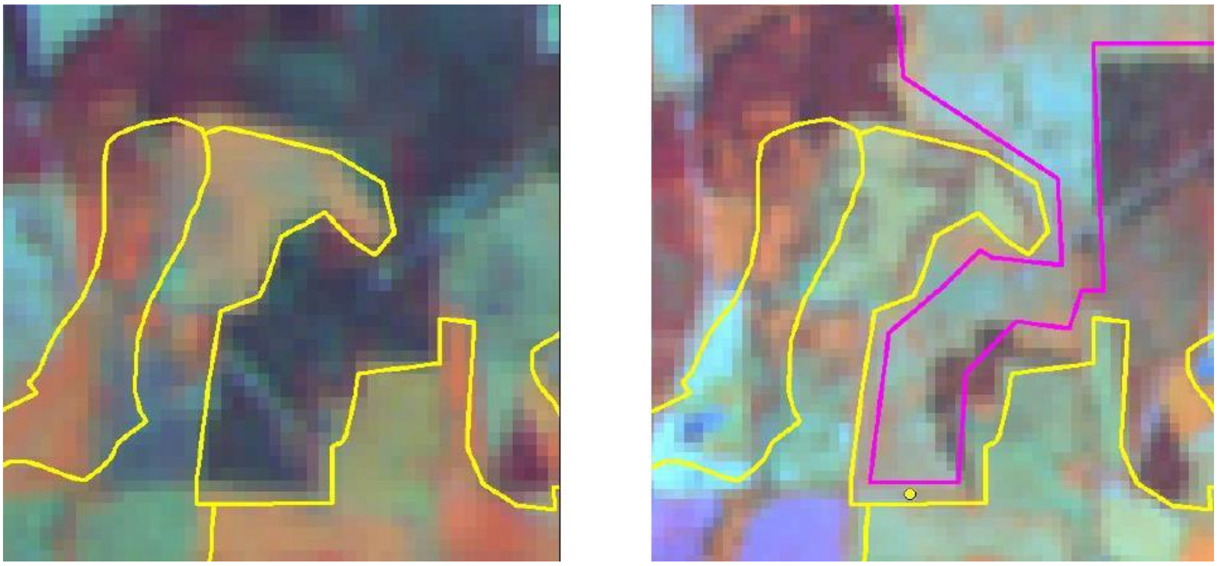

Figure 5 **Mistake:** Narrow channel between change outlines (right side, magenta) and CLC status layer outlines (yellow)

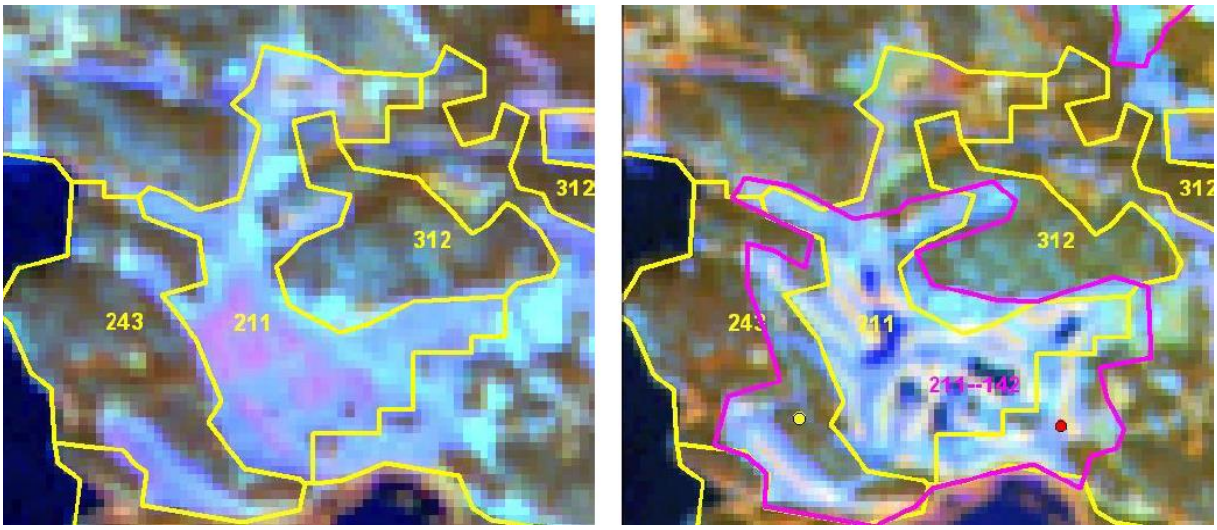

Figure 6 **Mistake:** Change outlines (right side, magenta) not matching CLC status layer outlines (yellow)

4.2.2.2.2 Coding

Interpreter should give two codes to each change polygon according to what is visible on the relevant imagery, one representing land cover in 2018 and the other in 2024. Change codes should always represent the change process that happened in reality. This means that codes can be different from respective codes in CLC2018 and CLC2024 databases (see also *Text box 3*).

When assigning the codes, the interpreter must be able to always answer the question: what is the process described by the code I gave? Is this process the same I see on the image pair? Is this really a CLC change? This way interpreter can avoid mapping seasonal differences as change or giving attributes that are meaningless on the field. See more details in 4.3.1/Real change.

4.2.2.2.3 Image dates

To avoid mapping seasonal differences as change, the interpreter should always be aware of image dates (year and month, at least). The best way to achieve this was to include image date in the image file name, so that it is visualised all the time. It is the same reason that makes image mosaics of limited use for CLC change mapping; in a mosaic, image dates are hard or impossible to check and radiometry (colours) are often strongly distorted. Knowing image dates is especially important in the following cases:

- Mapping vegetation of mountainous areas: vegetation reaches its full development / foliage cover only around June, so earlier images might mislead the interpreter.
- Mapping hot and dry (Mediterranean and strongly continental) areas: vegetation usually dries out by early summer, which is otherwise the "standard" date of images for land cover mapping. Thus vegetation (arable crops, grassland) is not detectable on such images, or it is almost impossible to distinguish arable fields from patches of natural grassland or even sparsely vegetated areas. Therefore, additional images from April/May are highly recommended to use in such areas (e.g. Iberian Peninsula, Anatolia). The same is true for distinguishing natural grassland areas from sparsely vegetated areas or bare rocks.
- Mapping changes of water bodies, especially reservoirs: being unaware of image dates might lead to mapping seasonal water level fluctuations (lakes shrinking due to summer heat and water take-up for irrigation) as permanent changes, which is a mistake. Same is true for Alpine rivers, where highest water level occurs in spring/early summer, due to snow melt.
- Mapping glaciers and permanent snow: images from not exactly the same date (optimally the date of smallest snow extent: late August or early September) are not comparable, thus using them leads to mapping false changes.

4.2.2.2.4 Nomenclature

Lessons learnt during previous CLC inventories and the respective verification processes have resulted in the creation of an enhanced version of the CORINE Land Cover nomenclature guidelines in 2017. It is required that the latest version of this document is used [6]. An online (html) version of the document is also made available.

4.2.2.2.5 Mapping changes of the 121 class (Industrial or commercial units and public facilities

As described in Chapter 4.1.1, a novelty of CLC2024 inventory is the voluntary mapping of photovoltaic power stations (solar parks) newly established between 2018 and 2024 on formerly non-built-up ground.

In case, the national team decides to engage in this voluntary extra work, and expresses its willingness to do so, the following rules apply:

- Only newly (between 2018-2024) established free-field solar parks need to be mapped, i.e. mapping should be done in the CLC-Change$_{2018-2024}$ dataset, but not in the CLC2018 (revision) dataset.
- The mapping should be done consistently, for the whole country territory, subdiving CLC class *121 – Industrial or commercial units and public facilities* into two level-4 subclasses in the CLC-Change$_{2018-2024}$ dataset:
    - *1211 – Industrial, commercial or public units other than free-field solar parks*

- *1212 – Solar parks mounted on formerly non-sealed ground (free-field solar parks).*

  In the CLC-Change$_{2018-2024}$ dataset code 121 will be considered invalid by the verification.

- General rules of change mapping apply (real changes should be mapped, codes should describe the real evolution process, geometry must match revision polygon outlines etc.). This also implies, that change between the two subclasses 1211 and 1212 is also possible, e.g. when solar panels (1212) are erected on a non-sealed part of an existing industrial unit (1211). (Note, that change polygon codes can be different from revision dataset's "mother polygon" code.)
- Resulting polygons will be extracted and delivered as a separate layer for exploring further use, while in the official European delivery they will be generalized into level-3 class 121. Main technical parameters must be fulfilled for the delivered level-3 dataset, which implies that rules of complex changes apply to mapping these level-4 changes. I.e. if one elementary change 211-1211 neighbours another elementary change 211-1212, and together make up a >5 ha new 121 area, the elementary changes can be <5 ha.

The visual photointerpretation software CLC2024 Support Package (InterChange) supports the application of level-4 classes.

4.3 PHOTOINTERPRETATION OF CHANGES

4.3.1 Introduction: figures and definitions

In the following chapter, schematic figures give guidelines on the way of interpreting changes. On these illustrating figures (***Figures 7-26***) the same legend is applied. Colour polygons represent patches visible on the satellite image(s). Polygons with thick solid outlines represent land cover patches that form a CLC polygon at the given database. These are also marked with the corresponding CLC code. Polygons with dashed outline show patches whose land cover has changed. Patches without an outline represent patches of land cover that do not form valid polygon in the given database.

Each explanatory figure consists of four boxes:

- First box shows the land cover status visible on IMAGE2018 and the polygon outlines in CLC2024 database.
- Second box shows the land cover status visible on IMAGE2024 without polygon boundaries. Dashed outline marks patches that have changed.
- Third box shows polygons to be drawn in the CLC-Change database. Polygons marked with red T will be deleted from the final CLC-Change database (see term "technical change" below).
- Fourth box shows the polygons as present in CLC2024 database (as the results of GIS addition of CLC2018 and CLC-Change$_{2018-202}$4 – see Ch. 6).

<u>Patch</u>

Patch is a continuous area having a common CORINE land cover type in reality and being recognizable on the satellite image(s). A patch becomes a valid CLC polygon only if its size exceeds the MMU.

<u>Direct delineation of changes</u>

Change polygons are drawn directly on the corresponding image by means of CAPI and not generated by GIS operation (intersection of databases) – see also in Ch. 4.2. Human expertise has control over the whole procedure thus helping to avoid creation of impossible or false change polygons.

Real change

Change polygons do not necessarily have to inherit their $code_{2018}$ and $code_{2024}$ from the corresponding CLC2018/CLC2024 polygon but can be different from those. Interpreter is supposed to attribute to the change polygon the $code_{2018}$ / $code_{2024}$ code pair that best describes the process that the given land cover patch has undergone in reality (see also *Text box 3*). Code pairs thus reflect real processes instead of differences of two databases (***Figure 7***).

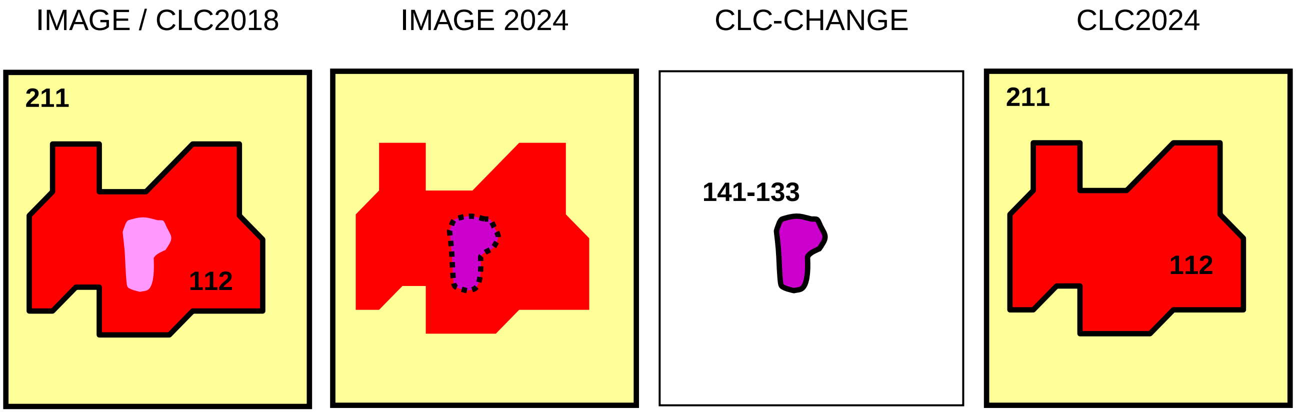

Figure 7 Principle of interpreting real change: the loss of urban green (141) < 25 ha by becoming a construction site (133) must be coded 141-133 in the CLC-Change database, although the patch is generalised into discontinuous urban fabric (112) in both CLC2018 and CLC2024.

Technical change (T)

Technical change polygon is an auxiliary change polygon used for avoiding some major (minimum 5 ha, maximum 25 ha) imprecisions of CLC2018 database. They are applied exclusively in the cases listed in the change typology (***Table 16***, types E & F[29]), and they are not numerous. Technical change polygons do not represent a change of land cover in reality but are consequences of the two different MMUs of CLC-Change (5 ha) and of CLC status layers (25 ha). They are used only in order to allow creation of a new polygon in CLC2024 by GIS operation, after this they are deleted from the CLC-Change database.

Technical change polygons are drawn by the interpreter during change mapping over those patches with size between 5 ha and 25 ha[30] and width ≥ 100 m:

- whose land cover has NOT changed between 2018 and 2024 (although might include < 5 ha changed patches);
- that are not present as polygon in CLC2018;
- but we want them to exist as polygon / part of polygon in CLC2024.

Technical change polygons must be given **identical $code_{2018}$ and $code_{2024}$ AND an additional attribute** that makes them identifiable and makes possible to select them automatically. The attribute added to each change polygon should be named "technical", having a value 1 if the change polygon is technical, and value 0 if not.

The operation of identifying and delineating technical changes requires that interpreter envisages the CLC2024 database in advance while interpreting CLC-$Change_{2018-2024}$.

The terms "changes" and "change polygons" without the tag "technical" in this document always mean real changes.

29 Illustrated and further explained by Figures 14 and 15.
30 An alternative (exceptional) application of technical change was mentioned in Ch. 4.2.2.1 for correcting CLC2018. In this case the size of technical change polygon is not limited to below 25 ha.

Complex change, elementary changes

Although the MMU for change mapping is 5 ha, in some cases change polygons < 5 ha are also mapped. When a new polygon is formed by taking area from several other polygons (e.g. a road construction), the individual connected change parts can be mapped even if they are < 5 ha, given that they altogether make up a > 5 ha complex change polygon. Elementary changes must have a common code either in 2018 or in 2024 and must make up altogether > 5 ha (***Figure 8***).

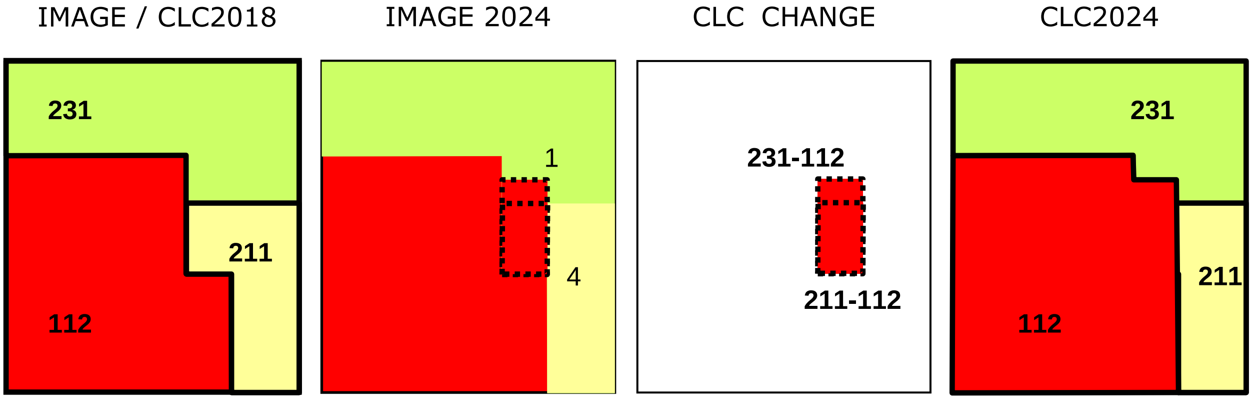

Figure 8 Complex change and elementary changes: Settlement (112) has taken 1 ha area from pasture (231) and 4 ha from arable land (211). These two elementary changes make up a complex change of 5 ha.

4.3.2 Most frequent thematic problems in mapping CLC-Changes

Photo interpreters must be aware that not all changes visible on the satellite images are treated as change by CLC approach. The situations and phenomena most frequently causing mistakes are listed below. See more details in [17]:

- transient phenomena such as floods and temporary water-logging;
- seasonal changes in natural vegetation, such as difference of biomass;
- seasonal changes in agriculture, such as effects of crop rotation on arable land;
- forest plantation growth, still not reaching the height and / or canopy closure of forest;
- changes of water level of Mediterranean / Alpine / karstic water bodies;
- temporal changes in water cover of fishpond cassettes being part of their management;
- changes in distribution of patches of reed and floating vegetation in marshes;
- seasonal changes of snow spots in high mountains.

The introduction of false changes must also be avoided. Many of these can and should be excluded by pure logics. These vary from country to country (e.g. while sea water does not normally change into pasture, it might happen in the Netherlands), thus following examples are not exhaustive and not binding for all cases. However, in the overwhelming majority of cases they can be considered valid.

Highly non-probable changes are for example (not a complete list, see more examples in [17]):

111 -> 112,121,131,132, ...	Densely built-up areas seldom disappear
2xx-324, 321-324	Agriculture classes and natural grassland cannot be interpreted as burnt (by definition, see nomenclature [6])
322 -> 323	Bushy vegetation of different climatic zones does not change to each other
411 -> 412	Peatland needs longer than 10 years-long time to develop.

4.3.3 Change typology – guidelines for interpretation

The rule of thumb of CLC2024 change mapping approach is that **ALL changes larger than 5 ha should be delineated regardless of their position** (whether being connected to existing an CLC2018 polygon or being island-like, see Ch. 4.2). To understand the context better, a typology of changes was created dividing all change cases into one of the following 8 theoretical types. Three databases play a role in CLC update:

- revised CLC2018, which cannot contain polygons < 25-ha,
- CLC-Change$_{2018-2024}$, which cannot contain polygons < 5-ha (except elementary changes, see ***Figure 8***).
- CLC2024, which cannot contain polygons < 25-ha and is created using the previous two.

Based on existence / non-existence of a corresponding polygon in each of the three databases (CLC2018, CLC-Change$_{2018-2024}$, CLC2024) a typology of changes can be created [11].

Let us assign an L logical variable to each patch, which has a value of 1 (true) if the patch in its database reaches the corresponding size limit and consequently emerges as a polygon. The value of L is 0 (false) if the patch is below the corresponding size limit, and does not form a polygon in the database. *A* refers to area in hectares.

$L_{2018} = 1$	if	$A_{2018} \geq 25$ ha,	$L_{2018} = 0$	if	$A_{2018} < 25$ ha;
$L_{ch} = 1$	if	$A_{ch} \geq 5$ ha,	$L_{ch} = 0$	if	$A_{ch} < 5$ ha;
$L_{2024} = 1$	if	$A_{2024} \geq 25$ ha,	$L_{2024} = 0$	if	$A_{2024} < 25$ ha.

The decision table with logical variables corresponding to each of the three databases includes altogether $2^3 = 8$ different types (***Table 16***).

Table 16 Theoretical change types (T refers to technical change) [11]

Letter code	L_{2012} $A_{2018} \geq 25$	L_{ch} $A_{ch} \geq 5$	L_{2018} $A_{2024} \geq 25$	Short explanation	***Remark***
A	1	1	1	Simple change	*Occurs the most frequently*
B	1	0	1	Small change in existing polygon	*Occurs frequently;* ***not interpreted***[31] *-> max. 5 ha error in CLC2024*
C	1	1	0	Disappearance of polygon	*Seldom occurs*
D	1	0	0	Disappearance of polygon with small change	*Occurs very seldomly,* ***not interpreted*** *-> max. 5 ha error in CLC2024*
E	0	1	1	Emerging of new polygon	***T*** *is used to avoid > 5 ha <25 ha error in CLC2024*
F	0	0	1	Emerging of new polygon with small change	***T*** *is used to avoid > 20 ha < 25 ha error in CLC2024*
G	0	1	0	Change only	*Occurs frequently*
H	0	0	0	Small change only	***Not interpreted***

Hereafter we give guidance on the way of handling each of the above types, illustrating them with examples. Of course, no universal recipe can be given for any of the cases. Thus, the following examples are schematic (they show a simplified reality) and do not list all possible combinations of codes and sizes. However, any change case falls under one of these theoretical types. The examples do not deal thoroughly with questions of generalisation, as these are well described in the CLC nomenclature document [6]. For figure legend see Ch. 4.3.1.

A. Simple change: a polygon > 25 ha in CLC2018 grows or decreases with a change > 5 ha, resulting a polygon > 25 ha in CLC2024

Being the most frequently occurring change type, changes > 5 ha connected to an existing (> 25 ha) CLC2018 polygon are always mapped (***Figures 9 and 10***).

31 Does not need to be included in the change database

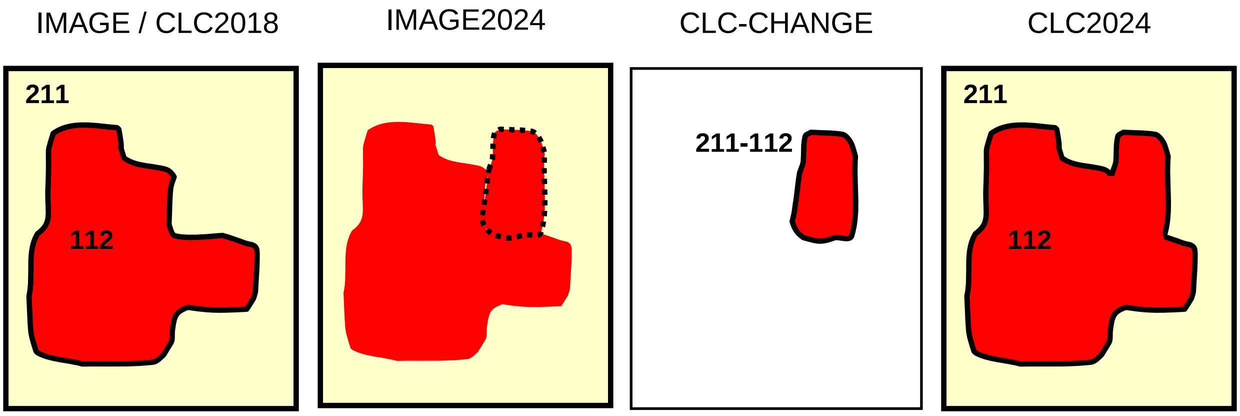

Figure 9 Simple change (growth): A settlement (112) > 25 ha grows with > 5 ha, occupying arable land (211)

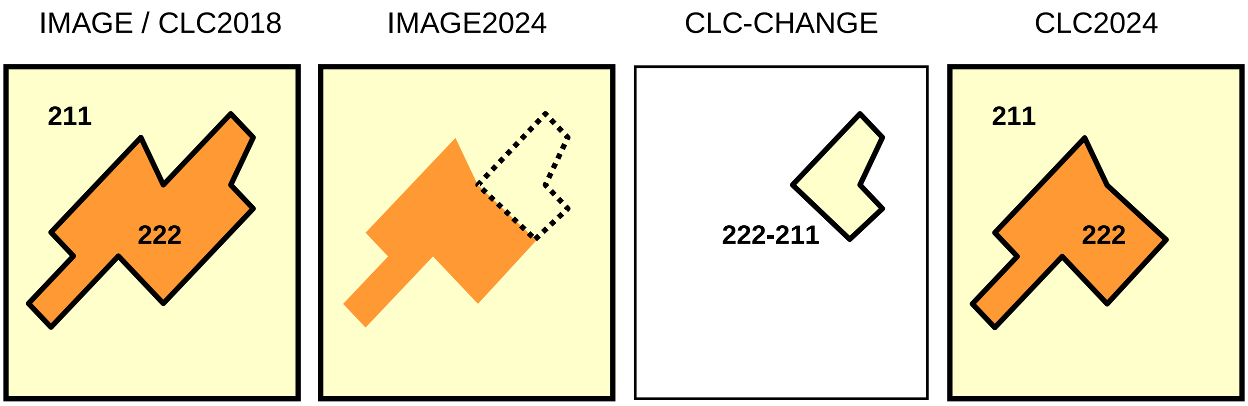

Figure 10 Simple change (shrinkage): A fruit orchard (222) > 25 ha decreases with > 5 ha, while area of arable land (211) is increasing. The resulting 222 polygon is still > 25 ha in 2018.

Following their delineation, change polygons must be given a $code_{2018}$ and a $code_{2024}$ representing the processes having occurred to the given patch in reality (see explanation at „real change" at Ch. 4.3.1).

B. Small change in existing polygon: < 5 ha change in polygon > 25 ha

No change polygons < 5 ha should be mapped except if they are elementary changes of a complex change > 5 ha (Ch. 4.3.1. and ***Figure 8***).

Remark: 10% exaggeration in size is allowed (i.e. 4,5 ha new industry is better to enlarge to 5 ha in order to keep it in CLC-Change).

C. Disappearing polygon: a polygon decreases to <25 ha with a change > 5 ha

If due to a change > 5 ha the size of a polygon decreases under 25 ha, it will disappear in CLC2018 because of generalisation, while the change polygon remains in CLC-Change. Only the part that has really changed must be delineated during change mapping (***Figures 11 and 12***).

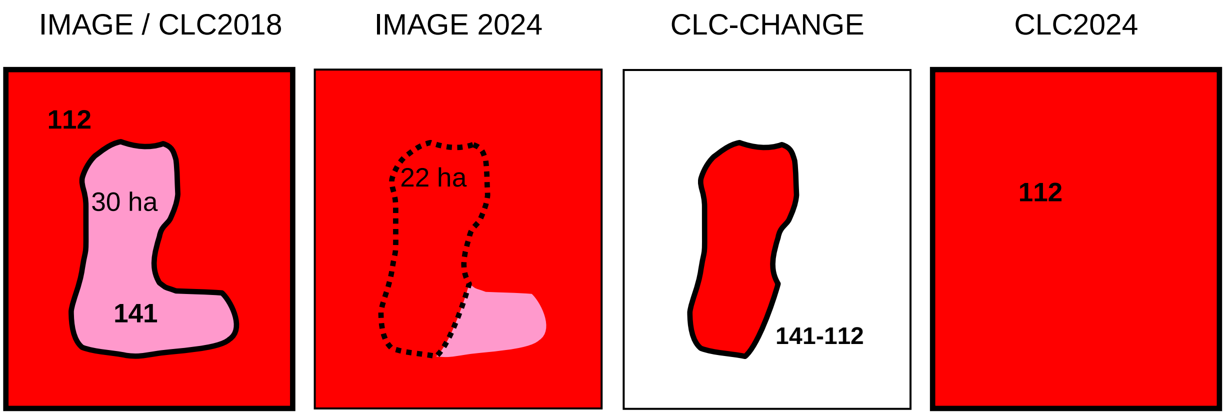

Figure 11 Disappearing polygon, case-1**:** Most of the area of a park (141) is built up so that the park's size actually decreases under 25 ha. Consequently, what is left of it is generalized into the settlement (112) in CLC2024.

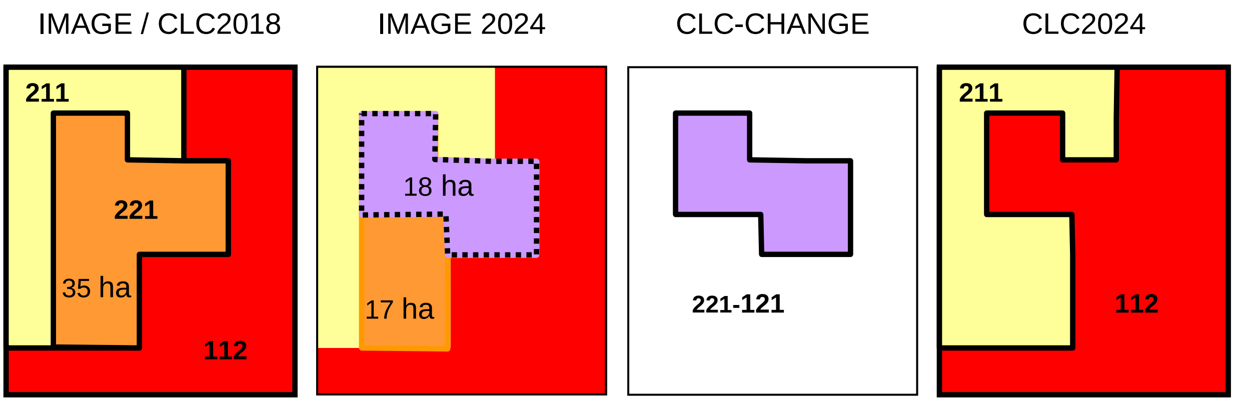

Figure 12 Disappearing polygon, case-2: Significant (> 5 ha, but < 25 ha) part of a vineyard (221) is occupied by new industry (121). A change polygon coded 221-121 is delineated in CLC-Change database. The area left from the vineyard is < 25 ha. Consequently, in CLC2024 the remaining vineyard and the new industry is generalized into arable land (211) and urban fabric (112), respectively.

D. Polygon disappearing with small change: a polygon decreases to < 25 ha with a change < 5 ha

In a few cases, existing polygons decrease to a size < 25 ha with a change < 5 ha. As change is < 5 ha, the changed patch should not be delineated. This causes a minor (< 5 ha) mistake in CLC2024.

Remark: 10% exaggeration in size is allowed (i.e. 4.5 ha new residential area is better to enlarge to 5 ha in order to keep it in CLC-Change).

E. New polygon: a polygons grows > 25 ha with a change > 5 ha

The simplest case of this type is the emerging of a new patch > 25 ha (***Figure 13***).

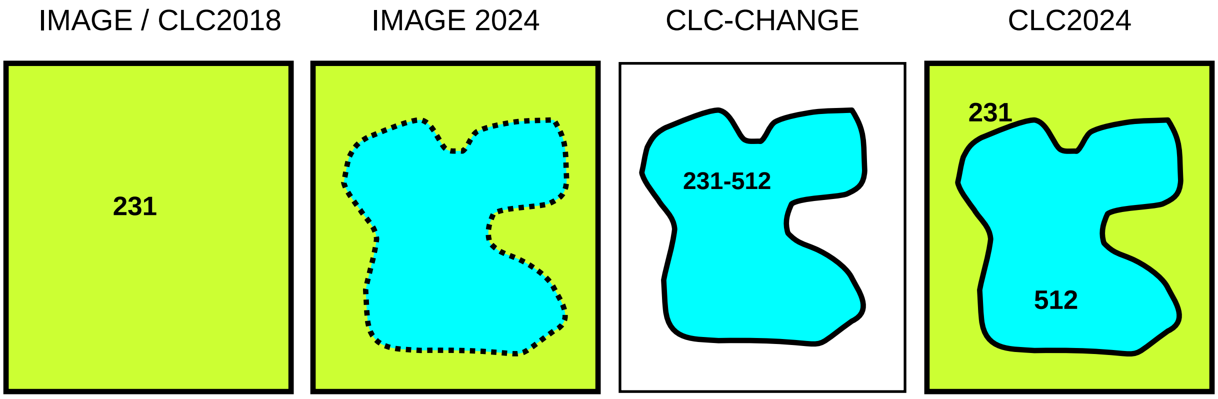

Figure 13 New polygon: A > 25 ha new fishpond (512) is established on former pasture (231).

If a patch that existed in 2018, but used to be < 25 ha (thus not mapped in CLC2018) grows with a change > 5-ha so that it exceeds the 25-ha limit in 2018, a so-called „technical change" polygon must also be applied. Besides delineating the real change (grown part of the polygon), the non-changed (originally existing) part must be delineated as well, with identical $code_{2012}$ and $code_{2018}$ and an additional attribute marking it as technical change. Using up the two types of change polygons, the patch will be included in CLC2024 automatically, whereas the technical change polygon will be deleted later from the final CLC-Change database (***Figure 14***). (For more information on technical changes see its definition at Ch. 4.3.1).

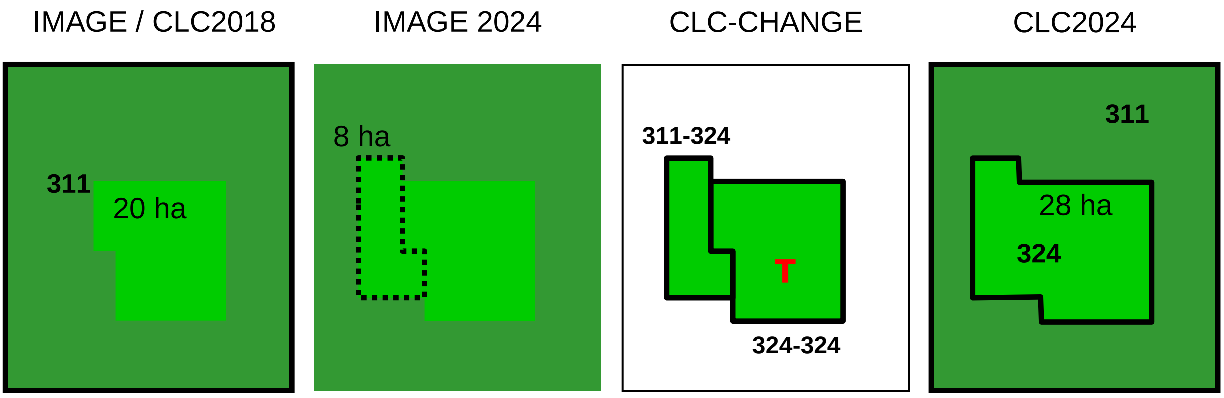

Figure 14 New polygon with Technical change, case-1: A 20 ha forest clearcut (324) grows with 8 ha. As a result, the clearcut's area exceeds 25 ha. Two change polygons must be delineated: an 8-ha real change (311-324) and a 20-ha technical change (324-324). The technical change will be deleted from final version of CLC-Change, while the corresponding change polygons will make up a 324 polygon in CLC2024.

To avoid inaccuracies being introduced into CLC2024, the same method is applied also in cases when the real change is > 25 ha so that it would make up a new polygon itself in CLC2024. This case too, a real change polygon must be drawn over the changed ("new") part and a technical change polygon must be drawn above the non-changed ("already existing") part if > 5 ha (***Figure 15***).

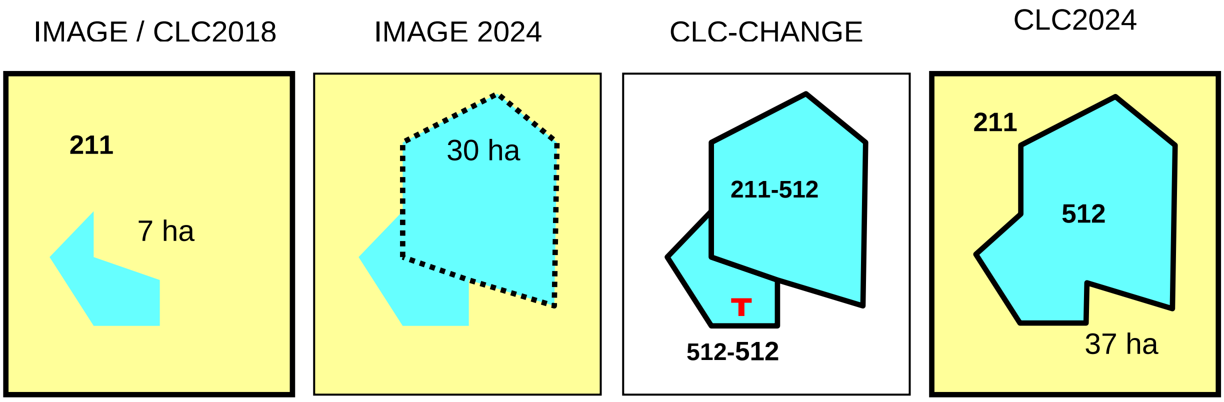

Figure 15 New polygon with Technical change, case-2: A 7 ha fishpond (512) grows with 30 ha. Although the change is > 25 ha, so the polygon would be enough to form new polygon in CLC2024, in order not to miss the 7-ha part, a technical change polygon (512-512) must also be delineated. This will be deleted from final version of CLC-Change, while CLC2024 will contain a correct 37 ha water body (512) polygon.

A special case of this type (combined with type C) is the code change of a polygon (***Figure 16***).

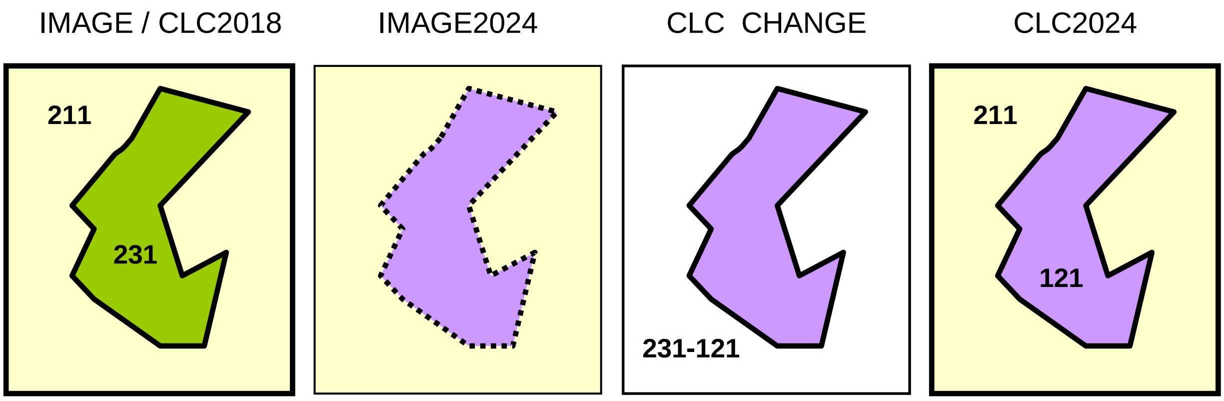

Figure 16 Code change: A new industrial unit (121) is built on a > 25 ha pasture (231), totally occupying its area. With a change 231-121 the pasture disappears, while a new industry emerges.

F. New polygon with small change: a polygon grows > 25 ha with a change < 5 ha

In the few cases when polygon grows over 25 ha with a real change < 5 ha, the real change should be added to the technical change polygon as well. Without using technical change, we would introduce a major (between 20 and 25 ha) mistake into CLC2024 (***Figure 17***). Using technical change, the newly appearing polygon will be included in CLC2024, while the change database will not contain any polygon here (no real change > 5 ha).

Remark: 10% exaggeration in size is allowed (i.e. 4.5 ha new sport and recreation area is better to enlarge to 5 ha to keep it in CLC-Change; it leads to case E).

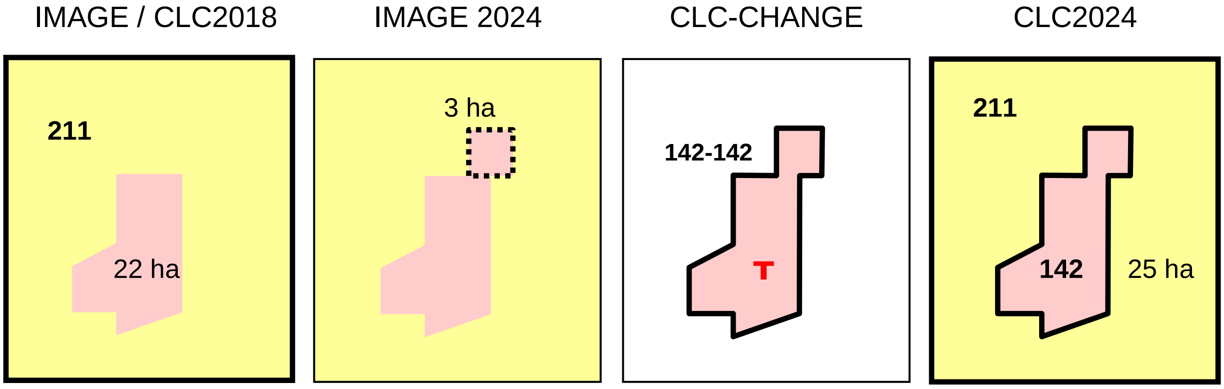

Figure 17 New polygon with small change: A 22 ha sport facility (142) grows with 3 ha, thus just reaching the 25 ha MMU. As changed part is < 5 ha, no real change polygon must be delineated. The polygon should however appear in CLC2024, so a 25-ha technical change (142-142) polygon must be drawn.

G. Change only: changes in a non-existing polygon

This type includes cases when the change polygon is not connected to a valid polygon neither in CLC2018 nor in CLC2024, while valid (> 5 ha) change occurred. This type of change also must be coded according to their real change process (***Figures 18 and 19***).

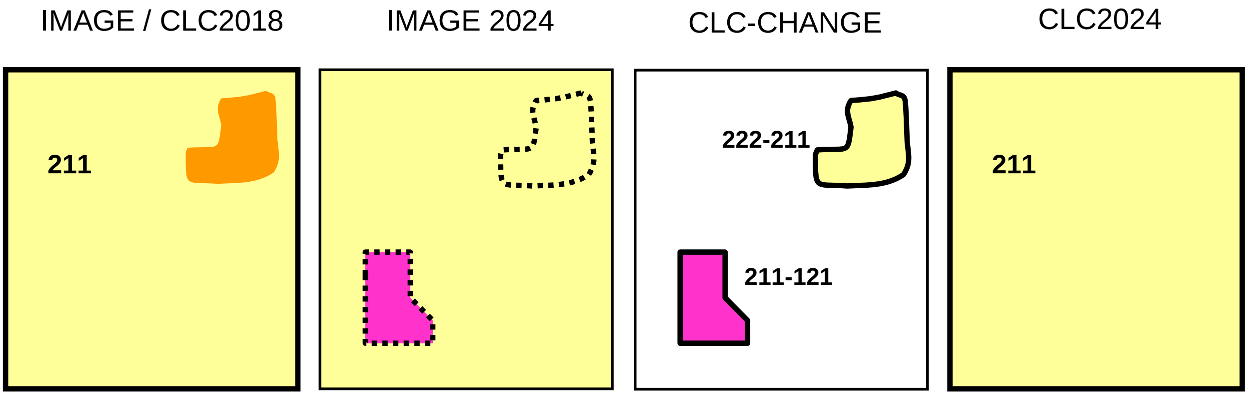

Figure 18 Changes in non-existing polygons, case-1: A new small industrial unit (121) > 5 ha is built on former arable land (211), while a small patch of fruit orchard (222) > 5 ha disappears because of being turned into arable land (211). Both patches must be delineated as changes (211-121 and 222-211), as being > 5 ha. No new polygons emerge in CLC2024, as corresponding change polygons are generalised.

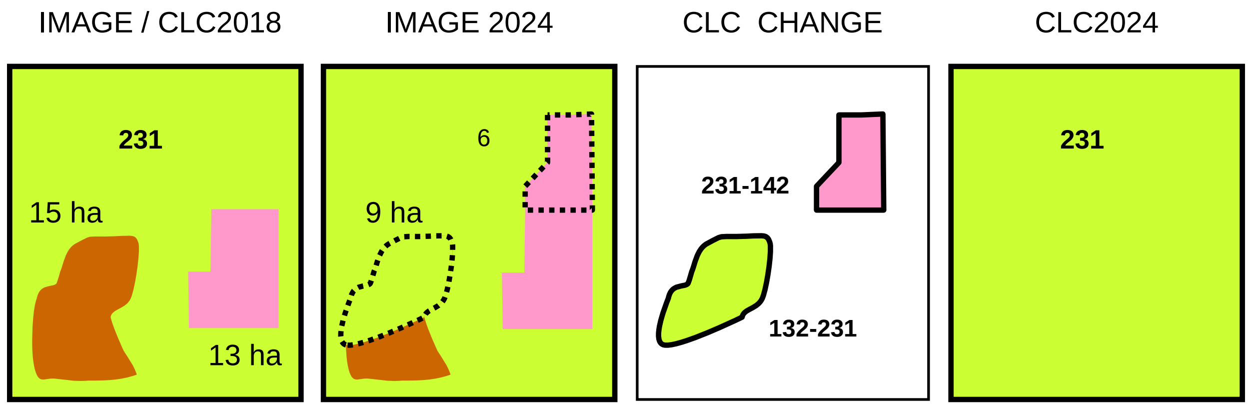

Figure 19 Changes in non-existing polygons, case-2: A 13 ha sport facility (142) expands with 6 ha, while in the neighbourhood 9 ha of a 15-ha dumpsite (132) is recultivated by being turned into grassland (231). Both changed areas are >5 ha thus resulting a valid polygon in CLC-Change database. However, none of them result a > 25 ha polygon in 2024.

H. Small change (< 5 ha) in not existing polygon (< 25 ha)

As polygons in all three databases are smaller than their respective area limits, this case should not be dealt with.

4.3.4 Treating changes in, by-definition, heterogeneous classes – changes at landscape level

CLC nomenclature includes some land cover classes that, by definition, represent heterogeneous landscapes, thus certain polygons are made up of a mosaic of smaller homogenous patches, most of them < 25 ha. This means a shift from a dominantly feature-level mapping generally applied by CLC to a landscape-level approach especially for classes: 242, 243 and 313.[32] If individual land cover changes occur within polygons of these classes in a way that they altogether change the characteristics of the area on a landscape level, then change polygons should be delineated on a landscape level, too. Let us take for example a 243 polygon, being mostly agricultural landscape with mosaic of small (< 25 ha) patches of semi natural features: forest, bushes, wetlands and / or natural grassland. If a few of the bushes are cut and turned into arable land, the main character of the polygon does not change, it is still an agricultural landscape with significant amount of natural features. This case changes must be mapped individually as 324-211, thus they will represent real changes in the CLC-Change database, whereas in CLC2024 the 243 polygon will be left unchanged as new 211 patches will be generalized into 243 (***Figure 20***).

32 Heterogeneous classes are not to be confused with general rule of CLC mapping i.e. all classes might have some portion with different land cover. E.g. Discontinuous urban fabric (112) might include < 25 ha parks, water bodies, industry etc.

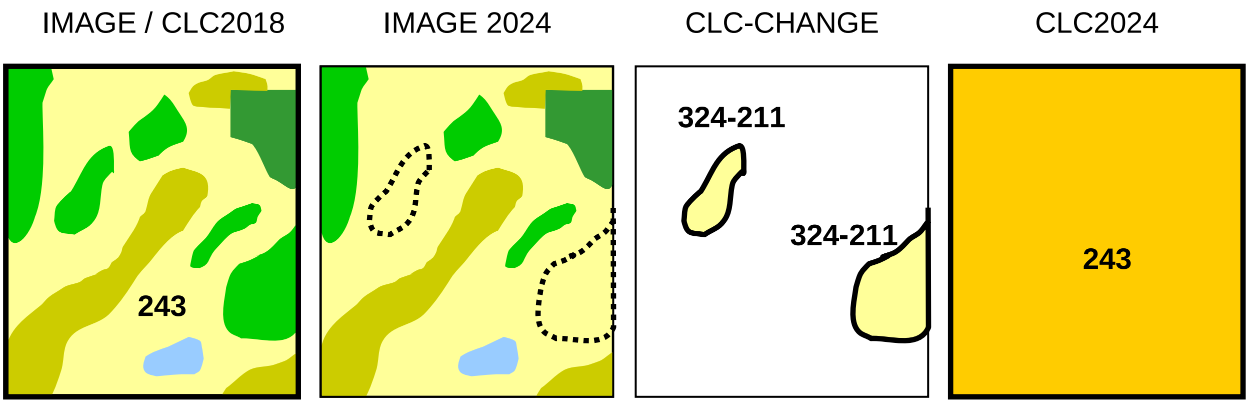

Figure 20 Changes in heterogeneous class 243 (no landscape level change): In a heterogeneous landscape (243) a few patches of semi-natural vegetation (324) are turned into arable land (211). As still significant area of natural vegetation is left, the character of the polygon does not change, it is still best characterised with code 243. Change polygons delineated must represent the real process (324-211). Due to generalisation, the 243 polygon will be left unchanged in CLC2024.

It might happen however, that due to an economic / social impact (say change in EU subsidies' system) or for some natural phenomena, all or most of the natural patches are turned into arable land, turning the whole landscape's character into agricultural. The area is not a mosaic of natural patches and agricultural land anymore, but mostly arable land. In this case the change happened at the landscape level, so the change polygon will include the whole area, its code pair being 243-211. It is only in these cases that the delineation of individual changes can be replaced by landscape-level change mapping (***Figures 21 and 22***).

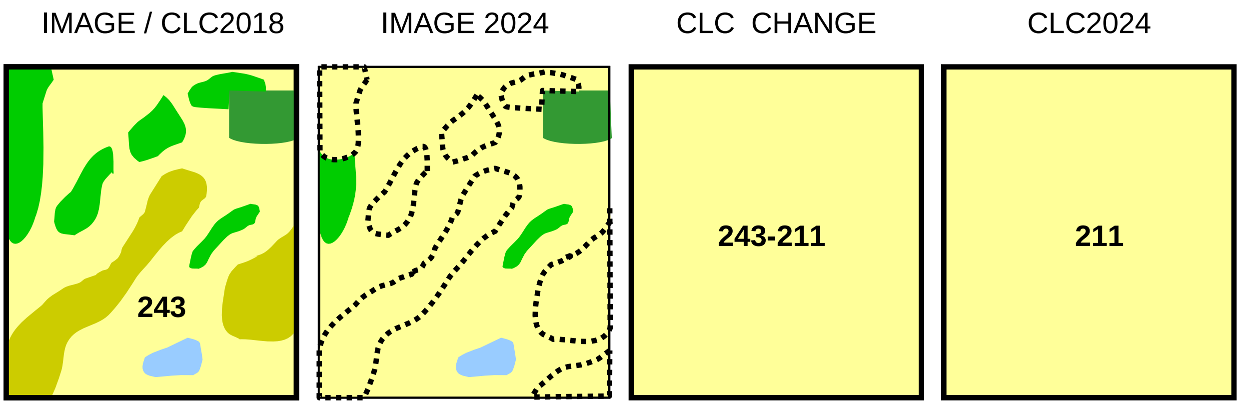

Figure 21 Changes in heterogeneous class 243 (landscape level change): In a heterogeneous landscape (243) most of patches of semi-natural vegetation (324, 321) are turned into arable land (211). As the area of natural vegetation left is not significant, the character of the whole area has changed. A 243-211 change polygon must be delineated.

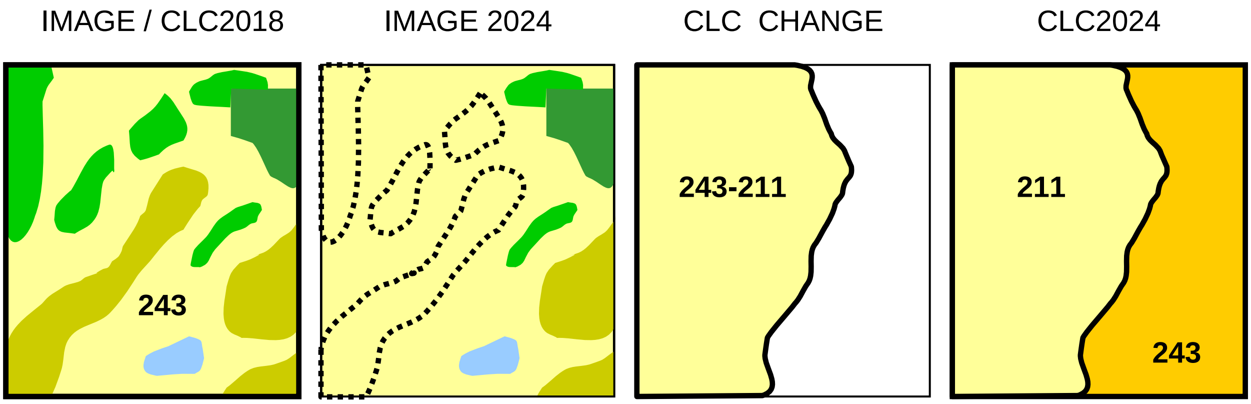

Figure 22 Changes in heterogeneous class 243 (landscape level change on part of the area only): In a part of a heterogeneous landscape (243) most of patches of natural vegetation (324, 321) are turned into arable land (211). The delineated change polygon (243-211) must cover only the changed part of the landscape.

Processes showing to the opposite direction (from homogeneous to heterogeneous landscape) should be treated similarly (***Figures 23 and 24***).

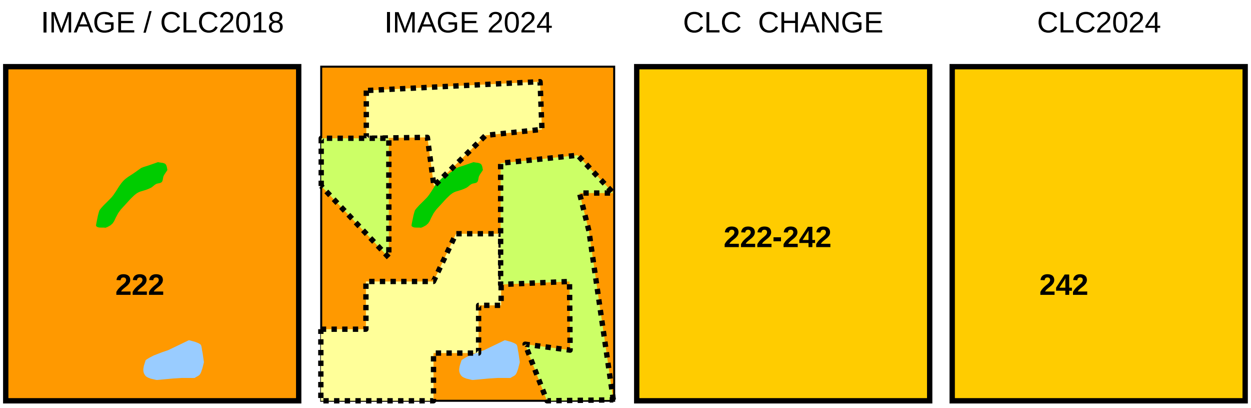

Figure 23 A homogeneous landscape turned into heterogeneous landscape: In an area dominantly occupied by orchards (222), a significant part of the plantations is cut and turned into arable land and pasture. The landscape becomes heterogeneous agricultural landscape (242); orchards do not dominate it anymore.

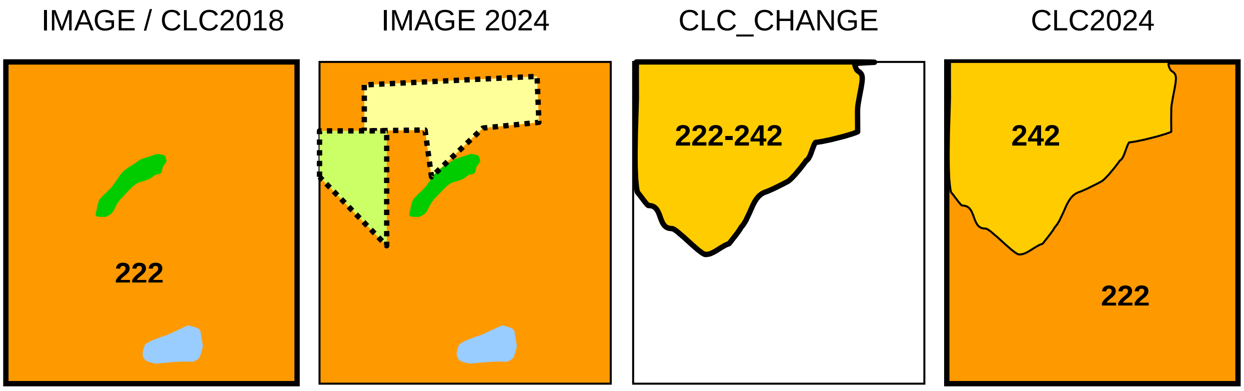

Figure 24 A homogeneous landscape partially turned into heterogeneous landscape***:*** If fruit tree plantations (222) are kept in a part of the same area, only the altered part should be delineated as change (222-242).

Similar approach should be applied for all three by-definition heterogeneous classes: i.e. 313, 242, 243.

4.4 CLC2024 Support Package (InterChange software)

The CLC2018 Support Package, specified by European Topic Centre on Urban, Land and Soil Systems (ETC ULS) has been successfully used by more than 31 national teams[33] in implementing CLC2018. It is a set of standalone applications developed with Embarcadero Delphi XE2 and TatukGIS Developer Kernel. Thus, user does not need to purchase, install and tune any other software to carry out CLC change mapping [15]. The CLC2018 Support Package, being a specialized, task-oriented software tool, significantly facilitated updating, change detection and mapping, quality control and correction of CLC databases by means of computer-assisted visual photointerpretation [16].

- The tool will be upgraded for the CLC2024 project, called CLC2024 Support Package [32]and will be provided to national teams.

Like its predecessors, the CLC2024 Support Package consists of two modules:

1. InterChange for interpreting land cover changes: Provides a tool for the revision of CLC2018 land cover database and supports the interpretation of land cover changes in order to create the CLC-Change$_{2018\text{-}2024}$ database. The program provides a convenient and easy-to-use interface for editing polygons in CLC2018 and CLC-Change$_{2018\text{-}2024}$ databases, for viewing and modification of polygon data and for finding and correction (revision) of errors generated during interpretation and editing. The software also supports "backward" mapping of changes, as well as the use of level-4 classes.
2. InterCheck for checking CLC databases: Serves the checking of revised CLC2018 (or CLC2024) and CLC-Change2018-2024 data. InterCheck program has been prepared primarily for supporting the CLC Technical Team, although national central teams might apply it as a tool for checking of the completed CLC2024 and CLC-Change2018-2024 databases. Many file formats are supported, not only those that has been prepared with InterChange.

User registration

CLC2024 Support Package will be available for all participating national teams free of charge. The submission of a registration form is the sole requirement of using the software. This (besides keeping record of users) enables developer to contact users in case an update of the software package is released. Download link for the registration form and the Support Package will be available for organizations / entities implementing CLC2024.

Like before, detailed help, and printable user's guide (in English) as well as user support are inherent parts of the package. ETC DI provides helpdesk service, similarly to the CLC2018 exercise. Helpdesk contact: barbara.kosztra@lechnerkozpont.hu

4.5 Alternative solutions for implementing CLC

During the implementation of the CLC2018 project some countries applied procedures different from visual photo-interpretation for deriving CORINE Land Cover data. These solutions aimed to reduce human workload by combining national GIS datasets, satellite image processing (IP) technology, on-screen digitization (visual photo-interpretation) and GIS-based generalisation. Most of these methods aimed to produce CLC status layer, but they were also successful in facilitating / partly solving the change mapping job.

These GIS/IP based alternative change mapping solutions are encouraged, if results are compatible (in terms of technical features and accuracy) with the standard method.

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33 Most of registered teams used both the interpretation and the verification modules of the software package, a few of them used only the InterChcek module, developed for quality control of datasets.

In case of change mapping major issues of non-compliance were as follows (as experienced during CLC2006, CLC2012 and CLC2018 verifications):

- Mapped changes are often not "real" changes, i.e. they do not represent a change that occurred in reality;
- Changes are topologically incorrect (e.g. overlap with other changes) or geometrically incorrect (e.g. narrow or sliver polygons);
- Change outlines do not match the boundaries of the CLC parent layer (i.e. CLC2012 in CLC2018 project).

These can be avoided by:

- Not taking uncritically the changes derived from ancillary databases, but considering them as potential changes, which are to be visually checked and approved by interpreters or used as background information in manual delineation of changes. This is especially true for changes of built-up areas, heterogeneous agricultural classes and non-forested natural classes. Forestry changes are easier to be automatically detected; they however also require, at least, partial visual control (especially forest growth);
- Making sure that source databases are timely, i.e. not outdated, but especially not fore dated (databases of buildings or spatial planning do often contain features that are planned to be raised, but in reality, are still not existing).

Taking CLC2018 database as a geometrical basis of change mapping is a necessary requirement. In the exceptional case when CLC2024 is produced first, and CLC-Change2018-2024 is derived by backdating, geometrical and thematic compliance with the new status layer (CLC2024) is still necessary.

5 ANCILLARY DATA

In-situ data in Copernicus programme by definition comprise all non-space-born data with a geographic dimension. Major use of in situ data in CLC project is to complement the satellite data during production and to verify or validate results provided from space-born data.

The photointerpreter should be aware that the primary source of information is IMAGE2018 and IMAGE2024, which are considered reference data concerning both date and thematic content.

Beyond these, recommended in-situ data include:

- Up-to date topographic maps (preferably at scale 1:25.000 / 1:50.000) to be used during the interpretation, mapping and validation processes;
- Orthophotos, taken optimally in 2017 and in 2023 (especially if topographic maps are outdated). Orthophotos are to be used only in those cases when interpretation by satellite images is not sufficient
- Thematic maps (built-up, vegetation, forestry, hydrology, snow and ice, etc.);
- Other ancillary data (e.g. LPIS[34], which has an utmost importance in precise mapping agriculture classes and their changes) for identification/interpretation and verification of land-cover mapping;
- 'Change alert layers' developed by the ETC DI to support mapping, especially urban sprawl and forest loss (layers will be made available for organizations/entities implementing CLC2024).
- Ancillary data complementing the above and being useful in CLC change mapping are Google Earth (GE) imagery (or equivalent): provides VHR image data, supporting the interpretation where no ortho-photos are available. Often multi-year time series are provided, which are very useful in understanding the evolution of the area. Major uses are: mapping fast-growing changes (e.g. constructions, mining, clear-cut, etc); identification of plantations (both fruit and forest), agroforestry (dehesa /montado) and scattered holiday cottages and their changes; use of crowd-sourced field photos attached to these images. Interpreter, however, should always a) be aware of GE image dates; b) treat GE data with a due precaution as non-valid image dates might occur; and c) field photos are often misplaced.

[34] Land Parcel Identification System

6 Production of CLC2024 database

In the CLC2024 project the CORINE Land Cover database is updated by the „change mapping first" approach (Ch. 4.2). During change mapping, discovered errors (thematic as well as geometric) of CLC2018 have to be corrected (Ch. 4.2.2.1), providing a revised CLC2018 dataset (or a layer of technical changes if revision is not to be done according to the national project plan).

CLC2024 database will be produced by adding CLC2018$_{rev}$ and CLC-Change$_{2018-2024}$ in a GIS, like it happened in CLC2018 project.

The two major prerequisites of producing CLC2024 out of CLC2018rev and CLC-Change$_{2018-2024}$ data by GIS is that

1. CLC-Change$_{2018-2024}$ outlines are geometrically based on CLC2018$_{rev}$ outlines.
2. Both CLC2018rev and CLC-Change$_{2082-2024}$ are topologically correct databases (no holes, no overlaps, no multi-part polygons, no dissolve errors).

If any of these conditions are not fulfilled, GIS operation will produce false result and slivers, therefore producing an incorrect CLC2024.

Integrating CLC2018$_{rev}$ and CLC-Change$_{2082-2024}$ in order to produce CLC2024 should rely on the equation:

$$\text{CLC2024} = \text{CLC2018rev} \ (+) \ \text{CLC-Change}_{2018-2024}$$

Where (+) means the following operation: CLC2018rev (revised CLC2018) and CLC-Change2018-2248 databases are intersected, then CLC-Change polygons' code$_{2018}$ is replaced by code$_{2024}$, and finally neighbours with similar code are unified (***Figure 25***). Small (<25 ha) polygons are generalized according to a priority table (***Figure 26***). As an option, polygons slightly below the 25-ha limit (e.g. 23,5 ha) can be manually enlarged by a photo-interpreter (***Figure 27***). The CLC Technical Team provides an ArcGIS toolbox written for the "intelligent" data integration, like in CLC2006, CLC2012 and CLC2018 projects [18].

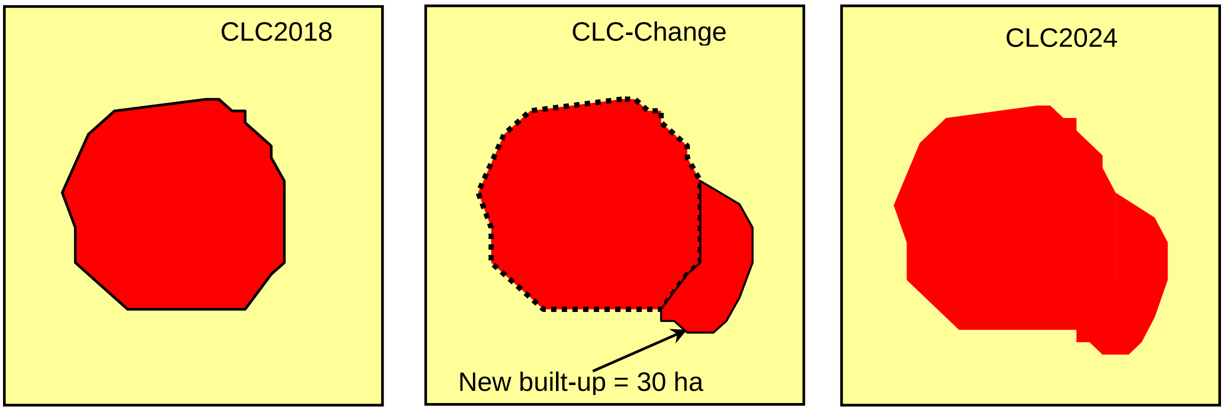

Figure 25 Increase of a settlement / decrease of arable land by 30 ha. As the change is >25 ha, the integration of CLC2018rev and CLC-Change$_{2018-2024}$ is straightforward and can be done automatically. The exact mathematical relation between the three databases (CLC2018rev, CLC-Change$_{2018-2024}$, CLC2024) is fulfilled.

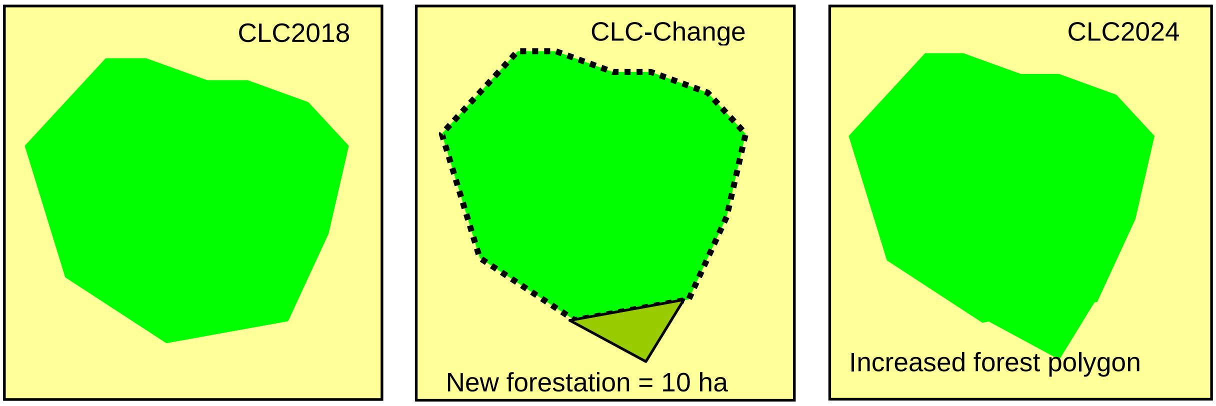

Figure 26 10 ha of new forest plantation on former arable land. As the change is <25 ha, the integration of CLC2018 and CLC-Change$_{2018\text{-}2024}$ is not straightforward and generalisation is needed. Using the priority table, this case can be solved automatically. The forest plantation area will be added to the area of the forest polygon. The exact mathematical relation between the three databases (CLC2018, CLC-Change$_{2018\text{-}2024}$, CLC2024) is not fulfilled.

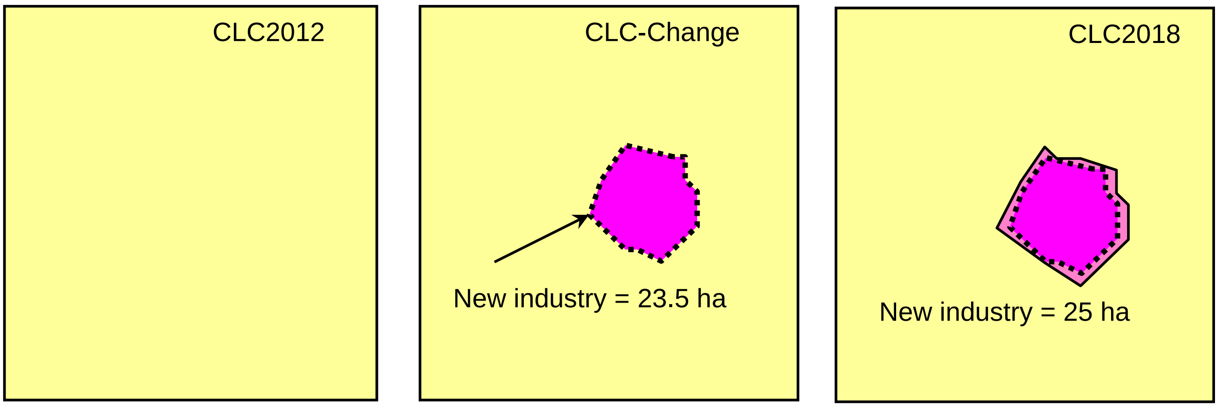

Figure 27 New industry (23.5 ha) on arable land. With an automatic process, this would have not appeared in CLC2024. However, with a slight exaggeration to reach the 25-ha limit, this object will be part of CLC2024. The exact mathematical relation between the three databases (CLC2018, CLC-Change$_{2018\text{-}2024}$, CLC2024) is not fulfilled. The generalization toolbox makes possible the setting up of a threshold above which polygons are manually generalized, allowing the above-described manual exaggeration.

7 METADATA

Like in the CLC2018 project, two levels of metadata are produced in CLC2024 project.

7.1 WORKING UNIT-LEVEL METADATA

The purpose of the working-unit level documentation is to make note on all steps of production of the CLC-change database. National teams are responsible for preparing working unit-level documentation for their CLC databases, for internal use within CLC projects. The templates for CLC2024 and an example of a filled-in form will be provided for organizations / entities implementing CLC2024.

7.2 COUNTRY-LEVEL METADATA

Country-level metadata mostly serve the users by informing them about the main parameters of the product. Country-level metadata are to be produced by the national teams for CLC-Change$_{2018-2024}$, CLC2024 and if applicable, for the revised CLC2018 databases.

As a general requirement and to enable the EEA to further publish and reuse the deliverables in accordance with the requirements of INSPIRE (Directive 2007/2/EC and the respective implementing provisions), the contractor shall provide metadata following the "INSPIRE Metadata Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119".

To facilitate the requirement to provide metadata files, the EEA has created the Metadata Editor. The editor includes a specific template with the title "CLMS metadata template" that shall be used by CLMS service providers. This template ensures the compliance with the abovementioned Technical Guidelines. Access to the metadata editor requires Eionet login, which can be provided upon request via sdi@eea.europa.eu (citing the reference number for CLC2024 call for tenders).

8 TRAINING AND VERIFICATION

Training and verification for CLC2024 are implemented by the CLC Technical Team under the guidance of the EEA, similarly to previous inventories.

8.1 TRAINING

Since the CLC2006 project, training of a National Team has been organised only on the request of the national team. As the methodology of CLC2024 is practically the same as that of CLC2006, CLC2012 and CLC2018 (except the voluntary mapping of solar parks, see Ch. 4.1.1), training will be held only in exceptional cases on the request of the country. The list of CLC2024 training courses foreseen (based on CLC2024 country questionnaire and to be confirmed at project start) are presented in ***Table 17***.

Table 17 Planned CLC2024 training courses (status 21/09/2022)

Country	**Reason of training**
Albania	New team
Croatia	New team; New method; Switch to using the dedicated CLC change mapping software InterChange
Cyprus	New team; Switch to using the dedicated CLC change mapping software InterChange
Estonia	new team
France	New team, New method; Switch to using the dedicated CLC change mapping software InterChange
Greece	New team
Ireland	Other: might need new resources to support in addition to existing knowledge
Italy	New team; New method; Other: team partially new
Kosovo	Possibly new team
Latvia	New team; New method
Malta	New team
Montenegro	New method; Switch to using the dedicated CLC change mapping software InterChange
Netherlands	Switch to using the dedicated CLC change mapping software InterChange
Spain	New method
Switzerland	New team
Türkiye	New team

8.2 VERIFICATION

Like in previous CLC projects, the CLC Technical Team will verify the revised parent status layer and the new CLC-Change layer ($CLC2018_{rev}$ and $CLC\text{-}Change_{2018\text{-}2024}$ databases). The reason to verify CLC2018rev is that according to the standard methodology CLC2024 is created by $CLC\text{-}Change_{2018\text{-}2024}$ added to $CLC2018_{rev}$ (see Ch. 6), so producing a good quality CLC2024 requires as good as possible quality CLC2018.

In case of few countries where the CLC2024 database is directly produced, CLC2024 and CLC-Change$_{2018-2024}$ databases will be verified.

The aim of the verification is two-fold:

- to inform the EEA about the work progress;
- to assist the country in producing a high-quality CLC update, which is harmonised across Europe.

In CLC2024 two verification actions per country are planned (***Tables 18, 19***):

- **1st verification** (usually remote verification, i.e. not visiting the country, data is sent to CLC Technical Team) is due when the first few working units are interpreted (e.g. 10-30% of the country). The main purpose of this action is to reveal problems in the early phase of implementation. Countries new in CLC or having less-experienced CLC team might be visited. In countries working with regional teams (Italy and Spain) only a single working unit need to send for first verification, representing the country. The sample size is standardised (***Table 18***), but sample location is determined by national team.
- **2nd verification** (in majority of cases remote verification) is due when around 75% of the country area is interpreted. The main purpose of this action is to check the database close to completion and suggest improvements if needed. The sample size is standardised, and sample location(s) are determined by CLC Technical Team.

It is the purpose to check altogether usually 10% of the country area (taking into consideration the 1st and 2nd verification. The proposed standard size of the verification working unit (VWU) is about 50 km x 50 km area within a S2 image frame. The number of samples to be checked in 2nd verification depends on the size of the country/region (***Table 19***). In case of poor result, re-checking of the working unit might be requested.

Due to financial constraints and to reduce implementation time the verification activity has been relaxed. Main points were as follows:

- Countries having area below 31.000 km^2 will not be requested to send a new sample for 2nd verification. In case of poor result, re-checking of the area of 1st verification might be requested.
- The practice of verification of Italy and Spain by regions has been dropped. It means that instead of a number of regional products Italy and Spain as a whole will be verified, like the other countries.
- For countries having area above 100.000 km^2 the number of samples are gradually reduced and consequently, less than 10% area will be verified.
- Further relaxation refers to checking the revision of CLC2018 focusing on areas having changed between 2018 and 2024 (see Ch. 4.2.2.1)

New element of CLC2024 is the introduction of level-4 classes *Industrial, commercial or public units other than free-field solar parks* (1211) and *Solar parks mounted on formerly non-sealed ground (free-field solar parks)* (1212). Mapping of these subclasses is voluntary and is aimed to be done only in the change database. However, if National Team engages in mapping these subclasses, CLC Technical Team will handle and examine them similarly to standard level-3 classes during verification. CLC2024 Support Package's quality control (verification) module, InterCheck is capable of handling level-4 classes.

Table 18 General scheme of verification in CLC2024

	1st verification	2nd verification	Data to provide to CLC TT; data format	Remark
sample selection by	national team	CLC Technical Team		
sample size to verify	a single area, about 50 km x 50 km in size within a Sentinel-2 tile (or the gap-filling satellite image)	about 50 km x 50 km areas within Sentinel-2 tiles (or the gap-filling satellite image). Number of areas depends on size of the country (see ***Table 19***).	revised CLC2018 (or CLC2024[35]) and CLC-Change2018-2024 in ESRI shapefile format	samples should be completed, i.e. full area interpreted
IMAGE2018 to provide to CLC TT	multitemporal imagery covering the sample interpretation(s)		Sentinel-2 or Landsat-8 data covering the sample area; in GeoTiff, LAN format	all IMAGE2018 data used in photo-interpretation have to be sent
IMAGE2024 to provide to CLC TT	ID (file name) of S2 (or Landsat-8&9) multitemporal images used in deriving CLC data should be provided for each sample		Sentinel-2 or Landsat-8&9 data covering the sample area; GeoTiff, LAN format	images to be sent by NT only if not the centrally provided IMAGE2024 is used
Orthophotos and topographic maps	Optional, but welcome	Optional, but welcome	WMS access welcome	recommended if available;

The InterCheck software (part of the CLC2024 Support Package) will be used in the verification, like in CLC2018. The basic technical features of both databases will be checked (topology, MMU, validity of codes, neighbours with the same code, etc). Thematic remarks will be written into the CLC and CLC-Change databases (associated to a polygon or a specific location) if mistakes were found in order to orient the correction.

The results of the verification will be expressed in qualitative terms as before, i.e. no quantitative accuracy assessment will be provided:

A (accepted) means: only minor problems were found;

CA (conditionally accepted) means: there are more problems but relatively easy to correct; following corrections the working unit is accepted;

R (rejected) means: there are many mistakes in the database (incorrect application of the nomenclature, omitted changes, false changes, etc.), which takes considerable work to correct. Each verification will be accompanied with a verification report and GIS file including the remarks.

[35] In case of some non-standard methodology if CLC2024 is produced first

Table 19 CLC2024 verification plan

Country	Area (km^2)	Remark	number of VWUs, 1st verification	Remark, 2nd verification	number of VWUs, 2nd verification
Liechtenstein	160	together with Austria	0		0
Malta	316		1	no 2nd verification planned,	0
Luxembourg	2 586		1	no 2nd verification planned,	0
Cyprus	9 251		1	no 2nd verification planned,	0
Kosovo	10 908		1	no 2nd verification planned,	0
Montenegro	13 812		1	no 2nd verification planned,	0
Slovenia	20 273		1	no 2nd verification planned,	0
North Macedonia	25 713		1	no 2nd verification planned,	0
Albania	28 748		1	no 2nd verification planned,	0
Belgium	30 510		1	no 2nd verification planned,	0
Switzerland	41 290		1		1
Netherlands	41 526		1		1
Denmark	43 094		1		1
Estonia	45 226		1		1
Slovakia	48 845		1		1
Bosnia and Herzegovina	51 129		1		1
Croatia	56 542		1		1
Latvia	64 589		1		2
Lithuania	65 200		1		2
Ireland	70 280		1		2
Serbia	77 453		1		2
Czech Republic	78 866		1		2
Austria	83 858		1		2
Portugal	91 568		1		3
Hungary	93 030		1		3
Iceland	103 000		1		3
Bulgaria	110 910		1		3
Greece	131 940		1		4
Romania	238 392		1		6
United Kingdom	244 820		1		7
Italy	301 318	no region-level checking	1	no region-level checking	8
Poland	312 685		1		8
Norway	323 802		1		8
Finland	338 145		1		8
Germany	357 050		1		9
Sweden	449 964		1		10
Spain	505 992	no region-level checking	1	no region-level checking	11
France	551 695		1		11
Türkiye	783 562		1		12
Total:	**5 848 048**		**38**		**133**

All participating countries (except Liechtenstein, which is verified together with Austria) are expected to send one verification working unit (VWU)[36] (about 50 km x 50 km in size) for 1st verification. The VWU should be selected from inside the respective S2 tile (or gap-filling satellite image) in order to minimize the number of IMAGE2024 images used in verification.

The location of VWUs for the 2nd verification are selected by the CLC Technical Team (see number of VWUs in ***Table 19***). These VWUs are expected to send to the CLC Technical Team. Countries having area below 31.000 km^2 will be exempted from 2nd verification.

36 The size of the verification working unit (50 km x 50 km) and its location is not necessarily coinciding with the size and location of production working unit.

9 Final quality control and delivery

9.1 Delivery Procedure

Delivery of national CLC2024 products from National Team (NT) to the EEA is part of the CLC2024 planning in countries and follows the agreed CLC2024 projects schedule. Any foreseen alteration of the delivery schedule shall be indicated to the CLC Technical Team in advance, so these can be accommodated appropriately in the project plan.

National data can be considered as 'ready for delivery' after the following steps are fulfilled:

1. Last verification action of CLC Technical Team took place and Verification Mission Report has been issued;

2. Recommendations specified in the Verification Reports have been integrated into the data by the NT;

3. Technical quality of deliverables has been checked internally by NT and screened using online CLMS QC Tool (see Ch. 9.1.1) to conform to all specifications as defined in the CLC2024 Technical Guidelines.

The following deliveries [delivery file name] are expected from the countries (xx means the two character-long ISO code of the country):

- **CLC-Changes (2018-2024)** - [CHA24_xx]
- **CLC2024** - [CLC24_xx]
- **CLC2018 revised** – [CLC18_xx]
- **Metadata** as specified in Chapter 7

In addition to ESRI Geodatabase (gdb) format (introduced during CLC2006) and Shapefile (shp) format, CLMS QC Tool supports also a modern GeoPackage (gpkg) format. GeoPackage is an open, non-proprietary, platform-independent and standards-based data format for geographic information systems built as a set of conventions over a SQLite database. Defined by the Open Geospatial Consortium (OGC), GeoPackage has seen widespread support from various government, commercial, and open source organizations. Thus, GeoPackage format is promoted as a primary delivery format, nevertheless previous options are still supported. For other file formats use please consult with CLC Technical Team (contact: jiri.tomicek@gisat.cz, CC: tomas.soukup@gisat.cz).

9.1.1 Online quality screening

When deliveries are ready to be uploaded , the NT performs final quality check using the CLMS QC Tool – standard Copernicus online technical quality screening service. Conformity to the CLC specifications as defined in these Technical Guidelines can be checked there and results are provided visually as well as reported via dedicated reports and errors correction supporting GIS files in automatic manner. The tool supports national teams in their DIY compliance checking in order to assure conformity of the final deliveries prior to upload to EEA in a standard, transparent and more effective way. This streamlines final data acceptance and provision of the related final CLMS QC Tool report.

CLMS QC Tool integrates all formal, technical and topological checks as defined in these Technical Guidelines, which can be done in fully automatic way. This standard set of checks and their centralized implementation shall assure that all checks are done in a standard and transparent way and also that no checks are skipped or omitted. Based on the experience from delivery and acceptance task in the previous CLC updates, the aim of the tool is to support:

- streamlining of the delivery process;

- assurance of technical consistency and semantic correctness of each individual national CLC database produced by participating countries;
- smooth and fast integration of data into the seamless European CLC database

CLMS QC Tool is available as web service via web address https://qc-copernicus.eea.europa.eu/ (***Figures 28 and 29***). All functionalities are run purely through web client and therefore doesn't impose any change to national team technical procedures, internal workflow or software environment setup. Eligible national team users will be notified with access information. For detailed information about the CLMS QC Tool functionalities please consult documentation the online *CLMS QC Tool Help* (https://github.com/eea/copernicus_quality_tools/wiki). The latest version of tool (> 2.0.0.) also makes the vast majority of functionalities available through the API, but it is not considered as primary option of the CLMS QC Tool use for CLC2024 delivery. For any additional questions related to CLC2024 technical quality screening service please contact jiri.tomicek@gisat.cz, CC: tomas.soukup@gisat.cz.

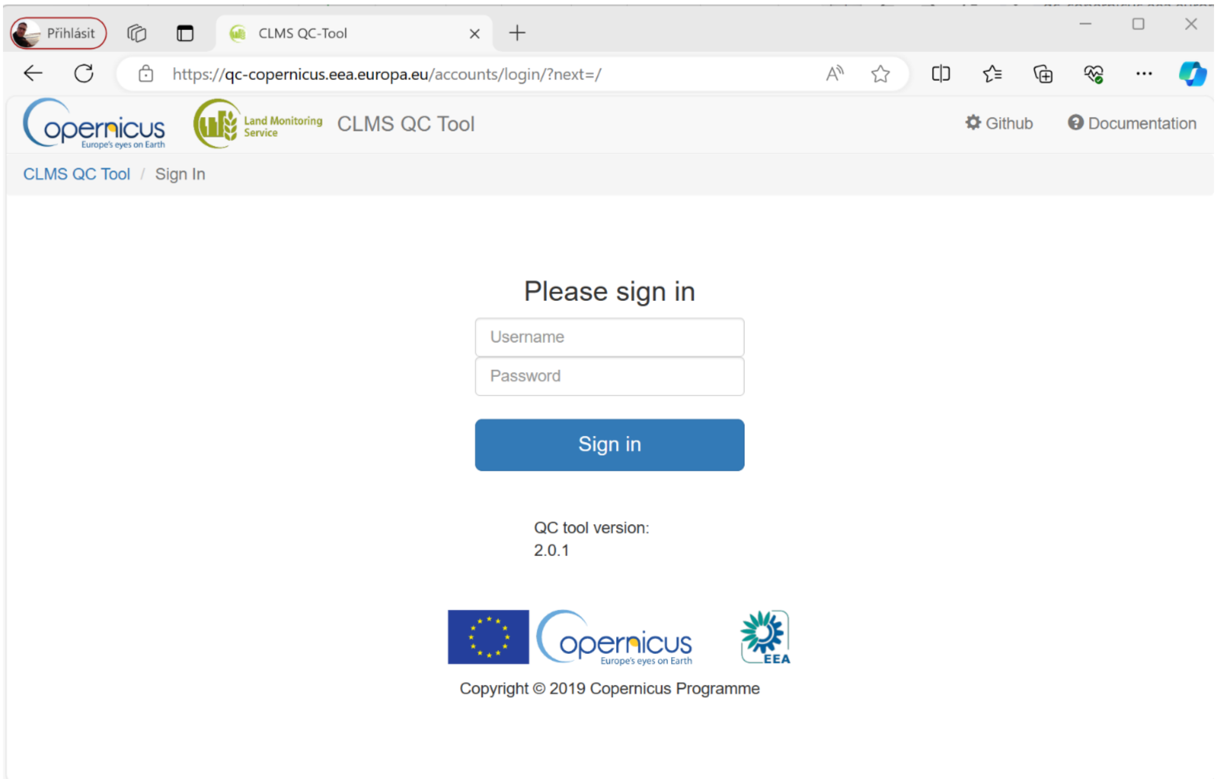

Figure 28 CLMS QC Tool login page - https://qc-copernicus.eea.europa.eu/

CLMS QC Tool has been developed by the ETCDI and is licensed under the EUPL, Version 1.2. Documentation includes detailed User Guide section describing in detail step-by-step the basic functions of the tool and guidance how to use it. The service publicly available at https://qc-copernicus.eea.europa.eu/ can be tested using demo login user: guest, password: guest. ***Figure 28*** shows example of CLMS QC Tool interface.

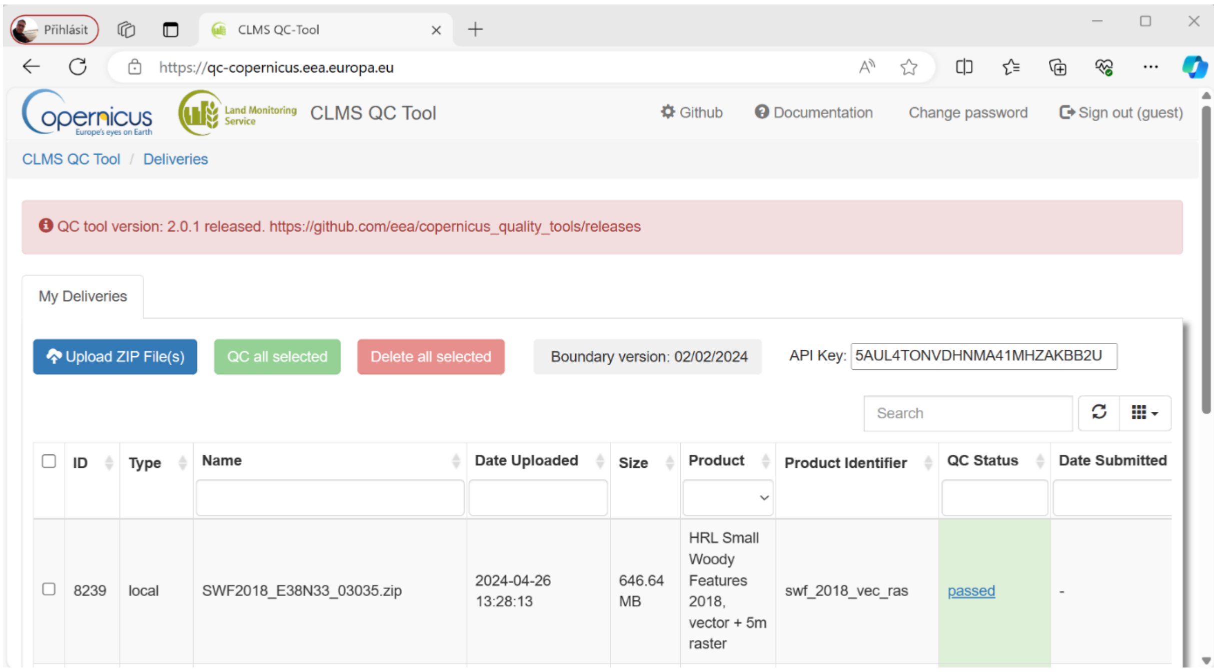

Figure 29 CLMS QC Tool main page - https://qc-copernicus.eea.europa.eu/

9.1.2 Final delivery

The final data delivery process is even more simple than during CLC2018 production. Accepted delivery via CLMS QC Tool is considered as the final data delivery. CLMS QC Tool Report will be generated automatically during checking process and available as part of the final delivery. CLC Technical Team will still maintain the final look-and-feel review of all final MS deliveries. In case of any issues found in the final data, the NT will be contacted for clarification or request to proceed with the improvement of datasets, new online checking and new submission via CLMS QC Tool. Nevertheless, such additional iterations will be exceptional if not fully avoided by introducing the online technical quality screening service.

9.1.3 Comparison to 2018 delivery procedure

As seen above the delivery workflow for CLC2024 update remains very similar as in the case of CLC2018, where technical quality screening service have been already in operation. The main upgrade of the delivery process includes:

1. Originally CLC specific QC tool has evolved into the standard general CLMS QC Tool following the same base principles of quality checking. The workflow assures technical consistency of each national CLC delivery from countries in shorter time and enable subsequent smooth and fast integration of data into the seamless European CLC2024 products.
2. No final delivery via the EEA Central Data Repository (CDR) upload is required. Accepted delivery via CLMS QC Tool is considered as the final delivery.
3. Former DBTA report is replaced by the CLMS QC Tool Report generated automatically as part of the checking and delivery process.

Similarly to previous CLC data productions, CLC Technical Team does the final look-and-feel review of all final MS deliveries and communicate with NTs any doubts or findings.

10 References

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LIST OF ABBREVIATIONS

CAPI	Computer Assisted Photointerpretation
CLC	CORINE Land Cover
CLC90, CLC1990	The first CLC inventory for reference year 1990
CLC2000	CORINE Land Cover update for reference year 2000
CLC2006	CORINE Land Cover update for reference year 2006
CLC2012	CORINE Land Cover update for reference year 2012
CLC2018	CORINE Land Cover update for reference year 2018
CLC TT	CLC Technical Team
CORINE	Co-ordination of information on the Environment
DEM	Digital Elevation Model
DG AGRI	Directorate General for Agriculture
DG ENV	Directorate General for Environment
EC	European Commission
EEA	European Environment Agency
EEA38	EEA38 composed of 32 member countries and 6 cooperating countries
Eionet	European Environment Information and Observation Network
ESA	European Space Agency
ESTAT	EUROSTAT, statistical office of the EU
ETC DI	European Topic Centre Data Integration and Digitalisation (2022-2026)
ETC ULS	European Topic Centre on Urban, Land and Soil Systems (2016-2022)
ETM+	Enhanced Thematic Mapper (US Landsat-7 sensor)
EO	Earth Observation
EU	European Union
FTSP	Fast Track Service Precursor (a term used in 2006 for CLC2006 and Imperviousness mapping)
GCP	Ground Control Points
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security (earlier name of Copernicus programme)
IMAGE1990	Satellite image coverage for CLC reference year 1990
IMAGE2000	Satellite image coverage for CLC reference year 2000
IMAGE2006	Satellite image coverage for CLC reference year 2006
IMAGE2012	Satellite image coverage for CLC reference year 2012
IMAGE2018	Satellite image coverage for CLC reference year 2018
IMAGE2024	Satellite image coverage for CLC reference year 2024
INSPIRE	Infrastructure for Spatial Information in Europe
IP	image processing
IRS	Indian Remote Sensing (satellites)
JRC	Joint Research Centre
LC	Land Cover
LU	Land Use
LISS	Linear Self Scanning (sensor on-board of IRS satellites)
LPIS	Land Parcel Identification System
MMU	minimum mapping unit
MMW	minimum mapping width
MSS	Multispectral scanner (US Landsat 1-3 sensor)
MS	Member States (of EEA)
MSI	Multispectral Imager (Sentinel-2 sensor)
NFP	National Focal Point
NIR	Near Infrared (sensor band)
NT	National Team (implementing CLC)
OLI	Operational Land Imager (sensor on-board US Landsat-8 and Landsat-9)

Phare	Poland and Hungary: Assistance for Restructuring their Economies (EU pre-accession aid in the 90s')
SAFE	Standard Archive Format for Europe (Sentinels)
SoER	State of Environment Europe Report (EEA publication in every 5 years)
SPOT	Système Probatoire d'Observation de la Terre (series of French EO satellites)
S2	Sentinel-2 (satellites)
QC	Quality control
SWIR	Short Wave Infrared (sensor band)
TM	Thematic Mapper (US Landsat-4 and Landsat-5 sensor)
TOA	Top of Atmosphere (reflectance)
UTM/WGS84	Universal Transverse Mercator projection; World Geodetic System 1984
VIS	visible and infrared (sensor bands)
VWU	Verification Working Unit
WP	Work Package
WU	Working Unit