Ref. Ares(2025)11612147 - 29/12/2025

D4.7 Integration Plan

Work Package 4 - Operationalization

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Date: 31.12.2025

Full Title	**Evolution of the Copernicus Land Service portfolio** (integrating novel EO data and latest machine learning algorithms to continuously monitor the status, dynamics and biomass of the land surface)			
Project number	101082130		**Acronym**	EVOLAND
Start date	01.01.2023		**Duration**	36 months
Granting authority	European Health and Digital Executive Agency (HaDEA)			
Project Coordinator	Vlaamse Instelling voor Technologisch Onderzoek N.V. (VITO)			
Date of delivery	**Contractual**	M36	**Actual**	M36
Type	R - Document, report		**Dissemination level**	PU - Public
Lead beneficiary	CLS			
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Keywords	CLMS prototypes, operationalization, TRL, ARL			

Document Revision History				
Version	**Issue date**	**Stage**	**Changes**	**Contributor**
0.1	15.11.2025	Draft	Population template	GAF, VITO, CLS
1.0	31.12.2025	Final	Review and finalization of deliverable	CLS, VITO, GAF

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Acronyms

Acronym	Description
AGB	Above-Ground Biomass
ALOS	Advanced Land Observing Satellite
ARL CAP	Application Readiness Level Common Agricultural Policy
CCI	Climate Change Initiative
CGLS	Copernicus Global Land Service
CLMS	Copernicus Land Monitoring Service
CRCF	Carbon Removal Certification Framework (CRCF)
EC	European Community
EO	Earth Observation
DEM	Digital Elevation Model
DG AGRI	Directorate General for Agriculture and Rural Development
DG ENV	Directorate General for Environment
DL	Deep Learning
EE	Entrusted Entities
EEA	European Environment Agency
EC	European Commission
ESA	European Space Agency
EU	European Union
EUDR	EU Deforestation Regulation
FCH	Forest Canopy Height
GEDI	Global Ecosystem Dynamics Investigation
GPP	Gross Primary Productivity
HR	High Resolution
HRL	High Resolution Layer
ICOS	Integrated Carbon Observation System
JRC	Joint Research Centre
LSC	Land Surface Categories
LR	Low Resolution
LUE	Light Use Efficiency
LULUCF	Land Use, Land Use Change and Forestry
ML	Machine Learning
n/a	Not Available
NISAR	NASA-ISRO Synthetic Aperture Radar
NGO	Non-Governmental Organisation
NNLT	No Net Land Take monitoring (NNLT)
NRR	Nature Restoration Regulation
NRT	Near Real Time
NVLCC	Non-vegetated Land Cover Characteristics
SAR	Synthetic Aperture Radar
SDG SLF	Sustainable Development Goals Small Landscape Features
SWF	Small Woody Features
TRL	Technology Readiness Level
VHR	Very High Resolution
VLCC	Vegetation and Land Cover Characteristics

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Applicable Documents

ID	Applicable document
[AD1]	D1.2 Service requirements report - Final version
[AD2]	D4.3 Stakeholder consultation report - Final version
[AD3]	D3.2 EvoLand Prototypes Report – Final version
[AD4]	D4.6 Report on candidates for operational roll out – Final version

1. Introduction

1.1 Introduction to project and document

This report is part of the EvoLand project, which aims to develop and qualify new candidate services for integration into the Copernicus Land Monitoring Service (CLMS) portfolio under Copernicus 2.0 & Copernicus 3.0.

- Copernicus 2.0: Improve existing services with higher spatial resolution, better timeliness, and thematic detail to meet EU policy needs (e.g., CAP, biodiversity, climate adaptation).
- Copernicus 3.0: Deliver next-generation, policy-driven, tailored products, integrating AI/ML, near-real-time monitoring, and interoperability across domains to support climate neutrality, resilience, and sustainability goals.

This document outlines the integration plan for these candidates into the existing service portfolio for Entrusted Entities (EE), based on user needs, technical feasibility, and policy relevance.

This report resumes:

- The readiness level of prototype services developed, outlining strength and weakness for technical issues as well as user-oriented issues.
- The policy and user perspective for future adoption.
- The integration plan, roadmap and next steps forward before operational roll-out.

The document is therefore organized in 4 sections:

1. This introduction including the terminology used
2. A summary of the evaluation exercise for all candidates
3. An integration plan worked out per candidate
4. Conclusion & Outlook synthesis the integration plan and project outcome

The deliverables [AD1] to [AD4] provide the basis and the link to the integration plan,

1. Positioning each candidate with clear use cases, user needs and requirements, outlining how they may enhance or complement the existing CLMS portfolio.
2. Identifying strengths & limitations reached per prototype, considering both technical and user-oriented assessments,
3. Covering the policy and user perspective together with a synthesis roadmap for transition to operations

1.2 Terminology used

Method = EvoLand was aiming at developing algorithms and methods required for the candidate CLMS services using existing and novel Earth Observation (EO) data, in-situ data and infrastructure.

Prototype = EvoLand has developed twelve next-generation CLMS product candidates monitoring the status and changes of land use/land cover and various land surface characteristics at high resolution.

Candidate = The main result of EvoLand shows up to twelve operationally benchmarked and qualified candidate CLMS services with a TRL5-7, which could have the potential to be taken up and integrated into CLMS by the Entrusted Entities from 2026 onwards.

2. Summary on Candidate Services

2.1 From User needs to Service Evolution Requirements

The final version of the **Service Requirements Report** [AD1] outlines how EvoLand aims to enhance the CLMS to better meet European policy needs by developing innovative prototype services that integrate Earth Observation, in-situ data, and advanced machine learning approaches.

By reviewing documentation and conducting targeted stakeholder interviews, the project has identified key geospatial information needs for policy domains such as LULUCF, biodiversity, agriculture, soils, water, and urban monitoring. These insights are translated into user requirements for the EvoLand prototypes, acknowledging that technical feasibility may constrain full alignment with user expectations. Initial prototype demonstrations and subsequent user feedback helped refine the service specifications, ensuring relevance to policy reporting, improved timeliness, greater thematic detail, and long-term consistency—factors considered essential for wider CLMS uptake and operational integration.

Building on the requirements baseline, the **Stakeholder Consultation Report** [AD2] synthesises the extensive feedback gathered through EvoLand's 2024 stakeholder engagement activities, including prototype demonstrations, webinars, and follow-up surveys. The report highlights strong user interest across all prototypes, with consistent emphasis on improving temporal frequency, thematic detail, transparency of methods, and interoperability with existing CLMS products.

Feedback revealed that users particularly value precision and long-term consistency, the ability to trace land-use trajectories, and better alignment with national reporting frameworks. The consultation also identified cross-cutting needs such as improved access to processing resources, clearer product documentation, and support for integrating prototypes into operational workflows. Overall, the document confirms broad endorsement of EvoLand's service directions while providing concrete, user-driven refinements to guide upcoming prototype iterations.

2.2 Qualification for operational roll out

The final version of the **report on Candidates for Operational roll Out** [AD4] presents the assessment process and results, based on a rigorous standard and common evaluation to ensure the delivery of high-quality products to end users.

12 prototypes have been defined, and 11 prototypes have been developed for 5 thematic domains:

- Forest (4 candidates): Continuous Forest Monitoring, Disturbance Mapping, Biomass Mapping, Tree Type Mapping.
- Agriculture (3 candidates): Cover Crop Type Mapping, Cropland/Grassland GPP Monitoring, Small Landscape Features.

- Water (1 candidate): Near real-time Water Bodies mapping.
- Urban (2 candidates): Continuous Imperviousness Monitoring, Automated Urban Dynamics Mapping.
- General Land Cover (1 candidate): Continuous Land Surface Categories mapping.

The candidate services underwent a comprehensive evaluation process to assess their potential for integration into the CLMS portfolio. The evaluation has been done jointly and objectively with all consortium members involved in the production.

The prototype “on-demand land cover mapping” (C11) was excluded from the operational roll-out assessment because it is an on-demand service, independent of fixed datasets, and therefore not suited to standardized benchmarking and operationalization within the CLMS framework.

The evaluation process has been conducted using two metric tools as follows:

(1) The **Technology Readiness Levels (TRLs)** which helps to manage the development process of space and other technologies, ensuring that each step is thoroughly vetted before moving to the next

Table 1. Technology Level Readiness per candidate at the end of Phase 1 (*)

	Technology Readiness Level (TRL)	1	2	3	4	5	6	7	8	9
		Basic Research		Applied research		Technology Development		System Development		
C01	Continuous forest monitoring									
C02	Forest disturbance mapping									
C03	Forest biomass mapping									
C04	Cover crop type mapping									
C05	Cropland/grassland GPP monitoring									
C06	Small landscape features mapping									
C07	Improved water bodies mapping									
C08	Continuous imperviousness monitoring									
C09	Automated land use mapping of urban dynamics									
C10	Continuous mapping of land surface categories									
C12	Tree Types Mapping									

(*) the detailed definition of the Technology Readiness Level can be found in the D4.6 Final report on candidates for operational roll out (AD4).

(2) **The benchmarking tool** which enabled to assess not only how well a candidate service serves the relevance of adding it to the CLMS, either as a new service or as an improvement on an existing service but also provide an indication of the associated timeframe until operational roll-out is possible as some service may require future evolutions and development before being added.

Table 2. Summary of assessment - all Benchmarking criteria (**).

Criteria	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C12
Science & Standards											
Level of innovation	++	++	o	+	+	+	+	o/+	o	++	+
Scientific acceptance	+	-/o	-/o	o	+	o	+	o/+	-	o/+	+
Impact & Relevance											
Answering user needs	o/+	o/+	o	+	+	+	+	+/++	+	+	+
Portfolio complementarity	++	++	+/++	+	++	++	+	+/++	+	++	++
Future continuation potential	++	+ /++	o	o	+ /++	+	++	+/++	++	++	++
Backward compatibility potential	n/a	n/a	n/a	+	+	o	+	+/o	+	+	+
Link to policy	++	+	++	++	+/++	++	+/++	+	+/++	+	+
Operational Feasibility											
Adequate in situ data	+	-/o	o	-	o	-/o	o/+	+/o	o	o/+	-
Adequate EO data	+ /++	+	-/o	o/+	+	o	+/++	++	+	+/++	++
Level of automation	++	o/+	+	o/+	+/++	+	++	++	+/++	++	+
Timeliness	++	+	+/++	+	+	o	+/++	+	++	++	++
Scalability to EE38 / global scale	++	o	o/+	o	+	o/+	++	++	+	++	o/+

(**) the definition of the criteria including the 5 levels of evaluation is detailed in the report D4.6 which is the Final report on candidates for operational roll out (AD4).

The TRL analysis shows that most services are not yet operational, which aligns with expectations at this stage of prototype development. Whereas a key aspect of the benchmarking assessment is a good understanding of the complexities of the CLMS both in terms of service production, operational requirements, and user needs.

The benchmarking criteria are sorted along three overarching groups:

- **Science & Standards,** which deals more with theoretical scientific aspects,
- **Impact & Relevance**, focusing on the users & stakeholders, CLMS and policy environment, and
- **Operational Feasibility,** which reflects more the technical characteristics and operational implementation of each candidate service.

The outcome of this assessment is that **most candidates prototyped are well aligned with user requirements and are well suited for integration within the CLMS portfolio** (all scores from + to ++). Nonetheless, several challenges remain, particularly regarding the availability of training and validation data and constraints in Earth Observation data accessibility as detailed in section 3.

Among the candidates,

- The most advanced —C01, C05, C07, C10 and C12— scored highly across all criteria and appear ready for progression beyond EvoLand. Note here that C12, has already been integrated into CLMS portfolio, while C5 and C11 are currently being brought into operation by the EE
- C04 and C06 are the candidates with the general lower score due to the complexity of producing an entirely new set of products highly dependent on the availability of VHR and/or in-situ input data and with complex definition.
- For the rest of the candidates, there is still room for improvement.

This analysis has been done by products and criteria. Whereas it is evident that some products are more advanced than others, the relative importance of specific criteria may vary depending on end-user priorities. **The final perception thus depends on the weight that the end-users and Entrusted Entities can assign according to the criteria.**

3. Integration plan into the Copernicus service architecture

3.1 General considerations

The integration of EvoLand candidate services into the CLMS architecture should build on the structured qualification and benchmarking performed in D4.6 [AD.04], which demonstrates strong thematic alignment and portfolio complementarity for most candidates. Many prototypes either fill identified gaps in the current CLMS portfolio or enhance existing services through higher spatial or temporal resolution and increased automation. Integration should therefore prioritise candidates that clearly complement existing products, preserve portfolio coherence, and support downstream use cases, while recognising the heterogeneous technical maturity of the candidates and adopting a phased integration approach aligned with their respective TRLs and criteria scoring.

Sustainable operational integration further requires long-term data continuity, high levels of automation, and compliance with CLMS technical and performance standards. The assessment highlights that limitations in training and validation data, as well as dependencies on future EO data availability, remain key risks for some services and must be addressed during transition to operations. Integration plans should therefore ensure scalability to pan-European coverage, robust automated production chains, adherence to Copernicus metadata and interoperability standards, and alignment with evolving Copernicus infrastructures and policy-driven user needs to guarantee long-term viability and continuity of the services.

The following sections review the eleven EvoLand prototypes per thematic domain: FOREST (4 candidates), AGRICULTURE (3 candidates), WATER (1 candidate), URBAN (2 candidates) and general/universal LAND COVER (1 candidate).

A full description of the EvoLand prototypes can be **found in the final version of the EvoLand prototypes report** [AD3].

As shown in figure 1, eight regions have been selected for assessment, the selection of them depends on candidates.

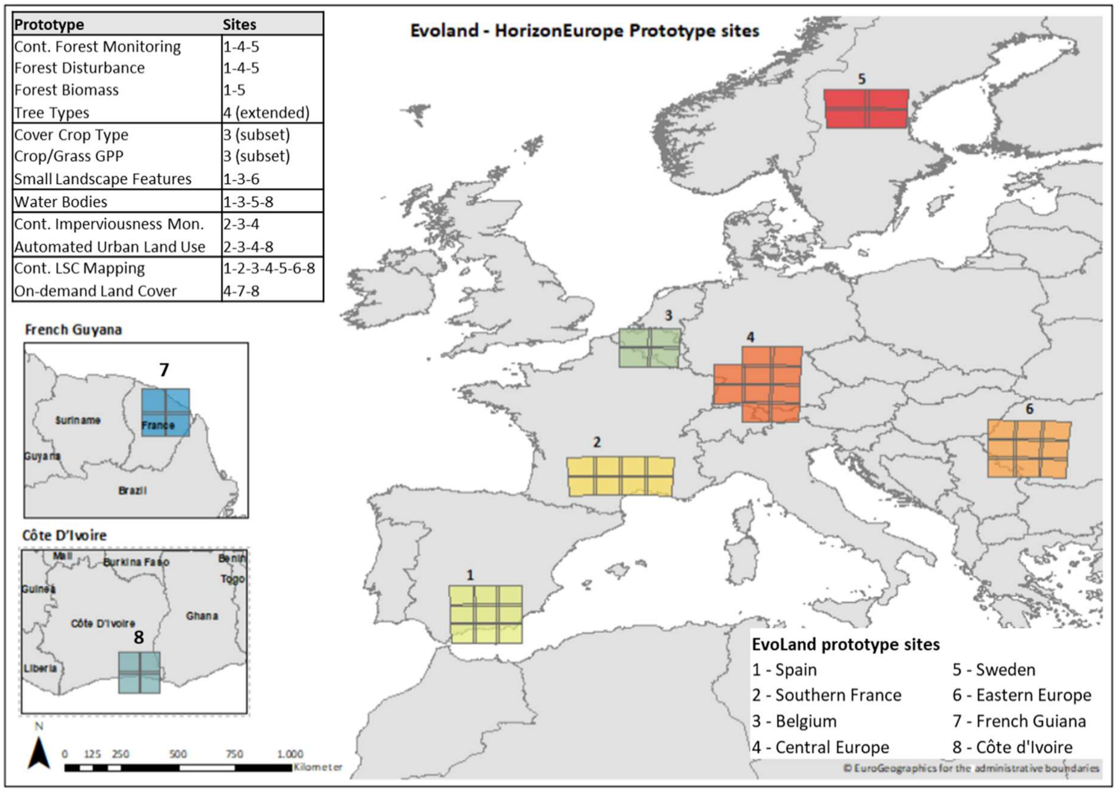


Figure 1: Identification of regions for assessment

3.2 Candidates on Tree Cover & Forest Thematic

There are 4 candidates with the following relevant CLMS land cover and land use thematic domain:

#	Candidate name	Positioning in CLMS	TRL reached
C01	Continuous Forest Monitoring	EVOLUTION	6
C02	Forest Disturbance Mapping	NEW	4
C03	Forest Biomass Mapping	NEW	4
C12	Tree Type Mapping	INITIAL	5-6

The assessment results of the candidate prototypes are recalled in section2. Key points and outcome for integration in the CLMS architecture are outlined below per candidate.

Candidate: C01 - Continuous Forest Monitoring

(1) Candidate Description

User Needs	To depict change dynamics of tree covered areas to better understand changes in tree cover for accurate monitoring and planning applications (see below use cases).
Use Cases	- Forest management and planning

	- Disturbance monitoring - Support of forest-related decision-making processes - Reporting on forest-relevant targets in EU policies, e.g. EUDR - Regulation on Deforestation-free Products
Pre-existing Know-How	Within the CLMS, products on forests and tree cover have a long history, providing information on: - Dominant Leaf Type (10m, yearly) - Tree Cover Density (10m, yearly) - Forest Type (10m, 3-yearly) - Changes (20m, 3-yearly)
Evolution of Requirements	To improve update frequency, as well as resolution for tree cover changes from 3-yearly at 20m spatial resolution to - yearly production with monthly information, - at 10m resolution.
Proof of Concept Achieved	The prototype developed produces tree cover disturbances maps, at an improved update frequency of existing forest masks. It has been assessed for three European test sites (see figure 1) and three subsequent reference years each: 1 – Spain: 2020-2022 4 – Central Europe: 2019-2021 5 – Sweden: 2020-2022 Assessment results and perspectives are given in next section.
Online Showcase	[EVOLAND: Continuous Forest Monitoring Prototype]()

This EvoLand candidate prototype aims to improves the timeliness of the status and change of CLMS High-Resolution Layer (HRL) products for Forest Monitoring by providing monthly resolved information within yearly products. Aiming for an almost fully automated processing approach, it provides results at 10 m spatial resolution.

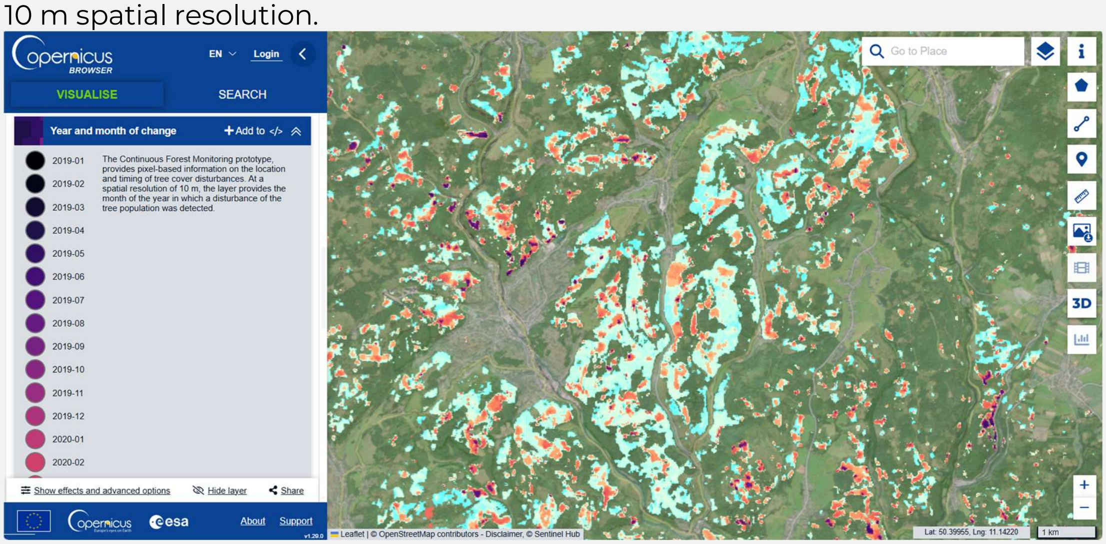


Figure 2: Forest in the Central European demonstration site (near Steinach, Germany) affected by a bark beetle infestation, being cleared step by step to avoid a further spread of the pest, beginning in summer 2019. Monitoring period 2019-2021 (Tile 32UPA)

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- A clear strength of the Continuous Forest Monitoring is, that it does not require any training data and it is almost fully automated. This makes the technical implementation independent from the often very limited availability and accessibility of adequate reference data like national data sets or other in situ data, which is still a problem for many other CLMS products.
- Its limitation is for a European wide production, because of the large amount of EO data needed for the model training. At least three full years of Sentinel-2 data are necessary to train robust models for the detection of disturbance events, which results in very high processing loads. As the methodology is very sensitive to clouds, good cloud masking is inevitable, which can increase the processing load additionally, depending on the implemented cloud masking algorithm.

Even if there should nowadays not be a technical limitation for the processing of large data volumes (in an ideal environment one can scale resources accordingly), adequate infrastructure for a timely production will require significant financial resources.

Considering User Oriented Assessment,

- The product is still not mature enough to serve all needs for near real-time forest monitoring. At this stage, disturbance events are detected with partially significant delay, which varies for different kinds of tree cover disturbances (e.g. clearing vs. insect infestations). Furthermore, the implemented approach showed varying accuracies for the three produced test sites, revealing general issues with some specific biogeographical conditions, which need to be further investigated.
- However, compared to other available forest disturbance products, the improved resolution is a big step towards the product users are requesting. With some further investigation for dedicated post-processing steps, e.g. to further reduce false detections, there is a clear potential to increase accuracies to a level that enables the reliable use for various applications across Europe.

Political Framework & Roadmap

Policy and User Perspective

Continuous monitoring of forests in Europe and worldwide is highly relevant for both the EU Forest Monitoring Law and the EU Deforestation Regulation (EUDR)[1]. Since forests are key carbon stocks this is also relevant input data for the LULUCF directive, while the forest contribution to biodiversity makes it applicable to the

[1] Note that there is currently a high degree of uncertainty about the timing and final scope of both these policies.

Nature Restoration Regulation and its economical role is reflected also in the recently adopted Strategy for a Competitive and Sustainable EU Bioeconomy.

Key users include forest management agencies (who may be public bodies, private companies or NGOs), forest certification bodies, EUDR Certification Bodies and National Competent Authorities, and agencies responsible for building national LULUCF inventories.

Compatibility and consistency with other CLMS products are crucial for existing users, while more frequent updates (at least annually), short latency between the availability of data, and flexibility in forest definitions are also important.

Potential barriers to adoption include difficulties in integrating the prototype with long-established monitoring systems. Capacity building, outreach, and close collaboration during the final stages of prototype development should help not only to overcome these barriers, but also to fine-tune the final product to better meet evolving policy requirements.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

As part of the CLMS pan-European component, the HRL Forest became operational in 2012. The initial 3-yearly updates have moved on to yearly updates since 2018 under the umbrella of the HRL Vegetated Land Cover Characteristics (VLCC) product suite, named now HRL Tree Cover and Forests.

After many years of CLMS operationality, the political framework is well established and the mechanisms for stakeholder decision-making and user consultation (by the EEs, the EC and the Copernicus Committee and User Forum) and service procurement are not expected to be critical.

The EvoLand suggestion for a Continuous Forest Monitoring product can be considered a logical extension of the HRL Tree cover and Forest portfolio and is well aligned with the goals of Copernicus 3.0 with regards to policy relevance, i.e. prioritization of tailored products to support EU needs like e.g. carbon monitoring.

As the procurement of the second HRL VLCC production cycle for the reference years 2025-2028 has just been finalized, the Continuous Forest Monitoring could be established together with the subsequent updates from 2029 onwards. It would be beneficial to use the time until then for further investigations and refinements to the methodology as described above.

Transition to Operations, Next Steps

For the transition to an operational product, the methodology needs to be further improved as stated below:

1) One thing to address is a faster detection of the disturbance events and further investigation needs to be conducted about why disturbances of the same kind can show significant differences in the timeliness of detection.
2) Further, the sensitivity of the method causes the need to elaborate a sophisticated workflow (e.g. a post-processing routine), to decrease the amount of commission errors, while reducing omission at the same time.

Now the trade-off between commission and omission errors is limiting accuracies to a certain extent.

3) A fusion of the optical with a radar-based approach could be worth investigating but would certainly further increase the already high processing loads to be expected for a pan-European roll out.

A major advantage of the implemented methodology is that it is of unsupervised nature, meaning it does not require training data to train the algorithm for the disturbance detection. Nevertheless, accurate reference data would be required to assess the accuracy of a tree cover disturbance product across Europe. To acquire such data will be inevitable for the transition towards an operational product but might involve large efforts.

Candidate: C02 - Forest Disturbance Mapping

(1) Candidate Description

User Needs	To distinguish between forest management and forest disturbances and identify the drivers of changes, due to (i) windthrow/storm damage, (ii) wildfire, (iii) insect infestations (e.g., bark beetle), and (iv) human-induced disturbances (e.g., forest clearing, clear-cutting, logging, and thinning activities)
Use Cases	- Forest management and planning - Support forest-related decision-making processes, enabling adequate reactions and measures to different problems
Pre-existing Know-How	None, but the Forest Disturbance Mapping complete the product candidate 1 to support forest management / resilience.
Evolution of Requirements	To identify changes behind forest disturbance events, specifically focusing on disturbances characterized by a decline in tree cover vitality or significant tree cover density loss. - On a yearly basis with monthly information, - At 10m resolution - For below disturbance agents: 1: bark beetle 2: clear cut/clearing 3: healthy trees 4: salvage logging 5: wildfire 6: storm/windthrow
Proof of Concept Achieved	The prototype developed produces maps of tree cover disturbances, with disturbance agent. It has been assessed for three European test sites (see figure 1) for three subsequent reference years each: 1 – Spain: 2020-2022 4 – Central Europe: 2019-2021 5 – Sweden: 2020-2022

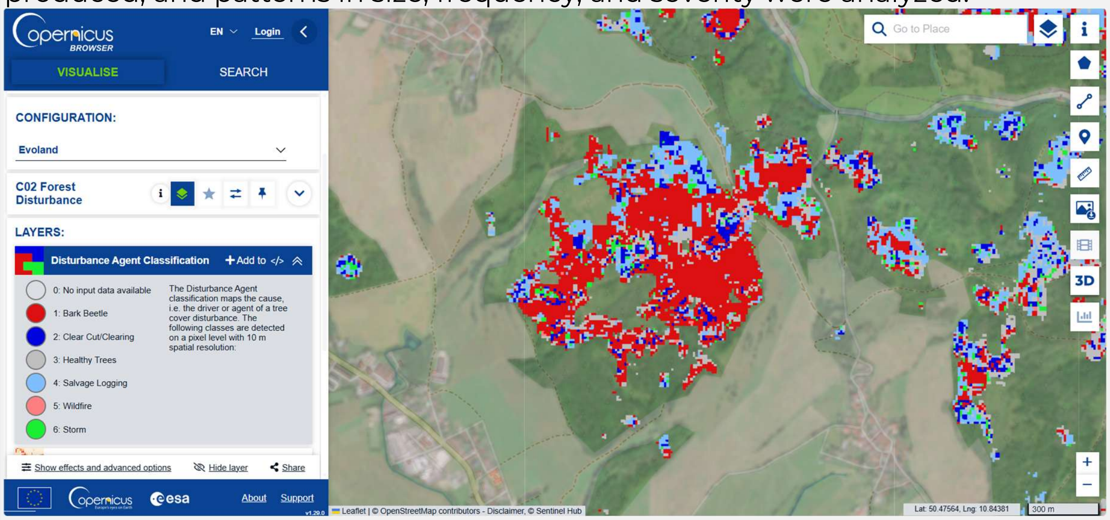
<table>
<tr><td></td><td>Assessment results and perspectives are given in next section.</td></tr>
<tr><td>Online Showcase</td><td>EVOLAND: Forest Disturbance Mapping Prototype</td></tr>
<tr><td colspan="2">This EvoLand candidate prototype maps forest disturbances continuously by leveraging synergies with the Continuous Forest Monitoring service. Using AI/ML methods trained with in-situ disturbance data and time series from prototype candidate 1, it identifies main disturbance agents (e.g., bark beetle infestations, wildfires, storms, logging). For selected sites, disturbance maps have been produced, and patterns in size, frequency, and severity were analyzed.


Figure 3 : A forest near Brattendorf, Germany, affected by a bark beetle infestation (red) starting in summer 2019. Further parts of the forest were subject to salvage logging (light blue) and clearing (dark blue).</td></tr>
</table>

(3) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- A clear strength is the technical approach chosen, robust and computationally effective, being capable to process large amounts of data. However, it is time-consuming for the demanding data download and time series pre-processing.
    - o The requirement that the product should at a minimum identify changes due to insect infestations, wildfires and storms is covered – only drought as an agent is not covered, since training the classifier towards detecting drought-induced changes would require a much longer time series analysis than available from Sentinel-2, and further ancillary data.
    - o The requirement that the product should distinguish between forest management and forest disturbances is partially covered by the fact that also human-induced clearings, clear cuts or selective logging events are captured, however, the information if these are human-induced action has been conducted due to forest management cannot be derived from EO data without further reference data.

- The most significant limitation for the extensive implementation of the disturbance mapping prototype is the availability of adequate reference data on different disturbance agents, needed both for training as well as validation.: To retrieve such data on a European scale seems to be very difficult at this stage.
- A further technical limitation is the dependency on the results of the candidate prototype 1 as an input to the disturbance classification. It has turned out that the partially significant delays in the detection of different disturbance events have an influence on the classified driver. Timely clearing activities do for example have the potential to obscure the initial cause of the disturbance.

Considering User Oriented Assessment,

- From a user´s perspective, the disturbance driver classification has partially shown good results; it is overall not yet mature enough to provide reliable information for users to derive potential measures for forest management activities or even political decisions.
- Because delayed disturbance detection can potentially lead to confusions in the detection of the disturbance agent, the classification might not be suitable for envisaged use cases, which need reliable information on the cause of a disturbance to derive the right measures, like for example adequate forest management in areas affected by insect infestations.
- There is clear user interest for such targeted product, but there are still further developments and improvements needed to reach the desired quality to move forward with a large-scale implementation.

Political Framework & Roadmap

Policy and User Perspective

Similarly to the previous prototype, monitoring of forests in Europe and worldwide is highly relevant for both the EU Forest Monitoring Law and the EU Deforestation Regulation (EUDR)[2]. Since forests are key carbon stocks this is also relevant input data for the LULUCF directive, while the monitoring of disturbance types (e.g. wildfire or infestation) is also relevant to climate adaptation under the EU Adaptation Strategy.

Key users include forest management agencies (who may be public bodies, private companies or NGOs), forest certification bodies, EUDR Certification Bodies and National Competent Authorities, agencies responsible for building national LULUCF inventories, and environment agencies and various national, regional and local authorities with responsibilities for managing infestations and wildfires.

A key factor determining the final end users is the output frequency of the product. Higher-frequency updates are particularly relevant for operational users such as park managers, while authorities with bi-annual reporting obligations do not require a similar update pace. In both cases, alongside accuracy and reliability, high priority is also given to the format of service delivery and its alignment with operational needs. Product uptake further depends on data quality, especially the

[2] Note that there is currently a high degree of uncertainty about the timing and final scope of both these policies.

ability to distinguish forest management activities from natural disturbances and to identify disturbance types. Training end users, supporting product integration, and sharing concrete use cases would help increase overall adoption of the service.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

Just like the Continuous Forest Monitoring prototype, the Forest Disturbance Mapping product would nicely extend the existing HRL Tree Cover & Forests products. It could support policies like the EUDR and the Sustainable Development Goals (SDGs; e.g. SDG 13 (Climate Action) and 15 (Life on Land)), addressing the evolution priority regarding policy relevance, as outlined by Copernicus 3.0.[3]

However, the methodology currently shows too many limitations preventing an operational roll-out with reliable results. As the procurement of the second HRL VLCC production cycle for the reference years 2025-2028 has just been finalized, the earliest integration in the VLCC product suite would be not before 2029. If the remaining time is purposefully and efficiently used to further develop and improve the methodology, it might become ready for operational integration by that time.

Transition to Operations, Next Steps

For the transition towards an operational product there are several issues to be resolved such as:

- First, the results of the disturbance classification are dependent on the quality of the continuous forest monitoring candidate 1, as one of its inputs. Inaccuracies in the candidate prototype 1, both with regards to detection delay and omission/commission errors propagate into the disturbance classification product. Further developments as well as transition to operations of both prototypes need to go hand in hand.
- Furthermore, one of the major issues is the absence of adequate reference data to train the algorithm for the detection of the different drivers (agents). It will be key to gain access to exhaustive training and validation data to enable an operational implementation of this product.

Candidate: C03 - Forest Biomass Mapping

(1) Candidate Description

User Needs	To survey forest biomass to support sustainable forest management conservation efforts and policymaking for carbon credit programs (see below use cases)
Use Cases	- Carbon stock assessment: modelling of carbon cycles - Deforestation and forest degradation assessment - Environmental monitoring: Estimation of potential wood supply

[3] Tender annex: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/tender-details/docs/5094b4e5-0796-47d4-9fc1-96daa5ac2192-CN/EEA.DTL.R0.25.016_Annex%206%20to%20TS_Summary%20CLMS%20Cop3.0_V1.pdf

	- Monitoring the impact of disturbance events, climate change studies
Pre-existing Know-How	None within the CLMS portfolio but biomass mapping is part of research projects for many years, as well as operationally performed in the Climate Change Initiative (CCI) Biomass, but not below 100m spatial resolution globally.
Evolution of Requirements	To produce annual high-resolution parameters (10-meters resolution) representative of Forest or Woody Biomass: - Forest Canopy Height (FCH) - Above-Ground Biomass (AGB)
Proof of Concept Achieved	The prototype developed produces Forest Canopy Height (FCH) and the Above-Ground Biomass (AGB). It has been assessed for 2 European test sites (see figure 1): 1 – Spain: 2021 5 – Sweden: 2020-2022) Assessment results and perspectives are given in next section.
Online Showcase	[EVOLAND: Forest Biomass Mapping Prototype]()

This EvoLand candidate prototype provides consistent estimates of above-ground woody biomass (AGB) and forest canopy height (FCH) to complement the CLMS portfolio. It exploits new EO missions (e.g., GEDI) and applies parametric and non-parametric models for pixel-level AGB estimation, adaptable to stakeholder needs.

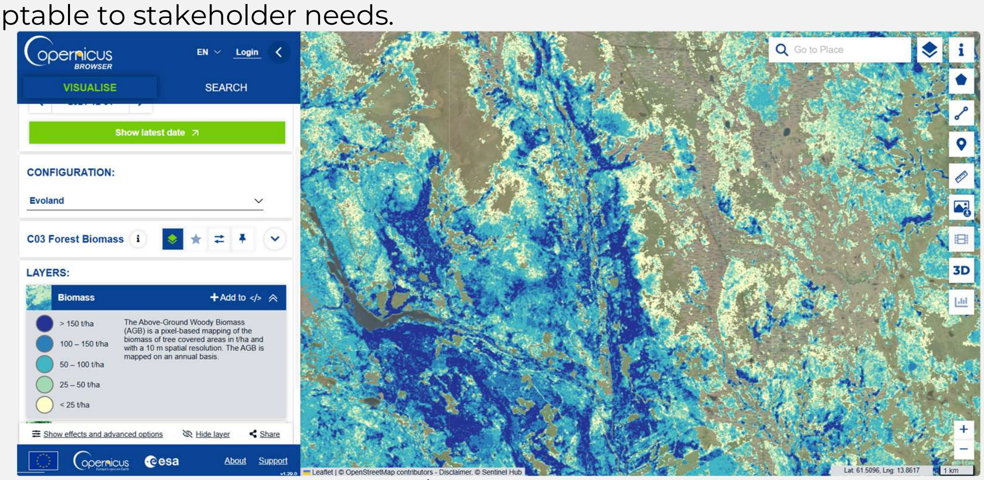


Figure 4: Prediction of the AGB (t/ha) for the Sweden test site for the reference year 2022

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- Systematic limitations can be seen from the results, based on Sentinel-2 and -1 data for the Forest Canopy Height (FCH) and Above-ground Biomass (AGB). Indeed, saturation effects at higher biomass and canopy height values led to underestimation, while AGB tended to be overestimated at lower biomass levels.

- As for other prototypes, the availability of adequate reference data remains a limiting factor. While models were performing well in medium- to lower-biomass regions (e.g. Sweden) these findings underscored the need for alternative input data.
- Future perspective would be to test using the L-band INSAR radar data, which was unfortunately not available for the project, to develop a more robust and transferrable approach.
- Besides that, the addition of FCH to an AGB product was in general identified as feasible, as both can be derived through comparable workflows with limited additional effort.

Considering User Oriented Assessment,

- From a user perspective, while the prototypes technical parameters, i.e. a pixel-based biomass product at 10m spatial resolution, are well aligned with the user needs, the varying accuracies and limited transferability across Europe, are clearly a limiting factor for its usage.

Political Framework & Roadmap

Policy and User Perspective

Forest biomass is relevant for the EU Forest Monitoring Law but is also key information for assessing carbon stocks, which is relevant both for the LULUCF directive and in the Carbon Removal Certification Framework (CRCF).

Key users may include forest management agencies, forest certification bodies, agencies responsible for building national LULUCF inventories and various actors along the carbon farming value chain. Within the carbon farming sector, land managers and forest owners are central actors, as they implement carbon removal practices on the ground. Market actors (such as buyers of carbon removal certificates and investors) rely on robust biomass data to assess credibility and risk. Civil society organisations also play an important role by scrutinising environmental integrity, transparency, and co-benefits.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

This prototype would fit in the Land Cover and Land Use part of the CLMS portfolio, as a new product under the HRL Tree Cover & Forests. Being compatible with the existing products, it would extend the available information, addressing several goals outlined in Copernicus 3.0, like the policy relevance with regards to carbon monitoring or the evolution towards higher spatial resolution and timeliness of biophysical products.

The methodology, however, currently still shows too many limitations preventing an operational roll-out with reliable results. The availability of additional, better suited satellite data such as from NISAR which has been launched in 2025 might lead to improved results and would further be in line with the Copernicus 3.0 goal to include new satellite inputs. However, further developments and testing are required first.

<u>Transition to Operations, Next Steps</u>

For the transition towards an operational product across Europe the applied methodology clearly has its limits. An approach based on optical EO data to derive biomass only seems to work in certain parts of Europe, with low or medium forest biomass. As mentioned above <u>the recently available NISAR data could pose major enhancement</u> in this regard and will have to be tested for the ability to derive forest biomass and canopy height for the whole of Europe with consistent quality.

Candidate: C12 - Tree Type Mapping

(1) Candidate Description

User Needs	To provide more fine-grained information of the current CLMS Tree Cover & Forest portfolio on the dominant tree species or genus (i.e. tree types at species/ genus level) to support environmental policies such as EU Biodiversity Strategy, LULUCF, Forest Strategy, as well as sustainable forest management and the transformation towards climate resistant forests.
Use Cases	Support to EU Biodiversity Strategy
Pre-existing Know-How	Current CLMS Tree Cover & Forest portfolio plus previous studies that have demonstrated the feasibility of differentiating between major coniferous and broadleaved groups. Recent attempts have shown the potential of time-series analyses for tree species mapping at national to continental scales.
Evolution of Requirements	To map at least 13 different tree type classes on genus and species level across Europe, at 10m spatial resolution. 0: No tree cover 11: Quercus (evergreen spp.) 12: Olea europaea 13: Eucalyptus 14: Other Broadleaved evergreen 21: Fagus 22: Quercus (deciduous ssp.) 23: Betula 24: Alnus 25: Populus 26: Other Broadleaved deciduous 31: Picea 32: Pinus 33: Other Coniferous
Proof of Concept Achieved	The prototype has been rolled out for one pilot site (see figure 1): 4 – Central Europe (see figure 1), a large test site covering 25 S-2 tiles, with an accuracy of 76%. Assessment results and perspectives are given in next section.

Online Showcase	[EVOLAND: Tree Type Mapping Prototype]()
This EvoLand candidate prototype develops a pan-European Tree Type map (13+ classes, 3-yearly updates) to complement CLMS forest products. Using harmonised field data and Sentinel-2 trained TempCNN models, it achieves 76% accuracy creates valuable input to support to track forest restructuring and support sustainable forest management.	

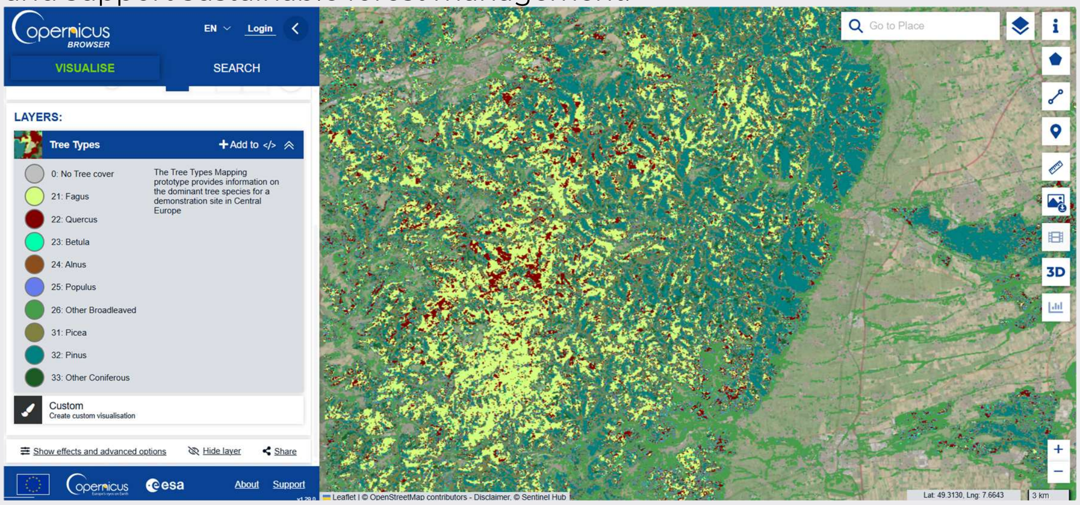



Figure 5: Prediction of Tree Type mapping for the Black Forest, Germany where Fagus, Quercus and Pinus appear to be the most dominant tree types.	

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- The proposed approach showed strong potential for tree type classification with Sentinel-2 time series data. The integration of diverse data sources, namely GBIF and TreeSat, combined with a rigorous filtering process, was a key factor in achieving an overall accuracy of 76.3% on the test set.
- While the model excels at classifying common species such as Quercus and Pinus, performance for less-represented classes is limited by the number of available training samples.
- Classification performance was particularly strong for dominant species with distinct phenological signatures, including Pinus and deciduous Quercus, whereas smaller classes which are often also mixed with other species suffered from confusion.
- The overall accuracy values of around 76% are therefore promising for operational applications in Central Europe, but class imbalance remains a significant challenge, especially for underrepresented species such as Populus and Betula.

Considering User Oriented Assessment,

- The provision of 13 Tree Types at genus and species level, at 10m spatial resolution in a European wide product, answers user needs for more detailed information on Europe’s forests, which is an important input to several

applications, with regards to sustainable forest management, the transformation towards climate resistant forest, and environmental policies.
- Limitations could arise from missing reference data, resulting in partially lower accuracies for underrepresented classes. High-quality reference data from regional and national forest inventories will be an important driver for the accuracy and trustworthiness of the product but is not easy to acquire due to data access restrictions.

Political Framework & Roadmap

Policy and User Perspective

Tree type mapping allows tracking of different categories of species type. This is relevant for the EU Forest Monitoring Law and the EU Deforestation Regulation (EUDR)[4]. Since different species retain different carbon stocks this is also relevant input data for the LULUCF directive and for the Carbon Removal Certification Framework. The forest contribution to biodiversity makes it applicable to the Nature Restoration Regulation. while changes in forest composition over time are relevant to the EU Adaptation Strategy. The economic role of forests is emphasised also in the recently adopted Strategy for a Competitive and Sustainable EU Bioeconomy

Key users may include forest management agencies, forest certification bodies, agencies responsible for building national LULUCF inventories, various actors along the carbon farming value chain, and various national, regional and local authorities with responsibilities for monitoring climate adaptation.

Both public authorities and actors from the private and non-governmental sectors show strong interest in such a prototype, especially when the information is combined with other forest analytics, such as biomass, disturbance mapping, or change detection, to provide a more comprehensive understanding of forest condition and dynamic

Product positioning in CLMS, Roadmap and Potential Timing for Integration

With the inclusion in the existing HRL Tree Cover and Forest product suite, the political framework is well established and the recently awarded second HRL VLCC production cycle for the reference years 2025-2028 has this new product already incorporated. It includes an initial ramp-up phase to work on the remaining limitations and prepare for the full European roll-out and will then be produced as a three-yearly product. With regards to Copernicus 3.0 it is providing an important extension of the CLMS portfolio, providing valuable input, supporting the EU Biodiversity Strategy, for example.

Transition to Operations, Next steps

The transition towards an operational product has already been started with the inclusion of this new product in the tender of the second HRL VLCC production cycle for the reference years 2025-2028.

[4] Note that there is currently a high degree of uncertainty about the timing and final scope of both these policies.

3.3 Candidates for Agriculture Thematic

There are 3 candidates with the following relevant CLMS land cover and land use thematic domains:

#	Candidate name	Positioning in CLMS	TRL reached
C4	Cover crop type mapping	INITIAL	5
C5	Cropland/grassland GPP monitoring	EVOLUTION	7
C6	Small Landscape Features and Forest (SWF)	EVOLUTION	3

The assessment results of the candidate prototypes are recalled in section2. Key points and outcome for integration in the CLMS architecture are outlined below per candidate.

Candidate: C04 - Cover crop Type Mapping

(1) Candidate Description

User Needs	To distinguish, annually, at 10m resolution, cover crop types ("Grass-like", "Leaf-rich", "Mix") during the secondary growing season to support agricultural monitoring and policy reporting (see below use cases).
Use Cases	- CAP Compliance & Subsidy Verification - EU soil monitoring law
Pre-existing Know-How	Within the CLMS, the current mapping of winter cover crops, based on Sentinel-2 & VLCC temporal features, distinguishes only two broad groups, and its accuracy is limited by lack of reference data.
Evolution of Requirements	The production must (1) be supported by sufficient and novel reference data and (2) have robust performance despite winter data gaps due to the presence of clouds and snow.
Proof of Concept Achieved	The prototype developed classifies grass-like and leaf rich cover crop classes. It has been assessed for one pilot-site (see figure 1): 3 – Belgium (subset): 2019–2020 Assessment results and perspectives are given in next section.
Online Showcase	EVOLAND: Cover crop type mapping

This EvoLand candidate prototype maps cover crop types at 10 m spatial resolution, complementing the VLCC service that currently detects cover crop presence only. Using new in-situ data and hierarchical deep learning models with Sentinel-1 and 2, the prototype aims to provide detailed information on when and where different cover crops are grown.

Figure 6. Cover crop types in Belgium for the reference year 2020.

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- <u>Clear strengths</u> for the demonstration of the technical feasibility of the Cover Crop Type prototype are listed below:
  - ✓ It relies on Sentinel-1 and Sentinel-2 time series together with HRL VLCC products, all of which are available annually and across the EU, making large-scale upscaling theoretically achievable.
  - ✓ The method demonstrates good separability among major crop groups—particularly between grass-like and leaf-rich cover crops—while its clear hierarchical typology enables meaningful grouping based on plant families and morphological traits.
  - ✓ Overall, the approach is grounded in a strong methodological foundation, combining a hierarchical machine-learning model with novel in-situ datasets that are explicitly tailored to user requirements.

Considering User Oriented Assessment,

From a user's perspective, there are <u>several key limitations:</u>

- The product remains at a low readiness level and has only been demonstrated in a single region; consequently, its maturity and transferability are limited, as regional agronomic differences constrain its suitability for consistent EU-wide operational deployment within CLMS.
- Additionally, users require more detailed, type-level information than the current accuracy can provide, particularly for distinguishing the ten most important cover crop types, which the prototype cannot yet reliably identify.

- And, the reliability of the product also depends heavily on improved reference datasets, access to high-quality in-situ data, as the availability of stable and validated reference data remains the main barrier to scaling across diverse agricultural regions.

Political Framework & Roadmap

Policy and User Perspective

The use of cover crops is integral to the EU Common Agricultural Policy (CAP), and is also a key factor in creating healthy soils under the Soil Monitoring Law, part of the EU Soil Strategy. The use of such crops is also used as input data for the LULUCF directive and may also be applied in the Carbon Removal Certification Framework (CRCF). The Nature Restoration Regulation and the EU Biodiversity Strategy introduce additional requirements related to farmland biodiversity, landscape features, and ecological connectivity, further strengthening the demand for integrated agricultural monitoring products.

As such, potential key users include CAP Paying Agencies, agencies responsible for building national LULUCF inventories and various actors along the carbon farming value chain. Within the CAP framework, ongoing efforts to simplify implementation and payment schemes increase the importance of efficient and automated monitoring solutions.

Product positioning in CLMS

The political foundation of this candidate prototype “Cover Crop Type Mapping” is closely tied to EU agricultural and environmental policy priorities, particularly the Common Agricultural Policy (CAP) and the strategic evolution CLMS under Copernicus 2.0.

Because cover crops are recognised by the CAP as a key sustainable farming practice, monitoring their presence and types directly supports policy implementation and compliance checks.

Requirements defined by the EEA and JRC further shape the service, ensuring that this candidate responds to emerging EU reporting needs and aligns with future monitoring expectations.

Transition to Operations, Roadmap and Potential Timing for Integration

The transition to operations for this candidate will require targeted advancements across methodological, data, and implementation dimensions to elevate the service from its current developmental state to an operationally viable CLMS product.

- Strengthening the availability and harmonization of reference datasets is the most critical enabler, as robust, multi-regional in-situ data are essential for improving classification accuracy and ensuring reliable distinction among the key cover crop types required by users.
- Strengthening user understanding of classification constraints and expected accuracy levels

- Expanding demonstrations beyond the initial test region will be equally important to assess model transferability across diverse agronomic conditions and to refine algorithms accordingly.
- Efforts should focus on stabilizing the processing workflow, enhancing the hierarchical classification logic, and defining clear accuracy expectations for different thematic levels so that users can make informed decisions.

Close collaboration with stakeholders such as the EEA, JRC, and national paying agencies will guide these developments and ensure alignment with policy reporting needs under the CAP. With coordinated capacity building, iterative validation, and progressive scaling, this prototype can mature into a consistent, user-trusted operational service within the Copernicus Land Monitoring portfolio.

The roadmap for the development of this candidate emphasises overcoming key technical and data-related challenges before the prototype can progress toward operational integration.

The primary bottleneck is the lack of consistent, high-quality reference data across Member States, which prevents robust model training and limits the ability to distinguish more detailed cover crop types. Enhancing the typology, improving separability between classes, and validating the approach in multiple regions will be essential steps in advancing this candidate. Indeed, the prototype is still at a low readiness level and has been tested only in Belgium, but the underlying EO data sources (Sentinel-1/2 and HRL VLCC) enable EU-wide scalability.

Given these constraints, integration of this candidate into the CLMS is unlikely in the near term. Its development timeline is closely tied to the broader Copernicus 2.0 horizon extending to 2027 and beyond. Only once sufficient European-wide reference data become available and accuracy requirements are met can move this candidate toward pre-operational or operational status.

In the short term, improvements will focus on expanding datasets, refining methods, and engaging stakeholders, while medium- to long-term integration will depend on meeting accuracy, thematic detail, and data coverage expectations.

Candidate: C05 - Cropland/grassland GPP monitoring

(1) Candidate Description

User Needs	To develop an accurate GPP product tailored to croplands and grasslands, usable from field to national levels (multi-scale productivity information) to support applications such as yield estimation, drought assessment, and carbon flux monitoring (see below use cases).
Use Cases	- Yield estimation and agricultural performance monitoring - Drought impact assessment and early warning - Field-level and regional productivity mapping for CAP reporting - Support to carbon budget assessments and ecosystem flux evaluation

Pre-existing Know-How	Within the CLMS, the current GPP estimation is provided at 300m resolution which are often insufficient for monitoring productivity dynamics at the field level. The production uses an improved Light Use Efficiency model and medium-resolution satellite images (e.g., Sentinel-3, MODIS). Additionally, the parameters and algorithms used are not specifically tailored to capture the productivity dynamics of agricultural lands such as cropland and grassland.
Evolution of Requirements	To improve upon existing coarse-resolution and deliver accurate, multi-scale productivity GPP information tailored to croplands and grasslands: - With a 10-meter resolution - Available every 10-day
Proof of Concept Achieved	The prototype developed uses Sentinel-2 data to produce GPP estimation at 10 m resolution over cropland and grassland locations. It has been assessed the test site for 2018 and 2022: 3 – Belgium The LUE model has been calibrated and validated using GPP in-situ data measured in ICOS towers in grassland and croplands. A 75/25 split of available in-situ data is used for the calibration/validation split. Assessment results and perspectives are given in next section.
Online Showcase	EVOLAND: Cropland/grassland GPP monitoring

This EvoLand candidate prototype develops high-resolution Gross Primary Productivity data (10-daily, 10 m) for grassland and cropland across Europe. Using an enhanced Copernicus GPP algorithm, calibrated and validated with ICOS Eddy Covariance in-situ data, it enables detailed evaluation of biomass and crop yield development within fields. A key improvement is the refined drought and temperature stress component, which better captures the impact of extreme weather on vegetation productivity, supporting more accurate monitoring of crop performance under climate variability

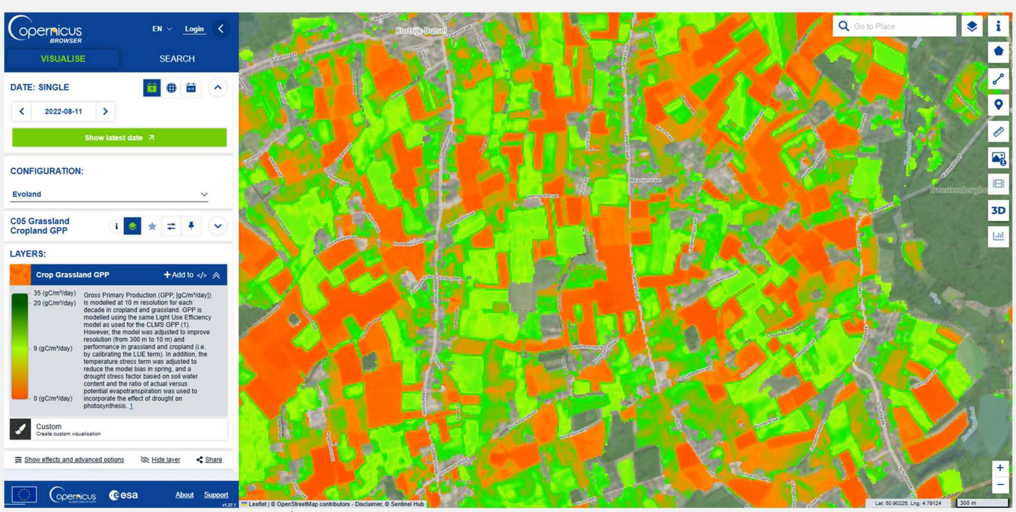


Figure 7. Cropland/Grassland GGP prototype for 11.08.2022 in Belgium.

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- A clear strength for this prototype is having demonstrated its strong technical potential to increase spatial resolution from 300 m to 10 m, which enables meaningful within-field productivity monitoring.
  Recalibrating the LUE model for cropland and grassland enhances its relevance for agricultural applications, while validation against ICOS flux tower data shows high precision, particularly for cropland. This candidate prototype also aligns well with user requirements for frequent updates, high-resolution monitoring, and the detection of management and harvesting events, addressing clear gaps in current CLMS GPP products.
- However, technical feasibility is still constrained by several limitations:
  - ✓ The prototype has only been implemented for one site and two reference years due to limited in-situ data, which restricts its ability to demonstrate robustness across diverse European conditions. This restricted rollout naturally limits early user engagement and prevents wider evaluation of the product across different agricultural conditions.
  - ✓ For both grassland and cropland there is still an overestimation of the GPP by the model, overestimation of the GPP by the model is mainly in the summer months. Though, in comparison with the original GDMP model the final prototype model clearly decreases the negative bias in springtime for cropland and reduces the positive bias in the summer months for both grassland and cropland
  - ✓ Moreover, the approach depends heavily on ICOS flux towers for calibration and validation, wherefore coverage remains sparse across Europe.

As a result, geographical transferability, scalability, and consistency across varying environmental conditions remain unproven.

Considering User Oriented Assessment,

- From a user perspective, the prototype is well aligned with expressed needs for finer-resolution productivity information and decadal updates to detect management practices and harvesting events, supporting CAP monitoring and climate assessments. Its ability to deliver high temporal detail and improved spatial granularity holds strong promise for operational uptake once the service is mature.
- Broader testing and improved accuracy will be essential before widespread adoption becomes feasible.

Political Framework & Roadmap

Policy and User Perspective

GPP is a measure of above ground biomass in croplands and grasslands. It is relevant for eco-scheme payments under the EU Common Agricultural Policy (CAP) and is also of interest for estimation of yields for food security. Since GPP also indicates carbon uptake it is also relevant input data for the LULUCF directive and may also be applied in the Carbon Removal Certification Framework (CRCF).

Key users include CAP Paying Agencies who must assess compliance with eco-schemes, national or regional food security agencies, agencies responsible for building national LULUCF inventories and various actors along the carbon farming value chain.

Engagement with core stakeholders such as DG AGRI, DG ENV, the JRC, and national paying agencies will help align the product with CAP reporting workflows and real operational demands.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

The political framework for this candidate is defined by the evolution of the CLMS under Copernicus 2.0, which aims to deliver higher-resolution, policy-relevant agricultural monitoring to support CAP implementation, climate reporting, and drought and productivity assessments. This candidate directly responds to these needs by proposing a 10 m, 10-daily GPP product that fills critical gaps left by current 300 m CLMS layers.

The roadmap for this candidate is shaped by its current technical maturity and dependency on robust reference data. Although the prototype demonstrates clear improvements—most notably increasing GPP resolution from 300 m to 10 m and refining the LUE model for agricultural land—, its development has been limited to one Belgian test site and only two reference years due to data constraints. Persistent issues such as GPP overestimation during drought periods and underestimation in the off-season also need to be resolved. Advancing this candidate will require validating the model across additional land-cover types, improving stress factors to reduce seasonal biases, expanding testing to more regions to assess transferability, and ensuring workflow scalability through OpenEO.

Scaling the service depends heavily on access to high-quality reference data—particularly ICOS flux tower measurements and harmonised meteorological inputs—which remain sparse across Europe. Furthermore, multi-site, multi-year validation has not yet been achieved due to limited demonstration.

Transition to Operations, Next Steps

The transition to operations for this candidate will require strengthening both the methodological robustness and the scalability of the processing chain so that high-resolution, 10-daily GPP products can be reliably generated across all agricultural regions of Europe.

While the prototype has already demonstrated strong performance — particularly through its crop— and grassland-specific calibration and its validation across numerous sites — further refinement is needed to ensure stable performance under diverse environmental conditions, including drought periods and off-season variability.

Expanding the in-situ data pipeline will be critical for sustaining calibration accuracy and improving model sensitivity to water stress, while continued optimization of the LUE-based workflow in cloud environments will support EU-wide production at the required cadence.

With these advancements, this candidate prototype can mature into a dependable CLMS component that provides actionable productivity intelligence from field scale to continental level.

Capacity building for this candidate will therefore need to focus on improving access to high-quality calibration and validation datasets, particularly expanding the use of ICOS tower measurements and harmonising ancillary meteorological and land-cover inputs across Europe. The report highlights that 21 ICOS towers were used for model calibration and validation, demonstrating the essential role of flux tower networks in enabling user confidence. As the prototype progresses, expanding this network of reference sites and supporting users in understanding GPP modelling concepts, such as light-use efficiency (LUE) adjustments and stress factor interpretation, will be critical for adoption. Guidance on interpreting uncertainties—such as seasonal biases and overestimation patterns documented in the validation results—will also help build user trust and analytical capacity.

Finally, the migration of the workflow to openEO is identified as a key enabler for future uptake, offering a scalable and interoperable processing environment. Capacity-building efforts will therefore need to include training on cloud-based processing, data pipelines, and accessing the high-resolution GPP products in operational contexts. With continued methodological refinement and expansion to additional regions, this candidate prototype has strong potential to become an operationally valuable product for agricultural monitoring, but its current user-readiness remains limited until broader validation and user-oriented support structures are established.

Candidate: C06 - Small Landscape Features

(1) Candidate Description

User Needs	To map the woody vegetated features outside forest and stable landscape features within agricultural areas (grass margin, stone walls, ditches)
Use Cases	✓ Soil and water conservation ✓ Biodiversity support ✓ Carbon sequestration ✓ Cultural Identity and rural landscape functionalities ✓ Indicator for CAP
Pre-existing Know-How	Current Small Landscape Features and Forest products (SWF) from CLMS for full Europe coverage which maps hedgerows and tree patches across Europe.
Evolution of Requirements	Enhance the product and enlarge thematic domain to small landscape features as follows. - SWF standard classes + additional classes derived from new Earth Observation (EO) datasets: grass margin, ditches, stone walls, ponds

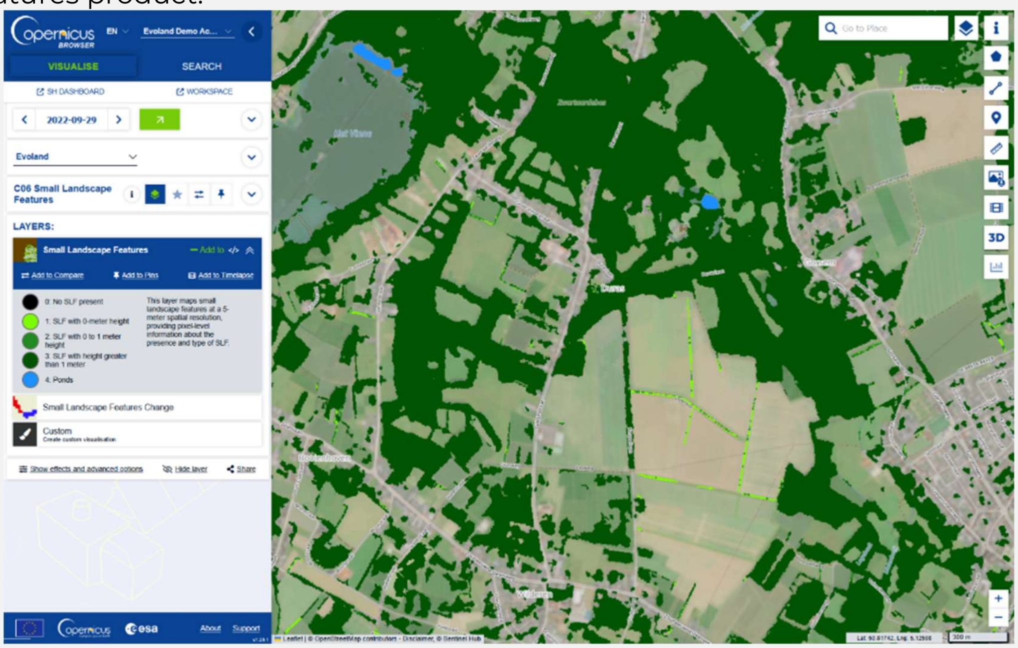
<table>
<tr><td></td><td>- 5 meters resolution
- Annual production</td></tr>
<tr><td>Proof of Concept Achieved</td><td>The prototype developed has demonstrated the feasibility for mapping Small Landscapes Features (SLF), that is hedgerows and tree patches and ponds across Europe for 2020–2022, annual, for 3 European sites (see figure 1):
1 – Spain
3 – Belgium
6 – Eastern Europe
Assessment results and perspectives are given in next section.</td></tr>
<tr><td>Online Showcase</td><td>EVOLAND: Small Landscape Features Mapping</td></tr>
<tr><td colspan="2">This EvoLand candidate prototype aims to improve the mapping of Small Landscape Features (SLF) across Europe, including woody elements, stone walls, ditches, ponds, field margins, and tracks. Leveraging novel EO data, it seeks to enhance both the accuracy and efficiency of the existing CLMS HRL Small Woody Features product.


Figure 8 : Small Landscape Features (SLF), that is hedgerows and tree patches and ponds in Booienhoven (Belgium) for the reference year 2021.</td></tr>
</table>

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- Compared to the existing SWF of the Copernicus portfolio, the results show that the hedgerows are detected at a finer resolution and present 3 subclasses. Moreover, it is complemented with small ponds that is a new class which does not exist in the current portfolio.
- Nevertheless, the production of SLF, is conditioned by two major elements. The products require (i) very high spatial resolution EO data at a minimum of 5m and (ii) adequate in-situ data. The VRH EO data can currently come only from

commercial data, or with super-resolved Sentinel 2 which is not a standard product which requires intensive pre-processing capacity. The in-situ data are rarely of good quality and often not harmonised form one site to the other (country or region).
- Also, ditches and stone walls are not detected at a high accuracy with only optical high resolution. As their identification is related to micro changes in the topography, the use of Lidar data in combination with VHR optical data is a requisite to get a high confidence and accuracy in the product.

Considering User Oriented Assessment
- The small woody features will certainly be used primarily by European and national institutions for reporting, running spatial analysis with other datasets and derived gridded indicators.
- The CLMS represents the European data set, but the Member states might put opposite their own national data. Cross nurturing is then a key element in case national data sets better map comparable small features.
- Among the features included in the Small Landscape Features, the woody vegetation layer is probably the most adapted to be used by EEA external users.
- While the prototype provides clear added value by offering annual updates of features adapted for the new CAP, a wider use is limited due firstly to a lack of awareness. In addition, remaining classification inaccuracies looked at local scale by practitioners can reduce user confidence for operational use.
- Early uptake will therefore come mainly from expert and research-oriented users capable of interpreting uncertainties, while broader adoption will require clearer communication of accuracy, expanded validation across diverse regions, and improved consistency in ambiguous classes.

Political Framework & Roadmap

Policy and User Perspective

Small landscape features are critical for biodiversity, and so monitoring these is essential to National Restoration Plans under the Nature Restoration Regulation, which is also tightly linked to eco-schemes under the EU Common Agricultural Policy. Such features are particularly relevant for pollinators (EU Pollinators Initiative) and birds (EU Birds Directive). By allowing mapping of ecological corridors within cities they also contribute to Urban Nature Plans. The extent of features such as hedgerows is also a key input for reporting under the LULUCF regulation.

There is a wide potential user base for such a mapping service, including national, regional and local authorities with responsibilities for reporting under the NRR, CAP Paying Agencies who must assess compliance with ecoschemes, and urban planners looking at urban nature. They are also relevant for agencies responsible for building national LULUCF inventories.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

The political foundation of the C06 Small Landscape features prototype is closely linked to EU agricultural and environmental policy priorities, particularly the

Common Agricultural Policy (CAP) and the strategic evolution CLMS under Copernicus 2.0 and the EU biodiversity Strategy for 2030.

SLF directly respond to the need to monitor improvements in agricultural practices and measures to get more resilient biodiversity with better connectivity between patches of natural and semi-natural ecosystems.

Provided that relevant VHR EO data remains consistently available, it is estimated that the integration of the candidate into the CLMS portfolio, at least the SWF and the ponds, not the ditches nor the stone walls nor the grass margins, can take one more year for adaptation to nearly full automatised production. The product could then reach a high degree of maturity and a TRL 9.

To better monitor and report timely on the evolution of the SLF, the prototype targeted an update on an annual basis following a procedure of change analysis. The technical feasibility is there but is constrained by the desire to acquire VHR data every year.

Transition to Operations, Next Steps

The prototype demonstrates clear improvements, i.e. additional information, use of Sentinel 2 resampled at 5m spatial resolution, and ready for annual production, but the production needs to be upscaled to larger areas to better estimate the production time.

Omission errors are linked with spatial resolution of EO data (S2 super resolution) which limits detection of smaller elements. Improvement would require higher spatial resolution with same temporal resolution (e.g. dense time series of VHR).

Commissions errors are also linked to spatial resolution of input EO data, but also consistency (or in fact absence of consistency) with ancillary data (height information) which can allow to filter out false positive for new classes.

3.4 Candidates on Water Thematic

There is 1 candidate with the following relevant CLMS land cover and land use thematic domain:

#	Candidate name	Positioning in CLMS	TRL reached
C7	Water Bodies	EVOLUTION	5

The assessment results of this candidate prototype are recalled in section2. Key points and outcome for integration in the CLMS architecture are outlined below.

Candidate: C07 - Water Bodies

(1) Candidate Description

User Needs	To better understand changes in global water surface area, the production of accurate, regular, and comprehensive water extent data is essential.
Use Cases	✓ Drought risk impact assessment ✓ Flood monitoring / prevention (past floods)

	✓ Input to water stock monitoring (lateral connectivity) ✓ Input to assessment of wildlife migration patterns and change
Pre-existing Know-How	Within the framework of CLMS, water area delineation is a key component, which exists along 2 product lines: - Monthly mapping of water bodies at 100m resolution, - 3-yearly high-resolution layer water and wetness mask at 10m resolution over Europe, 100m elsewhere
Evolution of Requirements	Near real time mapping of water bodies extent at higher resolution (in a few days, 10m resolution) with nature of water bodies, permanent versus temporary.
Proof of Concept Achieved	The prototype developed demonstrates the feasibility over 2020-2022 for the following four test sites (see figure 1): 1- Spain 3 – Belgium 5 – Sweden 8 – Ivory coast Assessment results and perspectives are given in next section.
Online Showcase	[EVOLAND: Improved Water Bodies Mapping]()
This EvoLand candidate prototype maps water body extent at <10 m resolution to support analysis results for seasonal assessment, water transitions analysis.  *Figure 9: Temporary and permanent water bodies for Fuensanta reservoir in Spain, as of May 13rd, 2021. The temporary water bodies here (light blue) show that the reservoir is at a high-water level stage compared to the whole previous year (darker blue).*	

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- Using Sentinel-2 native 10m resolution and super-resolution techniques, it complements existing Copernicus HRL and global products,

1) improving the characterization of water resources and dynamics across diverse landscapes,
2) ensuring near real-time mapping, with low computation cost

- Results demonstrated in pilot sites have proven how relevant and robust they are. There are still some points to enhance (such as to get better performance in snow-covered areas, cloud detection, scenes with low sun zenith angles, and shadowed regions) but is now approaching operational readiness.
- The algorithm could be deployed in a production environment to generate NRT/STC or lower-frequency water masks.
- The super-resolution clearly enhances the accuracy and resolution of the estimates but suffers from long time calculation for NRT/STC approaches. The use of a priori areas of interest could lower the calculation time but would impact ephemeral and new water bodies detection. That is why now the super-resolution approach is not considered for now for an operational rollout.

Considering User Oriented Assessment,

- EvoLand suggests new ways to map water bodies extent at a finer resolution (<10m) using EO data and super-resolution techniques to better characterize water resources and water dynamics in different kinds of landscapes (crop, urban, mountains, forest).
- In one product you can detect the patterns and trends in water bodies from one year to another. This new statistical approach is a novelty that provides direct insights on the behavior of all water bodies.
- This product is potential going beyond user's need for the global scale. Il the NRT/STC product may still need some algorithmic enhancements for robustness issues, the monthly product proved to be reliable

Political Framework & Roadmap

Policy and User Perspective

Accurate knowledge of water dynamics is key to the EU's Water Resilience Strategy and to the EU Adaptation Strategy. At an international level it supports the UN Water Action Agenda. Such knowledge is also essential for local action plans for managing particular bodies of water (rivers or lakes), and for assessing flood risks under the EU Floods Directive. Since small water bodies are key natural habitats, this data also supports national strategies under the Nature Restoration Regulation, for example those relating to free-flowing rivers.

Key users include water management agencies at national, regional and local level, river basin authorities, local and regional authorities involved in flood management, and national or regional environment agencies.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

This product is essential for the climate adaptation process and related policy cycle because it helps to address multiple risks at multiple scales, from local scales to the global level, owing to the transboundary and cascading nature of climate risks.

Near-real-time mapping of water bodies from satellite imagery is indeed critical for effective water management. Users who have expressed their interest are

- The European Environment Agency (EEA), the Joint Research Council (JRC) – contracting authorities overseeing the Copernicus Land Monitoring Service (CLMS).
- The National and Regional Authorities – Environmental agencies, ministries, and local governments.
- The Scientific & Research Communities – Universities, research institutes, and pro-jects studying vegetation phenology, land cover dynamics, and climate im-pacts.

It is now key to work out project with them on concrete areas of risk to make the point and support promotional activities to reinforce user uptake and build capacities of more users for:

- <u>Drought risk management</u>, namely for the step 1 of the adaptation process, for <u>impacts knowledge and risk assessment on water scarcity</u> which are essential before planning can be made.
  - ✓ The provision of water pixels being permanent or temporary adds a new information on a drought impact on the water surface. It may help the deciders to have an accurate knowledge of the water availability at a given date, providing them with information about areas which are under water stress or not for better policy making.
- <u>Flood prevention / planning</u>, that is the step 2 of the adaptation process.
  - ✓ A proper and UpToDate flood extent delineation helps the deciders in where to dispatch the rescue teams, and which roads are to be closed to traffic. The knowledge of past flood events is also important for projection as well as to drive the choice to be made in adaptation plan (buildable areas or not, road construction suitability, presence of wetlands, etc.).
- <u>Water stock risk management</u>, namely for the step 1 and is the step 2 of the adaptation process.

  Hybridized with hypsometric or area-volume rating curves, the water bodies' areas can provide estimate of water quantity changes and stocks, allowing the development of water management capacities from space alone. Indeed, the knowledge of available water stocks at a given date may help to prepare the future needs and use at a regional level and drive the policies to be made. It can also help dam manager to take the action of filling or emptying a reservoir during snow melt or heavy rainfall events for instance, to avoid dam failures or overflowing, leading to flood events.

<u>Transition to Operations, Next Steps</u>

Considering the high level of TRL reached, we see three parallel steps to be conducted before full deployment and operations

1) The candidates should now be upscaled, tested on more sites with final optimisation and tuning of code.
2) With first use cases to assess the product and initiate user feedback, for instance in observing small waterbodies, lateral connectivity, support or barriers to wildlife migration, or developing policy use cases (see above paragraph)

3) To promote the products, considering user needs, service use cases and feedback as well as its link with the policy framework.

3.5 Candidates on Urban Thematic

There are 2 candidates with the following relevant CLMS land cover and land use thematic domains:

#	Candidate name	Positioning in CLMS	TRL reached
C8	Continuous imperviousness monitoring	EVOLUTION	5
C9	Automated land use mapping of urban dynamics	EVOLUTION	5

The assessment results of the candidate prototypes are recalled in section2. Key points and outcome for integration in the CLMS architecture are outlined below per candidate.

Candidate: C08 - Continuous imperviousness monitoring

(1) Candidate Description

User Needs	To better, more closely and more frequently monitor changes of imperviousness status within the whole EU extent.
Use Cases	✓ Urban planning ✓ Flood risk management ✓ Biodiversity and Environment ecosystem ✓ Climate change and environmental impact studies
Pre-existing Know-How	Within the CLMS portfolio, products on imperviousness have a long history (2006-2024), providing information on: - Imperviousness Density (10m, 3-yearly) - Impervious Built-Up (10m, 3-yearly) - Imperviousness Change (20m, 3-yearly) - Imperviousness Change Classified (20m, 3-yearly) - Impervious Built-Up Change (20m, 3-yearly)
Evolution of Requirements	Need for monthly incremental updates (instead of every 3 years) of high-resolution layers (5m)
Proof of Concept Achieved	Continuous monitoring techniques and integration of new EO data has been assessed for this prototype development on the following sites (see figure 1) over 2020-2022, every 6 months: 2 – Southern France 3 – Belgium 6 – Central Europe Assessment results and perspectives are given in next section.
Online Showcase	EVOLAND: Continuous Imperviousness Monitoring
This EvoLand candidate prototype develops continuous monitoring of soil imperviousness, building on the HRL Imperviousness product. By integrating	

new EO data and continuous monitoring techniques, it aims to enable incremental updates and improved tracking of sealed areas.

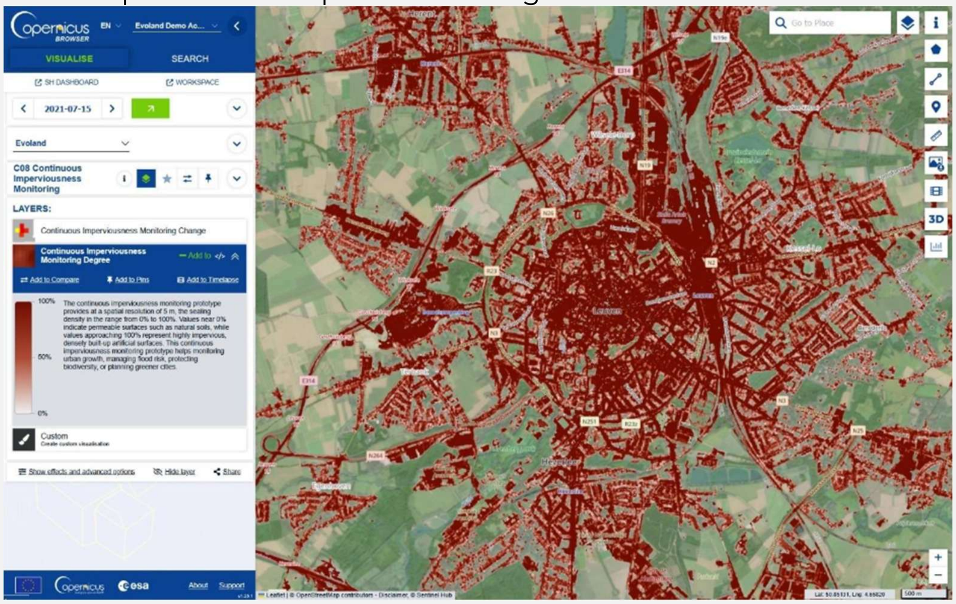


Figure 10 Degree of imperviousness on the city of Leuven and surrounding area (Belgium)

An animated demonstration of imperviousness detection can be seen on [Recording 2025-11-07 at 10.09.14.gif]

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- Using Sentinel-2 super-resolution technology has shown significant promise, enhancing the precision and overall quality of the processed data, it complements and improves the existing Copernicus HRL (spatial resolution and higher update frequency).
- Due to its high scoring for the operational feasibility, this candidate is ready to be tested at a larger scale. The current processing time of 2h per tile can be reduced with more adapted processing infrastructure (e.g. use of GPU) and will therefore impact the frequency of updates.
- The algorithm is ready to be deployed in a production environment and undergo some performance testing according to the processing capacities.
- The performance to update more frequently the imperviousness layer brings another challenge when addressing the change issues. This has not been addressed in this project, but it would require particular attention in the implementation as a service.

Considering User Oriented Assessment,

- The candidate is also ready to be proposed to end users to gather their feedback and level of satisfaction. New demonstration of processing capacities can be taken to assess the fitness for purpose and compare this improved product to the existing CLMS products.

- The ability of this candidate to deliver high temporal detail and improved spatial granularity holds strong promise for operational uptake. It is ready to be confronted to its use for urban planning or flood risks management for example.

Political Framework & Roadmap

Policy and User Perspective

Soil sealing, as characterised by imperviousness, is one of the key parameters to be monitored under the Soil Monitoring Law, part of the EU Soil Strategy. Imperviousness is also relevant for resilience to flooding and coastal degradation, and as such supports the EU Adaptation Strategy and the corresponding National Adaptation Plans. Imperviousness also supports monitoring the extent of urbanisation, relevant to various policies under the EU Cohesion Policy.

There are a range of potential key users, including National Competent Authorities for soil monitoring (designated under the Soil Monitoring Law), Environment Agencies, River Basin Authorities and Regional Authorities involved in climate adaptation, including flood planning, and local and municipal authorities dealing with local flood strategies.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

The political foundation of the Imperviousness candidate prototype is directly linked to the new EU directive on Soil Monitoring and resilience (Soil Monitoring law) where the degree of imperviousness is a key parameter to follow for the monitoring of the sealed surfaces in EU. It is also interesting for the development of (i) policies that regulate land-use planning, environmental conservation (EU's Biodiversity strategy for 2030), and climate adaptation and (ii) the strategic evolution CLMS under Copernicus 2.0 & 3.0.

Transition to Operations, Next Steps

For the transition to an operational product, the methodology needs to be further improved as stated below:

- Future efforts should prioritize the integration of advanced classification algorithms widely regarded as best-in-class by global scientific community that could bring significant improvements compared to existing techniques implemented in EvoLand. It seems essential to prioritise the development of AI and deep learning methodologies. It would help reducing commission errors that appear to be underestimated with persistent confusion in differentiating rocks or bare soils
- Although the contribution of the Sentinel-2 super-resolution technology is promising in terms of enhancing data quality, the current computation time is prohibitively high for envisaging its full operationalization on a pan-European scale. Furthermore, the potential improvement of the spatial resolution would constitute a paradigm shift. Future works will also provide an opportunity to assess the potential for area statistical issues in the context of the improved 5-

metre spatial resolution. As we have previously observed, the transition from 20 metres to 10 metres during the HRL IMD 2018 production presented certain technical challenges. It is therefore important to assess the impact of an increased spatial resolution on the statistics for the sealed area. To guarantee temporal consistency, it is essential to obtain meaningful and accurate statistics about the sealed surfaces in Europe, which is a fundamental element in the policy-making process.

- The change detection component is not yet fully mature. Reliable change detection will require further research to address challenges such as pixel misregistration and acquisition variability. Developing more robust and resilient methodologies will be essential to ensure consistent and accurate results.

Candidate: C09 - Automated land use mapping of urban dynamics

(1) Candidate Description

User Needs	To monitor changes in urban areas, that is for urban sprawl, urban renewal and renaturation
Use Cases	- Monitoring No Net Land Take (NNLT) - Identifying Illegal Dumping Sites and Unplanned Construction
Pre-existing Know-How	Within the current CLMS, the product exists exposing delineation of changes plus de-tailed characterization of these changes: construction / landfill, sealed, natural / agricultural, woody, water at 5 m resolution
Evolution of Requirements	To automate the mapping of the urban dynamics to get annual updates instead of the current three-year cycle.
Proof of Concept Achieved	The prototype developed has allowed to generate first products mapping urban changes between 2020-2021 and 2021-2022 on the following sites (see figure 1): 2 – Southern France 3 – Belgium 4 – Central Europe 8 – Ivory Coast Assessment results and perspectives are given in next section.
Online Showcase	[EVOLAND: Automated Urban Land Use Mapping]()
This EvoLand candidate prototype develops detection and characterization of urban changes. Using Sentinel-2 optical imagery and an automated processing chain based on machine learning, it enables annual changes mapping. Deep learning-based super-resolution technique enhances spatial detail, delivering results at 5-meter resolution for accurate monitoring of complex urban dynamics.	

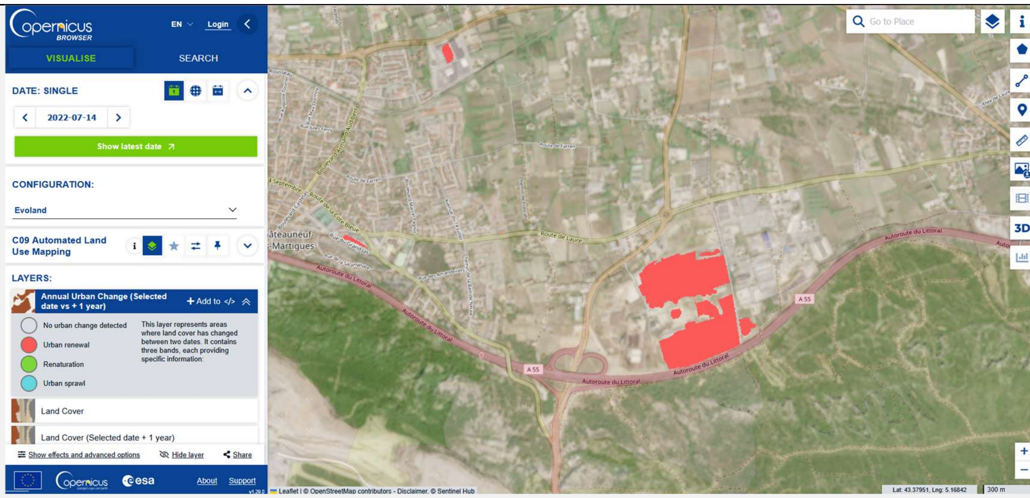


Figure 11. C9 product visualization on the Copernicus Browser

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

- The semi-automated processing chain provides an approach for mapping urban dynamics, allowing changes in the urban environment to be detected in a consistent and repeatable manner.
- It delivers two types of information simultaneously by identifying both the spatial extent of detected changes and the specific category to which these changes belong.
- Compared with the existing Urban Atlas product — which offers now a 3-years updates — the prototype achieves a more refined temporal resolution of one year, enabling more responsive monitoring of urban transformations.
- The integration of Super-Resolution applied to Sentinel-2 data enhances the spatial detail of the imagery, thereby improving the automated detection extent.
- However, the reduced performance observed in the Côte d'Ivoire test sites highlights limitations in the generalization of the method. Consequently, it is recommended that the system be applied only to European regions, and under the same input data conditions and processing environment as those used during development.
- Despite the overall effectiveness of the approach, some confusion persists between specific land use classes during classification, indicating that certain urban categories remain challenging to discriminate using the available spectral and spatial information.

Considering User Oriented Assessment,

- This tool is a valuable complement for urban planning activities, particularly in workflows that require early detection and prioritization of urban development or transformation.
- Image-based analyses primarily focus on land cover rather than land use. To advance towards a more detailed classification and align with project-oriented nomenclatures such as Urban Atlas, it is crucial to integrate reliable, regularly updated in-situ data—a component that is currently lacking.

Political Framework & Roadmap

Policy and User Perspective

- Up-to-date monitoring of urban dynamics is essential for city planning and for meeting reporting requirements under several EU environmental and climate policies. This type of information directly supports the development of Urban Nature Plans and contributes to reporting obligations under the Nature Restoration Law, which requires Member States to ensure a no net loss of green urban spaces by 2030.
- The prototype responds particularly well to the objectives of the EU Soil Strategy for 2030 and the forthcoming Soil Monitoring Law, which sets the long-term target of achieving no net land take by 2050. Because urban expansion and densification are key drivers of land take, the ability of the prototype to detect changes in built-up areas provides directly relevant data for these policy frameworks.
- It also aligns with the LULUCF Regulation (Land Use, Land-Use Change and Forestry), which requires robust monitoring of land-use transitions.

Concerning the relevance for Key user Groups,

- Potential primary users include urban planners, local and regional governments, and national authorities.
- Such users benefit from a regularly updated, automated overview of where urban transformation is occurring, which supports both policy compliance and local planning processes.

Product positioning in CLMS, Roadmap and Potential Timing for Integration

- The prototype can serve as a supporting or verification layer for the production of Urban Atlas (UA), helping identify areas where manual revision or validation is required.
- It can be used in parallel with Prototype C8 to monitor urban changes and, by extension, to track associated variations in imperviousness, offering complementary insights for urban monitoring workflows.
- Given its ability to detect both the extent and the type of urban changes, the product fits naturally as an intermediate change-detection layer within CLMS, strengthening existing update mechanisms.
- Its value lies particularly in its potential to provide early indicators of urban transformation, enabling CLMS operators to flag priority zones ahead of full map production.

Transition to Operations, Next Steps

- The methodology for detecting changes should be reviewed and potentially replaced by a more thematically oriented change-detection algorithm, capable of improving class differentiation — to orient the targeted changes, and a deeper exploration of deep learning–based approaches is recommended, to reduce errors observed in complex environments.
- To support operationalization, the automation of input imagery acquisition—whether through direct download or cloud-based ingestion—should be implemented. This would streamline the workflow, reduce manual intervention, and make the chain more scalable.
- A thorough scalability assessment of the processing chain is required to confirm that computational resources and infrastructure can support large-scale or pan-European deployment, particularly when using higher-resolution (5 m) Sentinel-2 derivatives.
- The product should be positioned primarily as an intermediate change-detection layer, intended to guide or assist manual production, rather than a fully standalone update product that fully meets all Urban Atlas specifications.
- The quality and reliability of change detection remain constrained by the availability of accurate, up-to-date in-situ data, which is currently inconsistent across countries. Progress toward operationalization will therefore depend on improving access to harmonized, regularly updated ancillary data sources.

3.6 Candidates for General / Universal Land Cover Thematic

There is 1 candidate with the following relevant CLMS land cover and land use thematic domain:

#	Candidate name	Positioning in CLMS	TRL reached
C10	Continuous mapping of land surface categories (LSC)	NEW	6-7

The assessment results of this candidate prototype are recalled in section2. Key points and outcome for integration in the CLMS architecture are outlined below.

Candidate: C10 - Continuous mapping of land surface categories (LSC)

(1) Candidate Description

User Needs	To provide continuous , high-resolution (10 m) information on key land surface categories — such as vegetation type, bare soil, water presence, and other surface conditions — as input for downstream services, e.g., a first rapid situational awareness and understanding of transitions between surface states, ranging from water dynamics mapping to ecosystem monitoring, detecting short-term processes such as harvesting, emergence, or wetness

	fluctuations (see below use cases) and land cover mapping.
Use Cases	- Inputs for hydrological, ecosystem, and climate models - Support for water dynamics mapping, including detection of temporary vs. permanent wetness - Monitoring harvesting, planting, and vegetation emergence events - Near-real-time land surface condition tracking for environmental reporting and emergency response
Relevant CLMS Thematic Domain	Land cover & land use mapping: **Land cover products**
Pre-existing Know-How	Existing CLMS products provide valuable discrete land cover classes updated seasonally or annually, along with thematic HRLs, but they do not offer continuous, pixel-level probabilities or near-real-time state characterization. Current land surface information (e.g., snow, water, imperviousness, vegetation conditions) exists in separate layers and at differing resolutions, limiting cross-domain interoperability and timely change detection.
Evolution of Requirements	To provide harmonized, flexible, and seamless land surface descriptors capable of supporting multi-domain applications: - Near Real Time products (cadence of 3-10 days, minimum latency) - At 10 m resolution - With probabilistic or continuous variables rather than rigid classes, - Ensuring consistency with existing CLMS layers - Suitable for integration/use into workflows of other candidates, hydrological modelling, soil moisture assessment, and agricultural monitoring.
Proof of Concept Achieved	The prototype developed generates new continuous land surface characteristic layers at 10 m resolution using Sentinel-1 and Sentinel-2 time series. It has been assessed on multiple demonstration sites (see figure 1) over 2020-2022 (monthly updates for 3 years, single scenes): 1 – Spain 2 – Southern France 3 – Belgium 4 – Central Europe 5 – Sweden 6 – Eastern Europe 8 – Ivory coast Assessment results and perspectives are given in next section.
Online Showcase	[EVOLAND: Continuous mapping of LSC]()
This EvoLand candidate prototype develops continuous 10 m land surface categories products for trees, shrubs, herbaceous vegetation, bare, water, snow/ice, built-up, shadows and clouds complementing CLMS land cover	

products. Using Sentinel-2 data and AI-trained models, it aims to improve timeliness and the thematic flexibility of land cover maps.

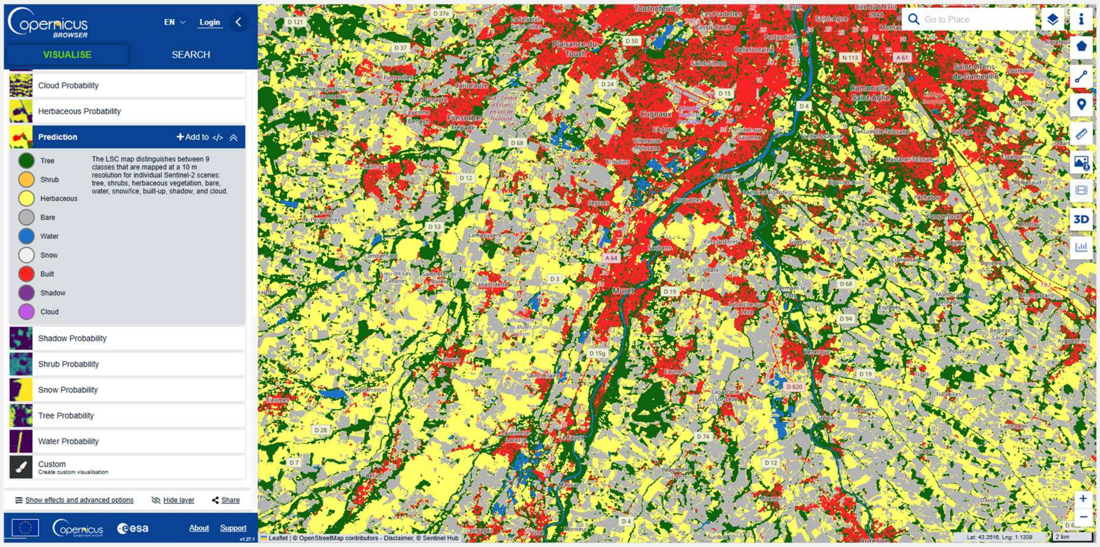


Figure 12. Continuous mapping of LSC of Toulouse (FR) for 03.08.2022.

(2) Integration Plan

Feedback from Feasibility Study, Strengths & Limitations

Considering Technical Assessment,

Clear strengths have been evidenced for this candidate prototype as follows:

- It has demonstrated a strong technical feasibility in implementing a modern deep-learning architecture (EVONet) designed to capture both contextual and fine spatial information, merging convolutional and pixel-based features to map land surface characteristics at high resolution, achieving an overall accuracy of approximately 82%.
- The method benefits from extensive use of Sentinel-2, DEM, and climatic embeddings, and employs automated annotation workflows to generate large training datasets efficiently, which supports scalability and reduces reliance on manual labelling.
- These characteristics make the prototype broadly transferable across biogeographical regions, and performance is generally robust for major physical surface classes such as trees, shrubs, herbaceous vegetation, bare land, and water.

However, several limitations remain:

- Achieving consistently high accuracies across all classes is challenging, particularly for classes with subtle spectral differences such as shrub versus other vegetation, which show lower accuracies and may vary depending on regional class distributions.
- The reliance on single-scene classification, combined with the sensitivity of some classes (e.g., snow, clouds, shadow) to acquisition conditions, introduces variability that can affect product reliability.

- Although the automated annotation workflow is efficient, it depends heavily on rules derived from annual land-cover layers and spectral indices, which may propagate downstream classification uncertainties.
- The prototype provides valuable fine-scale, timely land-surface information, showing its ability to detect transitions and seasonal dynamics, yet its operational deployment would require reliable cloud and shadow detection and further refinement of ambiguous vegetation classes to meet uniform accuracy expectations

Considering User Oriented Assessment,

- From a user perspective, the user uptake maturity is however still emerging, reflecting the novelty of Land Surface Categories product.
- While the prototype provides clear added value by offering near-real-time, high-resolution land-surface classifications—addressing long-standing gaps in existing CLMS land-cover products—its adoption is limited by remaining classification ambiguities and artefacts that reduce user confidence for operational use.
- Early uptake will therefore come mainly from expert and research-oriented users capable of interpreting uncertainties, while broader adoption will require clearer communication of accuracy, expanded validation across diverse regions, and improved consistency in ambiguous classes.
- Capacity building will be essential, particularly training on interpreting continuous land-surface outputs, understanding the automated annotation workflow, and accessing the service via cloud-based platforms such as openEO.
- With further refinement, expanded validation datasets, and sustained user engagement, this candidate has strong potential to evolve into a widely used component of future CLMS monitoring services.

Political Framework & Roadmap

<u>Policy and User Perspective</u>

Based on user feedback, annual product updates are sufficient for most policy reporting purposes, since policies such as the <u>LULUCF regulation</u> or <u>NRR</u> call for yearly reporting. Continuous mapping is instead used to monitor rapidly changing characteristics, such as snow extent over time, or to create alerts, e.g. for loss of grassland in a protected area.

As such the users of such a service are more operational, such as environmental agencies or ecosystem managers. In principle such data could also be used by regional bodies or urban authorities, though current uptake is low.

<u>Product positioning in CLMS, Roadmap and Potential Timing for Integration</u>

This candidate sits squarely within the broader Copernicus 2.0 ambition to modernise and extend land monitoring capabilities toward near-real-time, high-resolution, and thematically flexible products. Current operational land-cover datasets—such as ESA CCI (300 m), NASA MCD12Q1 (500 m), and CGLS Land Cover (100 m)—update annually and operate with fixed legends. <u>The analysis highlights</u>

that these products are insufficient for emerging EU policy needs that require timely, seasonally responsive, and adaptable land-surface information, particularly for monitoring anthropogenic pressures, environmental state, and ecosystems' evolution. This candidate therefore aligns with future CLMS user requirements gathered (see section 2), which emphasise the need for faster, more flexible land-surface characterisation to support policy implementation across climate, biodiversity, agriculture, and land degradation agendas.

The roadmap for this candidate prototype is shaped by both its strong technical performance and several dependencies that must be addressed before operationalisation. The prototype successfully demonstrates the feasibility of continuous, near-real-time mapping of land surface categories using a deep-learning architecture and multimodal inputs, and its implementation across three demonstration sites meets CLMS scalability principles. However, the prototype still shows confusion between certain classes (e.g., built-up vs. bare; woody vegetation vs. sparsely vegetated areas) and artefacts such as water misclassification in topographic shadows, indicating the need for further refinement of the classification pipeline.

Additionally, the EvoLand outlook highlights that the availability of high-quality training data at pan-European scale remains a major limiting factor for several prototypes, including general land cover services like this candidate. Improving access to harmonised reference datasets (e.g., snow/ice masks, height models, ground-truth land cover) is considered essential before operational deployment. Scalability to a continental extent is technically feasible but will need validation across diverse European conditions and seasons.

Transition to Operations, Next Steps

The transition to operations for this prototype should focus on strengthening the stability, scalability, and thematic consistency of its near-real-time 10 m land surface outputs so that they can reliably support a wide range of downstream applications.

Although the prototype has already demonstrated strong potential—achieving solid accuracy levels and providing flexible, probabilistic surface descriptors that complement existing CLMS layers—further work is needed to ensure robust performance across Europe's diverse environmental conditions, including dry regions where class probabilities fluctuate seasonally.

Enhancing harmonization with other CLMS products, optimizing the processing chain for continuous EU-wide generation, and improving the integration of Sentinel-1 and Sentinel-2 time series will be key steps toward operational readiness.

Expanding the validation framework and engaging closely with stakeholders such as the EEA, JRC, and thematic user communities will ensure that the service evolves in line with policy needs and operational workflows. With progressive refinement and scaling, this candidate can become a versatile CLMS product supporting water dynamics, agricultural monitoring, environmental change detection, and cross-domain analyses.

4. Conclusion & Outlook

The EvoLand project aims to support the evolution of the Copernicus Land Monitoring Service (CLMS) under Copernicus 2.0 and 3.0 strategies. These strategies focus on:

- Copernicus 2.0: Optimize and extend current services focusing on better performance (higher spatial resolution, better timeliness, and thematic detail) to meet EU policy needs (e.g., CAP, biodiversity, climate adaptation).
- Copernicus 3.0: Deliver next-generation, policy-driven, user-tailored products, integrating AI/ML, near-real-time monitoring, and interoperability across domains designed around EU strategic objectives for climate, resilience, and sustainability.

The project has gathered user needs, developed prototypes to address them, and assessed the resulting candidate solutions against user requirements, technical feasibility, and policy relevance. It also outlines an implementation roadmap for integrating these candidates into the CLMS portfolio for entrusted entities, including shared strategic phases, upcoming activities, and candidate-specific next steps.

11 prototypes have been developed for 5 thematic domains:

- Forest (4 candidates): Continuous Forest Monitoring, Disturbance Mapping, Biomass Mapping, Tree Type Mapping.
- Agriculture (3 candidates): Cover Crop Type Mapping, Cropland/Grassland GPP Monitoring, Small Landscape Features.
- Water (1 candidate): Near real-time Water Bodies mapping.
- Urban (2 candidates): Continuous Imperviousness Monitoring, Automated Urban Dynamics Mapping.
- General Land Cover (1 candidate): Continuous Land Surface Categories mapping.

Some candidates already exist within the CLMS portfolio and are marked as an EVOLUTION of current service to better match user & policy needs, some are INITIAL, worked out within other R&D projects, while others are completely NEW.

Table 3. EvoLand candidates.

Domain	#	Candidate name	Positioning in CLMS
Forest	C01	Continuous Forest Monitoring	EVOLUTION
Forest	C02	Forest Disturbance Mapping	NEW
Forest	C03	Forest Biomass Mapping	NEW
Forest	C12	Tree Type Mapping	INITIAL
Agriculture	C04	Cover crop type mapping	INITIAL
Agriculture	C05	Cropland/grassland GPP monitoring	EVOLUTION
Agriculture & Forest	C06	Small Landscape Features and Forest (SWF)	EVOLUTION
Water	C07	Water Bodies	EVOLUTION
Urban	C08	Continuous imperviousness monitoring	EVOLUTION
Urban	C09	Automated land use mapping of urban dynamics	EVOLUTION

Land Cover	C10	Continuous mapping of land surface categories (LSC)	NEW

The EvoLand project has provided a major step toward the next-generation of CLMS, delivering first prototypes in line with the Copernicus 2.0 and 3.0 strategies. Key findings are:

- Most prototypes align well with user requirements and show strong potential for CLMS integration: higher resolution, improved timeliness, and thematic flexibility
- Candidates support major EU policies like LULUCF Directive, EU Deforestation Regulation, Nature Restoration Regulation, Common Agricultural Policy, EU Soil and Water Strategies, Climate Adaptation Strategy, and more (see Table 4)
- Remaining challenges are due to the current limited access / availability to training/validation data, to VHR Earth Observation, and due to high processing loads for pan-European scaling. (see Table 5)
- One candidate, C12, has already been integrated into the CLMS portfolio, while C5 and C11 are currently being brought into operation by the EE.

A roadmap as a timeline with next steps have been discussed per candidate and resumed in 3 actions, 2 successive steps and a transverse issue:

- Short-term (2026–2028): Improve methodologies, expand validation datasets & territories, and engage stakeholders.
- Medium-term (2029 onwards): Integrate most advanced candidates like Continuous Forest Monitoring (candidate 1 proposed by GAF), Water Bodies (candidate 7 proposed by CLS), and LSC mapping (candidate 10 proposed by VITO) into CLMS.
- Capacity building and user training are essential for adoption and should be initialised / worked out in parallel of development tasks. First user cases have been identified per candidate in section 3.

Table 4. Candidates support major EU policies.

Candidates	C01	C02	C03	C12	C04	C05	C06	C07	C08	C09	C10
Policy Framework \ Thematic domain	Forest				Agriculture			Water	Urban		Land Cover
Strategic evolution of CLMS under Copernicus 2.0 & 3.0	X	X	X	X	X	X	X	X	X	X	X
EU Common Agricultural Policy					X	X	X				
EU climate adaptation strategy		X						X	X		
EU Biodiversity strategy for 2030	X	X	X	X	X	X	X		X		
EU Forest Monitoring Law	X	X	X	X							
EU Deforestation Regulation (EUDR)	X	X		X							
Land use, land use change and forestry regulation (LULUCF)	X	X	X	X	X	X	X			X	X
Nature Restoration Regulation (NRR)	X										X
EU Soil Strategy / Soil Monitoring Law					X				X	X	
Carbon Removal Certification Framework Regulation (CRCF)			X		X	X	X				
National Restoration Plans							X				
Nature Restoration Regulation (NRR)							X	X			
EU Pollinators Initiative							X				
EU Birds Directive							X				
Urban Nature & Retstoration Plans							X			X	
UN Water Action Agenda								X			
EU Floods Directive								X	X	X	
EU Cohesion Policy									X	X	

Table 5. SWOT analysis.

Domain	#	TRL reached	**MAIN** STRENGTHS	REMAINING WEAKNESS	NEXT PRIORITY
Forest	C01	6	Almost fully automated, **improved resolution**	Very high processing loads, **delay in observing disturbance events**	Faster & better detection of the disturbance events, **fusion of the optical with a radar-based approach**
	C02	4	Robust technical approach & **computationally effective**	Lack of accuracy, **dependency on results of candidate prototype 1**	**Get adequate reference data** on different disturbance agents, improve accuracy of candidate prototype 1
	C03	4	**Technical feasibility proven** comparable workflow for 2 parameters	Saturation effects leading to **underestimation**	**Search for alternative input data**, test using INSAR radar data
	C12	5-6	Strong potential for **tree type classification,** high accuracy	Limited performance for **underrepresented classes**	Access high-quality reference data from **regional and national forest inventories**
Agriculture	C04	5	**Technical feasibility proven**	Lack of **consistent, high-quality reference data** for upscaling	**Stabilise the process workflow** till input data are there, strengthen the user understanding of classification constraints and expected accuracy levels
	C05	7	**Technical feasibility proven**	Limited in situ data, **underestimation in the off season**	Resolve data constraints and **stabilise performance** across more sites
	C06	3	Technical feasibility proven with **identification of new classes relevant to agriculture** aside forest classes	Acquire **VHR data every year &** use **adequate in situ data**	One more year for adaptation to nearly full automatised production, upscaled to larger areas to better estimate the production time, **cross nurturing with national data sets**

Water	C07	5	**Improve characterization of water resources and dynamics** across diverse landscapes, **near real-time mapping & fine resolution for low computation cost**	Improvement still needed in **snow-covered areas, scenes with low reflectance, cloud cover detection and shadowed regions**	Upscaled, tested on more sites with final optimisation and tuning of code, **identification of pilot-users**
Urban	C08	5	Fully automated, Use of Sentinel-2 super-resolution technology **improve spatial resolution and higher update frequency**	**Commission errors** underestimated with persistent confusion in differentiating rocks or bare soils, **heavy processing time (2h per tile)**	**Improve change detection** & current processing time of 2h per tile (incl. S2 super resolution), **integration of advanced classification algorithms** (AI and deep learning methodologies)
	C09	5	Almost fully automated. Use of Sentinel-2 super-resolution technology **improve temporal resolution**	**Confusion between certain classes** (bare soil vs construction sites / quarry)	Get more **accurate in-situ reference dataset** to better work on the land use and decrease the number of confusions
Land Cover	C10	6-7	Technical feasibility proven, **value of merging different source of data** (Sentinel, DEM & climate data), complex to use	Low accuracy, **confusion between certain classes** (e.g., built-up vs. bare; woody vegetation vs. sparsely vegetated areas)	**Identify & access harmonised reference datasets** (e.g., snow/ice masks, height models, ground-truth land cover) to resolve confusion issues, harmonize with other CLMS products

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