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Capacity for Copernicus REDD+ and Forest Monitoring Services

REDDCopernicus

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Initial Design of the Copernicus REDD+ Service Component

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Summary

This document contains information on the initial design of a potential Copernicus REDD+ Service Component. It describes the initial main technical and organizational elements of the proposed service based the user requirements and the review of existing technical capacities for EO based forest monitoring. A benchmarking procedure has been applied to a list of potentially suitable forest monitoring products/datasets for selecting those with the best 'fit-to-purpose' level for REDD+ related forest monitoring tasks. The technical description of these preselected products serve as the basis for defining the technical specifications of the concepts of a potential REDD+ Copernicus service component. The main organisational elements (including EU regulations related to Copernicus, C-DIAS, distinction Core/Downstream services) have also been considered in relation to the design and implementation of a REDD+ Core Service Component. This proposed design will be the baseline for the assessment and user endorsement within the Learning Exercises (WP4).

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Executive Summary

The present report aims at defining an initial design of a potential Copernicus REDD+ Service Component. It is planned however that further fine tuning and consolidation will be made from the feedback to be obtained from national stakeholders participating in the regional workshops during 'Demonstration cases' and 'Learning exercises' in second half of year 2020. This report builds on the experiences of the former work packages (WP1 and WP2), where general user requirements have been collected and where the existing technical capacities for EO based forest monitoring have been reviewed.

Starting from these findings, the main technical elements that are needed for a Forest Monitoring System for Measurement, Reporting, and Verification under REDD+ and/or for SFM were identified. A benchmarking procedure has been applied to a list of potentially suitable forest monitoring products/datasets that were established in the previous work package (WP2). A selection of those products/datasets with the best 'fit-to-purpose' level for REDD+ related forest monitoring tasks has been done based on various performance criteria, including requirements for technical REDD+ reporting, requirements raised during the stakeholder consultation as well as aspects of operationality.

For the final selection of the most appropriate products, criteria on the thematic potential to fulfil internationally agreed definitions were included, e.g. criteria on forest definition, on land use categories, on activity data or on IPCC Approach and Tier levels. The CALM level (from WP2) was used as indication for the maturity and degree of operationality of different products/datasets.

The benchmarking approach resulted in the pre-selection of seven forest monitoring products of potential interest: (i) Sentinel-2 composites, (ii) Tree Cover Density, (iii) Seasonality Products, (iv) Tropical Moist Forest dataset, (v) Forest Canopy Disturbance Monitoring, (vi) Breaks For Additive Season and Trend, and (vii) RADAR Forest Cover Loss Alerts.

From this pre-selection, we derive a proposal for forest monitoring concepts as well as GIS analytical tools to be included in a potential REDD+ Copernicus service component. This proposal includes four key concepts: (1) Sentinel-2 Image Composites, (2) Pan-Tropical Tree Cover Density for the 2020 reference year, (3) Pan-Tropical Annual Tree Cover Change and (4) Pan-Tropical Tree Cover Disturbance Alerting.

These proposed concepts, represented by the selected products, will be validated during the 'Demonstration cases' and 'Learning exercises' in the context of regional workshops to be held before end of 2020. During these regional workshops, national users will assess the usefulness of the proposed concepts that will be illustrated by the selected products over representative test sites across the tropics.

The report provides furthermore an initial organisational overview for an institutional, financial and infrastructure framework to be considered for establishing a REDD+ Core service component. The main organisational elements in terms of institutional and financial frameworks are related to the existing European Union Regulations that govern the Copernicus programme; these include the six Core Services of Copernicus, the financial allocations for these programmes, and the roles/ responsibilities of the Entrusted Entities who are responsible for managing the different programmes. The infrastructure framework ensures that appropriate solutions are established in terms of input data, storage, processing and service delivery requirements. The Sentinel-2 constellation was designed to be the main source of data for such activities and can be complemented by Sentinel-1 Landsat 8 from NASA/ USGS, and also potentially ALOS2-PALSAR from JAXA. The available infrastructure capacities and gaps for the Copernicus Data and Information Access Services (C-DIAS) in Europe and their functionality in developing countries are also examined as well as the delivery data. Finally, important organisational aspects to be considered are the capacity building needs in developing countries related to REDD+ implementation, and how this will be addressed in a Copernicus service.

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List of Abbreviations

AD	Activity Data
AFD	Agence Française de Développement
AGB	Above Ground Biomass
AoI	Area of Interest
ARD	Analysis Ready Data
AWS	Amazon Web Services
BFAST	Breaks For Additive Season and Trend
BTR	Biennial Transparency Reports
CAFI	Central African Forest Initiative
CALM	Criteria for Consistently Assessing Levels of Maturity
CAMS	Copernicus Atmosphere Monitoring Service
CAR	Central African Republic
CCI	Climate Change Initiative
CGLS	Copernicus Global Land Cover
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
COP	Conference of Parties
Copernicus EMS	Copernicus Emergency Management Service
CR	Coarse Resolution
C-DIAS	Copernicus Data and Information Access Services
C3S	Copernicus Climate Change Service
DEFIS	EC Directorate-General for Defence Industry and Space (formerly DG GROW)
DETER	Detecção de Desmatamento em Tempo Real
DRC	Democratic Republic of Congo
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
EF	Emissions Factor
EFFIS	European Forest Fire Information System
EO	Earth Observation
EOMonDis	Earth Observation Services for Monitoring Dynamic Forest Disturbances
ESA	European Space Agency
ETF	Enhanced Transparency Framework
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCDM	Forest Cover Disturbance Monitoring
FCPF	Forest Carbon Partnership Facility
FIP	Forest Investment Program
FLEGT	Forest Law Enforcement Governance and Trade
FLR	Forest Landscape Restoration
FM	Forest Monitoring
FRA	Forest Resources Assessment

FREL	Forest Reference Emission level
FRONTEX	Frontières Extérieures (EU Border and Coast Guard Agency)
FSC	Forest Stewardship Council
F-TEP	Forestry Thematic Exploitation Platform
GAF	GAF AG, Consultant for Geoinformation services
GAIA	Geo AI Applications Facility
GCF	Green Climate Fund
GCOS	Global Climate Observing System
GEE	Google Earth Engine
GFCS	Global Framework for Climate Services
GFOI	Global Forest Observations Initiative
GFW	Global Forest Watch
GHG	Green House Gas
GHGI	Green House Gas Inventory
GIS	Geographic Information System
GLAD	Global Land Analysis & Discovery
GOFC GOLD	Global Observation of Forest Cover - Global Observation of Land Cover
GPG	Good Practice Guidance
GROW	EC Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
GSW	Global Surface Water
HCS	High Carbon Stock
HCV	High Conservation Value
HLS	Harmonized Landsat Sentinel2
HR	High Resolution
HRL	High Resolution Layers
IFIs	International Financing Institutes
INPE	National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais)
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KfW	Kreditanstalt für Wiederaufbau
LC	Land Cover
MMU	Minimum Mapping Unit
MR	Moderate Resolution
MRV	Measurement, Reporting and Verification
NDCs	Nationally Determined Contributions
NFMS	National Forest Monitoring Systems
NGOs	Non-Governmental Organizations
NRT	Near-Real-Time
NTFP	Non-timber forest products
NYDF	New York Declaration on Forests
OTB	Orfeo Toobox
PEFC	Programme for the Endorsement of Forest Certification
PSU	Primary Sampling Unit
R&D	Research and Development
REA	Research Executive Agency
REDD	Reducing Emissions from Deforestation and Degradation

REDD+	Reducing Emissions from Deforestation and Degradation "plus" conservation, the sustainable management of forests and enhancement of forest carbon stocks
RoC	Republic of Congo
RSPO	Roundtable for Sustainable Palm Oil
RSS	Remote Sensing Survey
RTRS	Round Table on Responsible Soy
R-PIN	REDD+ Readiness Plan Idea Notes
R-PP	REDD+ Readiness Preparation Proposal
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SEPAL	System for Earth Observation Data Acquisition, Processing and Analysis for Land Monitoring
SFM	Sustainable Forest Management
SIRS	Systèmes d'Information à Référence Spatiale, France
SNAP	Sentinel Application Platform
S2GM	Sentinel-2 Global Mosaic
TCD	Tree Cover Density
TMF	Tropical Moist Forest
UNFCCC	United Nations Framework Convention on Climate Change
UPS	Université Paul Sabatier Toulouse III, France
VHR	Very High Resolution
WCRP	World Climate Research Programme
WB	World Bank
WP	Work-package
WRI	World Resources Institute
WU	Wageningen University
ZD	Zero Deforestation

1 Introduction

1.1 Background

The advent of the European Copernicus Programme's Sentinel data with their high spatial resolution and revisit time at global, regional and national levels provides an unprecedented volume of data for improved forest monitoring which should be exploited by the European science and Earth Observation (EO) industry communities in order to provide maximum benefit to stakeholders and users involved in forest assessment and reporting in and outside Europe.

The REDDCopernicus Project aims to implement a co-ordination and consolidation of the existing European Capacity for EO based Forest Monitoring with relevant stakeholders, including International Agencies, Research Community and Private Sector. A key outcome of the Project will be a proposal for a framework for a Copernicus REDD+ Service (Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries), which can make use of the planned Copernicus Data and Information Access Services (C-DIAS) platform for improving EO data and product accessibility and functionality to end users. Furthermore, infrastructural and research gaps for EO Forest Monitoring at different scales (global to local) will be identified in order to define future Research and Development (R&D) Programmes which would address key gaps and priorities.

1.2 Objectives

The main objective of this deliverable is to develop an initial design of a potential Copernicus Forest Monitoring and REDD+ Service Component based on the findings of the 'Stakeholder Requirements and Policy Review' (D1.1 report) as well as on the 'Review of Existing Capacities in Forest Monitoring Assessment' and on the outcomes of the conducted international stakeholder consultation (D2.1 and D2.2 reports).

The initial design of such a Copernicus REDD+ Service Component will address both the main technical (including the selection of the products, the technical specifications) as well as organisational elements (including the implementation of the Service component, the integration with the existing Copernicus Services, the financial aspects, the service architecture and infrastructure).

The design also includes the pre-selection of key demonstration cases and learning exercises, which will be provided to key stakeholders in tropical countries in the context of a series of regional workshops, particularly in Africa and SE-Asia. In the context of these learning exercises, representatives from 'REDD+ countries' will have the possibility to assess the appropriateness and usefulness of the proposed methodological approaches, products and tools with respect to national needs of forest monitoring and reporting in the context of REDD+ and Sustainable Forest Management (SFM).

1.3 Summary from Previous Reports

The following Sections provide a summary of the outputs provided within the previous deliverables of the REDDCopernicus Project (namely D1.1, D2.1 and D2.2 reports) in order to prepare the initial design of the REDD+ Service Component. Section 1.3.1 describes the requirements on REDD+ Forest Monitoring (FM) in International and European Policy Segments and Section 1.3.2 summarizes the User Requirements identified for REDD+ FM. The outcomes of the assessment of existing capacities for EO Forest Monitoring in Europe (and beyond) is presented in Section 1.3.3. Section 1.3.4 provides a synthesis comparing the technical capacities identified against the User and Policy requirements in order to select those capacities, which could potentially contribute to the REDD+ Service Component. This Chapter forms the linkage of the first Work Packages to the current WP3.

1.3.1 Summary of Requirements for REDD+ FM in International and European Policy Segments

Global and national Forest Monitoring (FM) requirements related to SFM, climate change mitigation and adaptation efforts, and as a part of wider land monitoring for Green House Gas (GHG) assessments are evolving rapidly. Included in this is REDD+, which is a key driver in forest monitoring needs in tropical developing countries. Monitoring and reporting are carried out according to the performance scheme under which it is being implemented, for example the World Bank Forest Carbon Partnership Facility (FCPF), Green Climate Fund (GCF), or voluntary standards. Requirements do vary although several common needs can be identified such as that EO data are an essential data source and uncertainties should be assessed and considered for all approaches.

Many other monitoring needs stem from national reporting requirements for a number of international policies related to climate change. These include reporting requirements related to United Nations Framework Convention on Climate Change (UNFCCC), Nationally Determined Contributions (NDCs), biennial GHG updates, and regular global stocktakes, which all countries and the international community have to respond to. There is some urgency as this regular reporting is expected soon, specifically the first set of revised NDCs should be submitted in 2020, and the first global stocktake will take place in 2023. International reporting under these mechanisms should follow the guidelines as specified in the IPCC Good Practice Guidance (GPG), including the 2019 refinements, which also provide improved advice on the role of EO data for Activity Data (AD) estimation and biomass monitoring (for emissions factor (EF) production), and other national-scale monitoring and estimation of GHG emissions. Related to this, recent transparency requirements (i.e. the Enhanced Transparency Framework (ETF)) also increase the needs of countries and stakeholders for the accountability for climate action and performance. One key element of the ETF is the call for consistency among the various reporting mechanisms (i.e. Green House Gas Inventory (GHGI), Biennial Transparency Reports (BTR), NDCs, National Communications, etc.). This includes a need for consistency between national GHG reporting and mitigation policy options/ contributions.

Some monitoring needs have broader objectives than climate change, such as Sustainable Development Goals (SDGs), and a number are focussed specifically on forests such as compliance with voluntary efforts in both the forest and land use sector (i.e. voluntary commitments/ performance-based schemes, The Forest Law Enforcement Governance and Trade (FLEGT), High Conservation Value (HCV), High Carbon Stock (HCS), Roundtable for Sustainable Palm Oil (RSPO), Round Table on Responsible Soy (RTRS), Zero Deforestation (ZD) commitments, etc.) and forest certification schemes (i.e. Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), etc.). Other monitoring needs relate to national/ local land use planning such as the assessment of forest resources (*i.e.* timber production, ecosystem services, etc.). This tends to be more relevant in Europe, where guiding principles of forest management are outlined in the European Forest Policy Strategy from 2013, which includes SFM, the multifunctional role of forests, and resource efficiency. Forests are also seen as having a role as public amenities, biodiversity reservoirs, and climate regulators, and this requires extensive and regularly updated information, which certain EO data and products can provide.

1.3.2 Summary of User Requirements for REDD+ FM

A broad stakeholder assessment was carried out, which gathered information on specific User needs for FM, which were often very much related to policy requirements. A number of stakeholders responsible for data collection, analysis and reporting were involved in discussions, and these stakeholders covered a wider range of stakeholder types including Country representatives, Non-Governmental Organizations (NGOs), Private Sector, International Initiatives, the Research and Scientific Community, and Donors. Although there was a variety of needs noted for Users within these groups, there is broad consensus on a number of needs.

All Users require data including processed, analysis-ready satellite time series data, and thematic products for forest changes and forest characteristics (*i.e*. biomass, canopy cover, etc.). In a GHG reporting context (including for REDD+), information, which can contribute to both AD and EFs are key needs. Long-term data continuity and the availability of open and transparent information was essential for all stakeholders. In general, for AD a spatial resolution of <30 m and temporal resolution of <3 years was required across all stakeholders. Providing thematic information beyond forest area and changes are important including specifically information on forest degradation and broader forest-related land use changes. For biomass and EF data the Above Ground Biomass (AGB) pool was the most useful to stakeholders, however, information on soil and other carbon pools was also considered useful. Most stakeholders seek information on Intergovernmental Panel on Climate Change (IPCC) Tier 2 or 3 level. Data on biomass burning was also requested. Several stakeholders requested Very High Resolution (VHR) imagery or ground data, which is useful for the validation of estimates based on space-based products.

The intended service should provide novel data in order to overcome some of the current challenges in FM experienced by the Users. Technical challenges include monitoring dry seasonal forests, reducing uncertainties in EFs and in parameters useful for commercial forestry operations, monitoring degradation, distinguishing between tree crops (*i.e.* Oil Palm), plantations and natural forests, and accessing early warning forest change information, which is actionable.

Considering these needs, including some currently unmet needs, most stakeholders encouraged the development of a Copernicus global forest monitoring component if it is targeted at their needs and it provides a long-term, easy-to-access, and open set of products and services. Given the number and variability of potential contributions to such a service, the following data and products were proposed as potential core elements of a Service Component, and are listed in priority order in terms of the stakeholders, which would find them either useful or very useful (%):

1) Analysis ready image mosaics (87%),
2) Forest and land cover/use (change) map (86%)
3) Biomass and change map (85%),
4) Forest type maps (including plantations) (85%),
5) Cause of deforestation/driver map (76%),
6) Forest tree cover density and forest mask (76%).

In addition to these, users also requested:

- A Sentinel-based near-real-time (NRT) deforestation monitoring system,
- High Resolution (HR)/VHR optical dataset (<5m spatial resolution) with multiple bands, which is also suitable for validation,
- Ground data (i.e. existing plot data is compiled and made available for validation purposes) (as Copernicus provides in Europe),
- Products on degradation drivers – both biotic and abiotic: fire (also burned areas), pests, diseases, fuelwood collection, thinning, logging and other disturbance/forest damage drivers. They should be aligned with the IPCC classes,
- Products on biodiversity, ecosystems, and key habitats,
- Products on main forest structural variables (i.e. dominant species, height, volume, etc.) which would support assessments of forest resources.

Users provided information on the technical specifications of above products, showing that forest biomass related products should provide change including degradation information (including sensitivity of degradation assessment to socio-economic drivers), and regrowth. The adaptability to different definitions of degradation was pointed out. Drivers of change based on the IPCC classes or classes, which allow identifying the main drivers should be included to products on land cover/use change. For land use change, tree crops should be separately identifiable.

The capacities of the different expected stakeholders for taking up Copernicus products and services will be more heterogeneous as compared to a European service with generally higher capacities. Products should be provided with a certain flexibility to be tuned, so that broad needs can be met and be adaptable to country definitions and circumstances. Firstly, core products should be provided to the Users (e.g. in the context of national reporting on SDGs and global research aims) enabling quicker and easier data handling. Furthermore, those core products can be adapted to tailored products by

Users, or they are created by service providers in the context of downstream service provision to others. Providing open-source or other transparent solutions and platforms behind products will allow Users to adapt them to their needs. Utilizing existing platforms, which Users are already familiar with, and have documentation and support might be helpful in this respect.

Related to this, the integration of a capacity building component is crucial to address challenges for data use. A lack of infrastructure, capacity, and internet access in order to retrieve and utilize large volumes of data means that it must be assured that there is outreach to countries so that they are able to use and access data efficiently within the proposed platform. Finally, in order to ensure the uptake of services delivered under a future Copernicus Service Component, User engagement throughout the process to develop and implement a service will be essential. Several opportunities exist in order to guarantee that stakeholders are involved in the process, including regular interaction to gather new User needs and co-creation of products where Users can test and validate products using local validation data, so that they can be improved. Case studies in which the products are used in an operational context would demonstrate the utility of such a service.

1.3.3 Summary of Existing Technical Capacities in EO based FM in Europe

Capacities for global forest monitoring are increasing, as new satellites are launched and more data becomes available. Novel methods and tools are continuously being developed to process and understand data, with new cloud computing and other infrastructures being used for the analysis of large data volumes. Europe in particular has a wide and growing ecosystem of Earth Observation data supply, product and service providers. In this context, it is useful to mention that the European Commission is planning to establish an EU Observatory with global coverage on deforestation, forest degradation, changes in the world’s forest cover, and associated drivers. Based on already existing monitoring tools, it will support the availability of, the quality of, and the access to information on forests and commodity supply chains. The Copernicus REDD+ Service Component is expected to be closely linked to the EU Observatory, providing key data products for it.

Moreover, the EU Forest Information System for Europe (FISE) which is used to be under JRC responsibility and is now managed by EEA from February 2020, is designed as a knowledge database to better understand the complex environmental and societal challenges. At this moment, FISE, which is covering only Europe, does not have its own monitoring component, in particular because EEA is also managing the pan-European component of the CLMS.

Capacity for global forest monitoring is defined as the technical and organizational ability to implement the envisaged REDD+ as well as global forest monitoring Service component. The following types of capacities were systematically assessed:

- Availability and provision of EO Data and Ancillary Data and their suitability for Forest Monitoring/ REDD+,
- Geospatial Products of potential relevance for the Forest Monitoring and REDD+ Component
- Existing methods/ algorithms and tools for the processing EO Data into geospatial data products for Forest Monitoring/ REDD+,
- Data processing infrastructure, platforms and services,
- Production capacities to implement complex and big data workflows for product generation (relevant project experiences in EO FM).

A number of capacities were identified, which are useful for wide range of tasks related to REDD+ and FM needs. Many are well-developed capacities, which have been demonstrated and used for reporting purposes around the globe.

Firstly, a wide range of HR and VHR EO data and Ancillary data suitable for FM are publically or commercially available. Freely-available datasets include those from the Copernicus Programme’s Sentinel Satellites. These passive and active remote sensing systems provide massive amounts of continuous optical and Radar EO imagery in the high to medium resolution range globally on a day-to-day basis and can be considered as an essential base for a Core Copernicus REDD+ and FM Service

Component. In addition to this, other datasets, including the Landsat satellites and European contributing missions are useful. This includes commercial VHR data, which is particularly useful from the context of calibration, training and validation in the Core and Downstream context.

Geospatial Products are also of relevance for FM and REDD+ needs. Capacities of these products include analysis ready EO imagery based on the Sentinel datasets (*e.g.* Sentinel-2 Global Mosaic (S2GM)). Even though these datasets are not currently globally available, the potential to produce these globally has been demonstrated. Existing Copernicus Land Monitoring Components (some currently only available at the European level) such as forest status maps are mature for forest and tree cover and change (*e.g.* the European HR layers). Copernicus Global Land Cover maps are available, but resolution is lower than requested by most users. Demonstration projects, which will provide Sentinel-based higher resolution land cover products are in progress (*i.e.* ESA World Cover). Global biomass maps are evolving operationally but remain at the lower levels of maturity. For near real time alerts, several methodological options exist, which utilize both optical and radar dense time series data (and are discussed in the methods section of the report), however operational products are not yet in existence except for Global Forest Watch (GFW) Global Land Analysis & Discovery (GLAD) Alerts.

Both methods (*i.e.* algorithms and approaches) and tools (*i.e.* ready to use software solutions) are available and are utilized in the context of FM. Image processing toolboxes including SNAP and OTB are useful for all essential pre-processing tasks for EO data. Both SNAP and OTB are fully open source and freely available for use, containing mature pre-processing and analysis methods, which have been tested at scale. Tools, which can be used for specific tasks such as time-series analysis exist (*e.g.* Breaks For Additive Season and Trend (BFAST), and probability chain) as well as those specifically used for disturbance monitoring (Forest Cover Disturbance Monitoring (FCDM) methods) and near-real time (NRT) approaches (and Sentinel-based Radar Forest Cover Loss alerts). Many of the algorithms are implemented in Google Earth Engine (GEE) and System for Earth Observation Data Acquisition, Processing and Analysis for Land Monitoring (SEPAL), so can be used as stand-alone tools or taken and adapted and scaled-up to operationality. Other general toolboxes include Joint Research Centre of the European Commission (JRC)'s IMPACT toolbox and Food and Agriculture Organization of the United Nations (FAO)'s OpenFORIS tools, which can be used for a number of EO related tasks specifically in the domain of FM. These represent easy-to-use toolboxes, which can be ready for use at the national or regional level.

Several European and non-European Service and Infrastructure/Platforms were assessed, which include both online or local systems to access, process and derive EO related data for FM purposes. These infrastructures can be used in the development of a Core product, or in downstream service provision. GEE and Amazon Web Services (AWS) are well-known platforms which are established for the processing of large amounts of data, and GEE along with SEPAL have been demonstrated and used in a number of REDD+ countries for reporting. In Europe other options are now available including the C-DIAS's and the Forestry Thematic Exploitation Platform (F-TEP) initiated and still partially funded by ESA, as well as FAO's SEPAL. There are five DIASs under Copernicus and they are already to varying degrees operational, and contain large amounts of EO data and a variety of tools and applications that can be used to process and download the data.

In addition to data, methods and platforms, European EO Service Provider and Research Community has demonstrated capacity to implement complex and big data workflows for product generation in large-scale projects. Relevant projects have been carried out in a number of, if not all REDD+ countries. In addition to the development of products, methods and tools, they have also been demonstrated in country scenarios and integrated into workflows, for example National Forest Monitoring Systems (NFMS) and REDD+ Measurement, Reporting and Verifying (MRV) systems. This demonstrated experience is essential for the implementation of the Copernicus Forest Monitoring and REDD+ Service Component.

1.3.4 Selection of Technical Capacities based on User and Policy Requirements

The aim of the first work packages of this project (summarized in Sections 1.3.1, 1.3.2 and 1.3.3) was to assess the need for and get inputs on the content of a REDD+ and FM Service Component, as well as to identify what potential capacities are available and mature.

The next step is to identify which of the mature capacities are best suited to meet specific Policy and User Needs. A Policy requirements summary has been developed which includes the extent to which the User and Policy needs can be met to produce a coherent and complete Service. The information gathered in D2.2 of this project on the concepts themselves provides the input into the user requirements assessment. Here, we assess the criteria to understand whether the capacities can meet the Policy and User needs. Based on the policy needs and user types and their needs identified in D1.1 of this project, we divide the identified policy initiatives into six groups, which have similar data and monitoring requirements.

The first three (I-III) are related to REDD+, including reporting requirements, policy development and also assessment of progress on REDD+ and other mitigation initiatives at the global level. The last three (IV-VI) are other needs, and are not necessarily related to REDD+, however some overlaps exist with the first three categories such as needs for reporting on SDG Indicator[1] 15.1.1: Forest area as a proportion of total land area requires similar information as REDD+ reporting. For those products, which are not yet globally available, we assume for the purposes of this exercise that they have been scaled to cover the relevant area of interest for each policy group.

I. **REDD+ and National Green House Gas (GHG) Reporting:** Country Users primarily have to report according to the UNFCCC and REDD+ requirements; which are following the estimation and reporting framework from the IPCC GPG. Reporting is done by relevant government department, sometimes with support from International Initiatives such as UNREDD. Data requirements are detailed in the IPCC GPG. Requirements here are that the data are multitemporal, available/ demonstrated in the tropics (or could be assumed to be replicated in the tropics) and could contribute to AD or EF data required for reporting.

II. **Nationally Determined Contributions (NDCs) and Climate Change Policy Development:** Countries need to develop targeted climate change policies and have to present them in their NDCs to the UNFCCC. Useful data includes information on land use following deforestation (drivers), different maps of forest change, biomass and emissions and removals to show the hotspots of changes and their causes and options to mitigate such emissions. More detailed information at the local level is required, which also includes other forest related variables than the AD and EF information required for REDD+ reporting. Timely data for policy adjustments (such as NRT) can be useful and allows for responsiveness to illegal activities for example.

III. **Global Stocktake and Technical/ Independent Assessments:** The Global Stocktake agreed on in 2015 under the Paris Agreement requires globally consistent information, which is reported regularly and helps for consistent linkage of national GHG inventories and activity accounting towards a global assessment. The first Global Stocktake is expected in 2023, with

[1] SDG Indicator : On September 2015, the 193 Member States of the UN adopted the 2030 Agenda for Sustainable Development – including 17 Sustainable Development Goals (SDGs) and 169 targets. The Agenda commits the international community to end poverty and hunger and achieve sustainable development in all three dimensions (social, economic and environmental) over the next 15 years (2016-2030). In March 2016, the UN Statistical Commission identified as a "practical starting point" 230 indicators to monitor the SDGs' 169 targets. http://www.fao.org/3/a-i6919e.pdf

the following Stocktakes taking place every 5 years thereafter (2028 and 2032). In addition there are technical assessments (i.e. done by the UNFCCC roster of experts) or scientific analysis that make use of large area data sources. The main need here is to have additional information independent but consistent with data reported to the UNFCCC, for example REDD+ submissions of FRELs as well as BURs and their Technical Annexes with the REDD+ results. Coarser data for global assessments can be useful here – and global data provides consistent information, which is also relevant in this context.

IV. **FLEGT and Sustainable Forest Management (SFM):** In 2003, the European Commission (EC) adopted an Action Plan for The Forest Law Enforcement Governance and Trade (FLEGT), which has as its main objectives to improve governance and reduce illegal logging as well as encourage trade in legally sourced timber in countries that export timber to the EU. FLEGT requires information, which can help to address direct and indirect drivers of forest loss, and the effective use of forest resources. Data might include information on forest management, forest cover and illegal activities. Stakeholders include country users who are responsible for the production of local forest management plans – such as those in Europe who have to adhere to the European Forest Policy Strategy from 2013 which includes SFM, the multifunctional role of forests, and resource efficiency. The forestry sector in Europe is affected by several other EU frameworks covering a wide range of sectors (e.g. Biodiversity strategy and Bioeconomy strategy). Similar requirements to those for policy can be found here - detail is key and other forest variables in addition to AD and EF are of interest.

V. **Transparency, Certification and Enforcement Applications:** Relevant Stakeholders include International Organizations and NGOs who are actively using forest data to fulfil their role as independent watchdog organizations and as advocacy and implementing bodies. Users also include Private Sector Organizations which are multi-national companies operating outside Europe who are interested in providing sustainable supply chain products and certifying forest products and their services in tropical regions. Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) are examples of globally recognized standards, and both of them set international frameworks and criteria for developing national and subnational certification standards. Here, timeliness of data is important for enforcement actions, and for sustainable supply chain related needs. Higher resolution data, which is more detailed on forest change can be useful.

VI. **Sustainable Development Goals (SDGs, indicators 15.1.1, 15.2.1, and 15.3.1):** Forest area and change data is required for reporting SDG Indicator 15.1.1: Forest area as a proportion of total land area. Monitoring requirements for FLEGT and SFM are similar to those for reporting on SDG Indicator 15.2.1: Progress towards sustainable forest management. Land cover information is needed for SDG Indicator 15.3.1 on the proportion of land that is degraded over total land area, and also for the New York Declaration on Forests (NYDF) goal 5 to “Restore 150 million hectares of degraded landscapes and forest lands by 2020”. For the three SDG indicators, some of the data needs are similar to those from the other five policy categories described above. Indicator 15.1.1 on forest area has similar requirements to REDD+ reporting, and indicator 15.2.1 has similar needs to SFM needs. Indicator 15.3.1 on Land Degradation Neutrality requires broader land cover change information, which can also be useful in relation to REDD+ policy development for example.

Based on the descriptions of the six policy types, criteria to determine whether the products/datasets meet the six policy requirements are outlined in Table 1.

Table 1: Criteria to determine whether policy requirements are met for the products/datasets

	Policy	Does the proposed concept support the policy requirements?		
Overall REDD+ Policy requirements				
I	**REDD+ and National GHG Reporting**	Yes, either multitemporal AD or EF information can be gathered from the concept.	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information
II	**NDCs and Climate Change Policy Development**	Yes, information related to land use, drivers of change, detailed information about forest characteristics, or timely data upon which action can be taken can be derived from the concept.	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information
III	**Global Stocktake and Technical / independent Assessments**	Yes, globally consistent information is provided or can be obtained over long time periods for the key variables - AD and EF.	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information
Sustainable development and forest management requirements				
IV	**FLEGT, and Sustainable Forest Manaement**	Yes, specifc relevant forest parameters can be identified, including information on forest	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information
V	**Transparency, Certification and Enforcement Applications**	Yes, NRT information can be derived from the concept.	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information
VI	**SDGs 15.1.1, 15.2.1, and 15.3.1**	Yes, one of the SDG indicators selected can be supported -from both a monitoring perspective, or in terms of identifying actions to support the related target.	Somewhat, in combination with other data, or with processing.	No, the concept does not provide the information

The assessment of the overall FM policy requirements with regards to all 26 FM products/datasets (i.e. geospatial products and methods of relevance for FM and REDD+ service component) is provided in Table 2.

Table 2: Summary analysis of the overall FM/REDD+ policy requirements assessment of 26 products/datasets gathered in D2.2

			Overall REDD+ Policy requirements			Sustainable development and forest		
N°	Acronym	Concept Category	REDD+ and National GHG Reporting	NDCs and Climate Change Policy Development	Global Stocktake and Technical / independent Assessments	FLEGT, and Sustainable Forest Management	Transparency, Certification and Enforcement Applications	SDGs (15.1.1, 15.2.1, and 15.3.1)
1	S2GM	Remote Sensing Imagery	Yes	Yes	Yes	Yes	Yes	Yes
2	JRC-L1C-S2-COMP		Yes	Yes	Yes	Yes	Yes	Yes
3	CGLS-LC100	Global Land Cover/Fire products	No	Somewhat	Yes	No	No	Somewhat
4	CGLS-FCOVER300		No	No	No	No	No	No
5	CGLS-BA300		Somewhat	No	Yes	No	No	No
6	CGLS-LAI300		No	No	No	Yes	No	Yes
7	EFFIS		Somewhat	Somewhat	No	Somewhat	No	Somewhat
8	GWIS		No	No	Somewhat	No	No	No
9	CCI Land Cover		No	No	Somewhat	No	No	Yes
16	WorldCover		No	Yes	Yes	Yes	Somewhat	Yes
10	HRL-TCD	Forest Status	Yes	No	No	Yes	No	Yes
11	HRL-DLT		Yes	Yes	No	Yes	No	Yes
12	HRL-FTY		Yes	No	No	Yes	No	Yes
13	HRL-SWF		Yes	Yes	No	No	No	Somewhat
14	CCI Biomass		Yes	Yes	Yes	No	No	Somewhat
15	Globbiomass		Yes	Yes	No	No	No	Somewhat
17	TMF	Forest Status/Change	Yes	Yes	Yes	No	No	Somewhat
18	GFW		Yes	Yes	Yes	No	No	Somewhat
19	PRODES		Yes	Yes	No	No	No	Somewhat
20	FRA	Forest Cover Change	No	No	Yes	No	No	Somewhat
21	BFAST		Yes	Yes	No	Yes	Yes	Yes
22	FCDM-optical		Yes	Yes	No	Yes	Yes	Yes
23	FCDM-radar		Yes	Yes	No	Yes	Yes	Yes
24	GLAD	Near real time alerts	No	Yes	No	No	Yes	Somewhat
25	BAYTS		No	Yes	No	Yes	Yes	Somewhat
26	DETER		No	No	No	No	Yes	Yes

Based on this assessment, most of the products/datasets (except the Global Land Cover/Fire products) provide policy relevant information related to REDD+, either for national or global reporting requirements, or in order to develop related policies, which can support REDD+ objectives. The Near Real Time (NRT) Alerting systems (such as BAYTS) are not providing support for the REDD+ reporting due to lacking uncertainty information but are really important for other REDD+ related activities such as illegal logging detection and interventions. In addition, the products/datasets also provide some information, which is useful for other policy requirements such as for certification purposes or SDGs.

2 Main Technical Elements of the Service Component

This Chapter provides a description of the initial design of the main technical elements necessary for a Forest Monitoring System to be used for Measurement and Reporting under REDD+ and/or SFM. This will bring a proposition of the first technical foundation for the expected FM/REDD+ component to be included in the European Copernicus Programme.

The identification of the most appropriate FM products/datasets is conducted through a benchmarking analysis that allows assessing the 'fit-to-purpose' level of potential datasets and methods that were pre-identified from WP2 (Consultation and Review of Existing Capacities in Forest Monitoring). While D2.2 report mentions toolboxes next to datasets and methods, Chapter 2 of this deliverable focuses only on the latter two, as they constitute the core of a REDD+ Service Component.

The justification/ rationale for the benchmarking process is provided in Section 2.1 and the selected benchmarking approach is described in Section 2.2. The pre-selected FM products are then described in details in Section 2.3 leading to the initial definition of potential FM products for the REDD+ Service Component in Section 2.4.

2.1 Rationale of a Benchmarking Approach

As a first step to design a future Copernicus REDD+ Core Component and potential downstream services, it is important to assess the 'fit-to-purpose' level of the various technological developments that were pre-identified in WP2, namely 26 products/datasets. The overall objective of this step is to identify those technological developments that can be used and are the most appropriate for the initial design.

In this context, a benchmarking of the various pre-selected technologies was conducted. Benchmarks are reference points that allow comparing performance. "Benchmarks can be comparing processes, products or operations, and the comparisons can be against other parts of the business, external companies (such as competitors) or industry best practises. Benchmarking is commonly used to compare customer satisfaction, costs and quality"[2]. There are three types of benchmarking:

- process benchmarking – which focuses on discrete work processes and operating practices (benchmarking specific work processes);
- performance benchmarking – which compares products and services (benchmarking performance measures and product characteristics such as reliability, durability and costs);
- strategic benchmarking – which examines how companies compete (Bogan & English, 1994).

For the initial design of the main technical elements of a REDD+ Service Component, the application of a benchmarking process is aimed at comparing products/datasets derived from D2.2 and at identifying those that are the most 'fit for purpose' for REDD+.

Thus, the objective of this benchmarking exercise is to assess the performance of the processes behind the datasets and methods that were pre-identified in WP2 as potentially relevant for REDD+ and to rate their performance, utility and quality in relation to REDD+ requirements. Therefore, a comparison of all datasets and methods that have been rated as pre-operational and operational in the CALM assessment of D2.2 is undertaken in WP3. This comparison is based on a set of criteria and the results are analysed through a matrix approach.

[2] https://www.bernardmarr.com/default.asp?contentID=1753

2.2 Benchmarking Approach

2.2.1 Description of the Benchmarking Approach

2.2.1.1 First Steps of the Benchmarking

The comparison of all 26 products/datasets from D2.2 is undertaken based on a set of criteria using a matrix approach. A set of assessment criteria that are considered relevant and 'fit-to-purpose' for a REDD+ service component or, more generally, for a global monitoring system has been defined for the benchmarking analysis. The selected criteria for assessment can be organised into four categories:

A. 'REDD+ technical requirements' such as Forest Definition Marrakech Accord, IPCC Land Use Categories, Forest Area Change, Change in Forest Land Remaining Forest Land, IPCC Approach, IPCC Tier, Uncertainty assessment,
B. 'User requirements' such as Geographical Scalability, Potential Historic coverage, Temporal frequency, Documentation availability,
C. 'Requirements for Operations' such as CALM level, Applicability across biomes/ ecosystems, Efficiency to produce accross large/ global scale,
D. 'Service and Continuity' such as the existing global service and future service continuity.

The analysis leads to a suitability rating that allows identifying the most suitable candidate products/ datasets, whose associated concepts are to be included in a REDD+ Service component. A set of the most suitable candidates will be retained for the learning exercises to be implemented in WP4.

Under Copernicus Global Land Service, an operational product is defined as with documented, non-relevant limitations that largely satisfy the applicable user requirements and/or are considered mature[3]. This Copernicus operationality definition is dealt through our benchmarking approach under criteria from categories A and B for the user requirements and criteria from categories from C and D for the maturity. As the CALM rating was used to assess the level of maturity of the products/datasets, the benchmarking process was focused on pre-operational products/datasets (CALM levels 4 to 6) and operational products/datasets (CALM levels 7 to 9), even some products/datasets at research level (CALM levels 1 to 3) were kept for consistency.

2.2.1.2 Description of the Benchmarking Criteria

A set of 16 criteria has been developed to assess the 'fit-to-purpose' level of the 26 products/datasets pre-identified from D2.2. These criteria belong to the four main categories described in the previous Section and therefore their order of description follows such broad categories but does not reflect any level of significance. Below Table 4 shows all criteria with their possible answer options as well as the underlying numerical rating for the benchmarking analysis.

A1. Forest Definition under the Marrakech Accords

REDD+ implementation has to comply with UNFCCC COP decisions[4]. Although a number of terms or concepts are not specifically defined within the COP decisions (e.g. the terms 'deforestation' and 'forest degradation') the general framework is available in official decisions (Marrakech Accords) or IPCC document (Good Practice Guidelines) and are complemented by internationally accepted guidelines (GOFC GOLD, 2016; GFOI, 2016)

[3] https://land.copernicus.eu/global/products/development-stages

[4] https://redd.unfccc.int/fact-sheets/unfccc-documents-relevant-for-redd.html

For REDD+ implementation, the forest definition is provided in the Marrakech Accords with some flexibility for the parameter of minimum area and threshold of tree cover to be selected by the countries:

1. Minimum forest area: from 0.05 to 1 ha,
2. Potential to reach a minimum height at maturity in situ of 2-5 m,
3. Minimum tree crown cover (or equivalent stocking level): from 10 to 30 %,
4. Predominant forest use.

With this definition, it is only when the tree crown cover falls below the minimum threshold (between 10 and 30%) selected by a given country that land is classified as non-forest. The specific national tree cover thresholds have implications on where the boundaries between deforestation and degradation occur.

The first criterion of the benchmarking is to assess if the product/dataset does support to the application of the Forest definition under the Marrakech Accords. This implies to tackle at least one of the three parameters: (1) Minimum Mapping Unit (MMU) from 0.05 to 1 ha, (2) assessment of the tree height at maturity, (3) assessment of the tree canopy cover percentage. If at least one of these parameters is reached the rating for A1 is labelled as 'High'.

An underlying parameter for the MMU is the spatial resolution of product/dataset that is usually strictly related to the spatial resolution of the EO input data. The optimal/potential spatial resolution of the pre-identified products is labelled as VHR (<5 m), HR (5 – 30 m), Moderate resolution (MR, 30 – 100 m) or Coarse resolution (CR, 100 m – 500 m). VHR or HR data are required to be compliant with the minimum area parameter of the forest definition of the the Marrakech Accords.

A2. IPCC Land Use Categories

The definition of the land-use categories for greenhouse gas inventory reporting is provided in the IPCC Guidelines (2006). The definitions of land-use categories for greenhouse gas inventory reporting are: (i) Forest Land, (ii) Cropland, (iii) Grassland, (iv) Wetlands, (v) Settlements and (vi) Other Land.

This implies that, if the reduction of tree cover is not followed by a change in use, such as in the case of timber harvesting, the land remains as forest land (no deforestation) but can be reported as forest degradation (reduction in biomass).

This benchmarking criterion assesses if the thematic content of the product/dataset can support the mapping of IPCC Classes.

A3. Activity Data: Change in Forest Area

The mapping of changes in forest area (e.g. deforestation) is aimed at contributing to the production of high-accuracy 'activity data' (i.e. area estimates) required for REDD+ reporting.

The mapping of forest areas can also contribute to reducing the uncertainty of emission factors through spatial mapping of main forest ecosystems (GOFC GOLD, 2016).

This benchmarking criterion allows assessing if the thematic content of the product/datasets can support the mapping of forest area changes (deforestation or forest extension). The multi-temporal aspect is key for this criterion.

A4. Activity Data: Change in Forest Land Remaining Forest Land

Another key element for the reporting of REDD+ is the assessment of changes within forest land which leads to changes in carbon stocks (e.g. degradation). The techniques to monitor changes within forest land are still considered to provide lower accuracy 'activity data' and poor complementary information on emission factors (GOFC GOLD, 2016).

This benchmarking criterion assess if the thematic content of the product/dataset can support the mapping of changes in forest land remaining forest land. The multitemporal aspect is key for this criterion as well as the frequency of analysis in order to identify small scale forest disturbances with short duration of impact on tree cover.

A5. IPCC Approaches for Representing Land Area

The IPCC Guidelines for National GHG inventories describe three different approaches[5] for representing the activity data, or the change in area of different land categories:

1. Approach 1 provides the total area for each land category – typically from non-spatial country statistics – but does not provide information on the nature and area of conversions between land uses, i.e. it only provides "net" area changes (e.g. deforestation minus forestation) and thus is not suitable for REDD,
2. Approach 2 involves tracking of land conversions between categories, resulting in a non-spatially explicit land-use conversion matrix,
3. Approach 3 extends Approach 2 by using spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques.

For REDD+ implementation, land use changes are required to be identifiable and traceable, i.e. Approach 3, or Approach 2 with additional information on land use dynamic, are needed for land tracking (GOFC GOLD, 2016). This benchmarking criterion assess which IPCC Approach the product/dataset can support.

A6. IPCC Tier Reporting Levels

The Emission Factors (EF) are derived from assessments of the changes in carbon stocks in the various carbon pools of a forest. The Emission Factors can be provided by countries at different Tier levels, defined in the IPCC GPG (2006):

1. Tier 1 uses IPCC default values (i.e. biomass in different forest biomes, carbon fraction etc.),
2. Tier 2 requires some country-specific carbon data (i.e. from field inventories, permanent plots),
3. Tier 3 highly disaggregated national forest inventory-type data of carbon stocks in different pools and assessment of any change in pools through repeated measurements, which may also be supported by modelling.

Moving from Tier 1 to Tier 3 increases the accuracy and precision of the estimates, but also increases the complexity and the costs of monitoring. Tier 2 is the minimum required for reliable estimates and therefore for REDD+ process. This benchmarking criterion assesses, which IPCC Tier the product/dataset can support.

A7. Uncertainty Assessment

Uncertainty is an unavoidable attribute of practically any type of data including area and carbon stock estimates in the REDD+ context. Identification of the sources and quantification of the magnitude of uncertainty will help to better understand the contribution of each source to the overall accuracy and precision of the REDD+ estimates, and to prioritize efforts for their further development. The proper manner of dealing with uncertainty is fundamental in the IPCC and UNFCCC contexts: The IPCC defines inventories consistent with good practice as those, which contain neither over - nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable (GOFC GOLD, 2016).

This benchmarking criterion assess if uncertainty of the product/dataset (dataset or method) has been assessed qualitatively or quantitatively.

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[5] IPCC approaches to consistent representation of lands (2019), online access on November 2019: https://www.ipcc.ch/site/assets/uploads/2019/06/19R_V0_02_Glossary_advance.pdf

B1. Geographical Scalability

The datasets and methods have been designed for a specific scope and produced at a specific scale. In the REDD+ context, there is a need to get scalable approaches in order to serve local needs as well as global requirements. The geographical scalability is the ability to maintain effectiveness during expansion from a local area to a larger region. This benchmarking criterion assess if the product/dataset is scalable with following rating: (i) Not scalable, (ii) moderately scalable (global to regional, local to regional) or (iii) highly scalable (local to global).

B2. Historical Coverage

An important requirement for REDD+ implementation is the assessment of historical data for the determination of the Forest Reference Emission Level (FREL). The period for historical analysis that can be potentially accounted by the product/dataset is assessed using three categories: Long-term history (10+ years), Short-term history (2-10 years) and Very short-term history (<2 years).

B3. Temporal Frequency

The REDD+ reporting requires regular assessment of the activity data, ideally annually. The period length of analysis or repetition rate that can be considered by the product/ dataset is assessed in order to define its potential frequency. The criteria is reported with following periods: (i) from 1 year or below, (ii) up to 3 years and (iii) more than 3 years.

B4. Documentation

The description of the product/dataset through user guides or publications is important to ensure transparency and replicability of the results. The availability of the documentation related to each product/dataset is assessed including the product descriptions, technical specifications, publication in scientific journals.

C1. CALM Level

The criteria to Consistently Assess Levels of Maturity (CALM) of products/datasets related to REDD+ MRV have been developed by the Global Forest Observations Initiative (GFOI). Information has been gathered in Deliverable D2.2 on the products/datasets including elements such as the CALM level, which are used here for criteria C1. The CALM rating is used as indication for the maturity and degree of operationality of the potential products/datasets.

C2. Applicability across Biomes/ Ecosystems

The tropical regions cover large variety of biomes and ecosystems. This criterion aims at assessing the applicability of the products/datasets across different biomes (e.g. Humid evergreen forests, dry forests, montane etc.).

C3. Efficiency (Labour/Cost) to Extent across Large/ Global Scale

This criterion assesses the capability of each product/dataset to be extended over large areas/ at global scale in a cost efficient manner. The amount of training data required by the product/ dataset is taken into account as well as the level of automation (from manual intervention to fully automated processing).

D1. Existing Global Service

This criterion deals with the question whether the product/ dataset is already in place (or almost) for a global service. The products/ datasets that already exist as global services are not further considered under the design of the main technical elements for Copernicus REDD+ component in order to avoid duplication with this existing service. Such existing products, if considered as important contribution to REDD+ implementation, can be made available in a REDD+ component (e.g. linked on the final platform, etc.). Therefore, if the product/dataset is already in place as a global service, it is no more considered for REDD+ component, and is assigned with the lowest rating.

D2. Future Service Continuity

An important element for the User of a land monitoring service is to get information about the service continuity in order to understand if it can rely on this service for a long period. This criterion assesses the expected duration of the provision of the concept/product under a potential REDD+ component based on security of financing, sensor data and programmes. If a service (under the Copernicus program or any other program) is existing and its future continuity is ensured, the lowest rating is provided.

The full list of criteria is presented in following Table 3 with their 3 levels of assessments ('possible answers').

Table 3: Questions and answer options for each of the benchmarking criteria to assess the 'fit-to-purpose' level of the products/datasets.

N°	Title	Source of Criterion	Question	Possible answers		
			Rating value	**3**	**2**	**1**
A1	Forest Definition Marrakech Accord	Technical REDD+ requirements	*Does the thematic content allow the application of the Forest definition of the Marakech Accord (minimum forest area 0.05-1 ha, 2-5 m tree height at maturity, Minimum canopy cover 10-30 %)*	Yes	Yes, but requires additional processing/ data	No
A2	IPCC Land Use Categories		*Does the thematic content support the mapping of IPCC Classes?*	Yes, all classes available	Yes, but requires additional processing/ data	No classes relevant for REDD+
A3	Forest Area Change		*Does the thematic content support the mapping of forest area change?*	Yes, deforestation mapping supported	Yes, but requires additional processing/ data	No
A4	Change in Forest Land Remaining Forest Land		*Does the thematic content support the mapping of changes in forest land remaining forest land?*	Yes	Yes, but requires additional processing/ data	No
A5	IPCC Approach		*The IPCC Activity Data (AD) Approach the tool/method can support*	Approach 3. Spatially explicit tracking of land-use conversions over time, either by sampling or wall-to-wall	IPCC Approach 2. Tracking of conversions between land-use categories, not spatially explicit	IPCC Approach 1. Total area for each land use category, but no information on conversions (only net changes)
A6	IPCC Tier		*The IPCC Tier for Emission Factors (EF) that the product/tool/method can support*	Tier 3: Higher-order methods include models and can utilize plot data to address national circumstances	Tier 2: Same as Tier 1 but with country specific emission factors/ data	Tier 1: Gain loss method using default emission factors and parameters
A7	Uncertainty assessment		*Can the uncertainty of the estimates of the concept be assessed?*	Yes		No
B1	Geographical Scalability	User requirements	*Ability of the concept to change the scale of the analysis*	Highly Scalable (Local to Regional to Global)	Moderately scalable (Regional to global OR local to regional)	Not Scalable down to local
B2	Potential Historical coverage		*Length of the historical period for potential analysis (according to the availability of input datasets)*	Long term History (10+ years)	Short term History (2-10 years)	Very short term history (<2 years)
B3	Temporal frequency		*Period length of analysis / repetition rate of concept*	<= 1 year	2-3 years	> 3 years
B4	Documentation avaibility		*Product descriptions and specifications available*	Yes, available and documented in a	Yes, available only for technical teams and	Not available
C1	CALM level	Operating Requirements	*levels of maturity (CALM) of the investigated concept*	Operational (7-9)	Pre-operational (4-6)	Research (1-3)
C2	Applicability across biomes/ ecosystems		*Is the presented concept applicable across relevant biomes (eg. Humid evergreen forests, dry forests, montane etc.)?*	Yes, is demonstrated accross different biomes	Potentially, but not demonstrated yet	No, method/ algorithm is specific to certain biomes
C3	Efficiency (labour/cost) to produce across large/ global scale		*Is the concept producable / abblicable across large scale cost efficiently?*	Yes, possible to produce in accurate and cost efficient manner	Yes, possible to produce with moderate cost efficiency	No, high cost and labour productions
			Specific rating value for D criteria	**2**	**1**	**0**
D1	Existing global service	Service and Continuity	*Is the concept already or almost already in place for continous global service?*	No	Yes, within other Program than the Copernicus	Yes, already under the Copernicus Program
D2	Future Service Continuity		*If the service is existing, what is the potential period for future analyses based on security of financing, sensor data and programmes?*		Uncertain	Ensured
	Good Candidate for the Learning Exercises		*Suitable Candidate to be evaluated during the Learning Exercises*	Good to very good	Medium	Not suitable
			N.A. = Not Applicable			

For the analysis of the benchmarking assessment the possible answers for the criteria groups A (REDD+ technical requirements), B (User requirements) and C (Operational requirements) are replaced by ranking numbers (green = 3; yellow = 2; red = 1) in order to allow a quantitative (comprehensible) evaluation for each group. The rating of the groups are then averaged into a "combined fit" rating. Criteria D (Service and continuity with ranking numbers green = 2; yellow = 1; red = 0) are averaged as well and this so derived factor is finally used to weight above "total fit" rating. Figure 1 illustrates the logic of the benchmark rating applied.

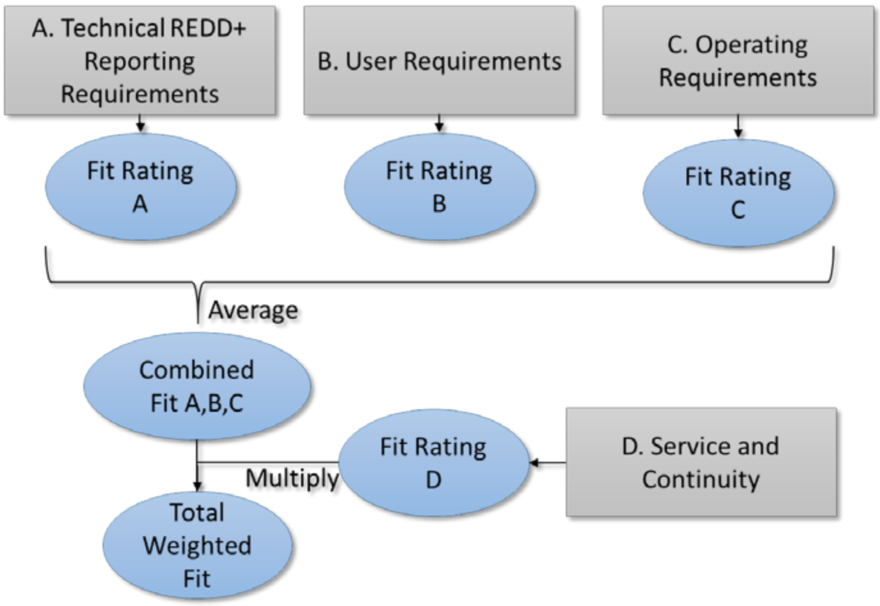

Figure 1: Approach for calculating the benchmark rating.

2.2.2 Benchmarking Assessment

Based on expert knowledge from the Consortium members, the associated concepts of the different products/datasets identified in Deliverable D2.2 are assessed in the light of the 16 selected criteria in order to evaluate their fitness for purpose. The pre-identified products/datasets are grouped into six main categories:

1. Remote Sensing Imagery: Sentinel-2 Global Mosaic (S2GM), Sentinel-2 cloud-free composites (JRC-L1C-S2-COMP),
2. Global Land Cover/Fire products: Copernicus Global Land Service (CGLS) such as Copernicus Global Land Cover v2 (CGLS-LC100), Fraction of green Vegetation Cover (CGLS-FCOVER300), Burned Area (CGLS-BA300), Leaf Area Index 300m (CGLS-LAI300), European Forest Fire Information System (EFFIS), Global Wildfire Information System (GWIS), ESA CCI Land Cover Maps (CCI Land Cover), ESA WorldCover,
3. Forest Status: Tree Cover Density (HRL-TCD), Dominant Leaf Type (HRL-DLT), Forest Type (HRL-FTY), Small Woody Features (HRL-SWF), ESA CCI Biomass, ESA Globbiomass map,
4. Forest Status/Change: Tropical Moist Forest (TMF), Global Forest Watch: Global Forest Change (GFW), INPE Deforestation Monitoring (PRODES),
5. Forest Cover Change: FAO Forest Resources Assessment RSS (FRA), BFAST, Forest Canopy Disturbance Monitoring (FCDM-optical/radar),
6. Near real time alerts: GLAD Alerts (GLAD), RADAR Forest Cover Loss Alerts (BAYTS), INPE Real Time Deforestation Detection (DETER).

The results of the benchmarking analysis are summarized and presented in Table 4. The analysis includes 26 Forest Monitoring products/datasets. The associated concepts of these products/datasets are assessed according to a set of 16 criteria that are summarized in four synthetic categories (Fit for REDD+ technical requirements, Fit for User requirements, Fit for Operations requirements, Fit for Service & continuity). The combination of the evaluation of all categories of criteria allows to identify the most appropriate candidates for the Initial design of the technical specifications that will be assessed during the Learning Exercises ("Good Candidate for the Learning Exercises"). Only products/datasets with ratings above an empirical threshold (> 4.8 ranking points) are considered as further candidates (Good/Very Good candidates).

Table 4: Summarized benchmarking matrix analysis of the pre-identified 26 FM products/datasets for the four categories criteria (A-B-C-D) and the results (Total Fit)

			A	B	C		D	
N°	Acronym	Concept Category	Fit for REDD+ policies	Fit for User requirements	Fit for Operations requirements	Combined Fit	Fit for Service and Continuity	Total fit
Source of Criterion			Overall relevance (A1-A7)	Overall relevance (B1-B4)	Overall relevance (C1-C3)	Average (A-B-C)	Overall relevance (D1-D2)	(weighted by criteria D)
1	S2GM	Remote Sensing Imagery	2.4	2.5	2.3	2.4	0.0	0.00
2	JRC-L1C-S2-COMP		2.4	2.8	2.7	2.6	2.0	5.21
3	CGLS-LC100	Global Land Cover/Fire products	2.0	2.0	2.7	2.2	0.0	0.00
4	CGLS-FCOVER300		1.8	2.5	3.0	2.4	0.0	0.00
5	CGLS-BA300		2.0	2.5	3.0	2.5	0.0	0.00
6	CGLS-LAI300		1.7	2.5	3.0	2.4	0.0	0.00
7	EFFIS		2.0	2.5	3.0	2.5	0.0	0.00
8	GWIS		1.8	2.5	3.0	2.4	0.0	0.00
9	CCI Land Cover		2.0	2.5	2.7	2.4	1.0	1.19
10	WorldCover		2.2	2.5	2.0	2.2	1.0	1.11
11	HRL-TCD	Forest Status	2.5	2.5	2.3	2.4	2.0	4.89
12	HRL-DLT		2.0	2.5	2.3	2.3	2.0	4.56
13	HRL-FTY		2.5	2.5	2.3	2.4	2.0	4.89
14	HRL-SWF		2.0	2.5	2.0	2.2	2.0	4.33
15	CCI Biomass		2.3	2.0	2.0	2.1	1.0	1.06
16	Globbiomass		2.3	2.3	1.7	2.1	1.0	1.04
17	TMF	Forest Status/Change	2.8	2.8	2.3	2.6	2.0	5.28
18	GFW		2.8	2.8	3.0	2.9	0.5	0.72
19	PRODES		2.5	3.0	2.3	2.6	0.5	0.65
20	FRA	Forest Cover Change	2.7	2.8	2.3	2.6	0.5	0.65
21	BFAST		3.0	2.8	2.3	2.7	2.0	5.39
22	FCDM-optical		3.0	3.0	2.3	2.8	2.0	5.56
23	FCDM-radar		2.8	2.5	2.7	2.7	2.0	5.31
24	GLAD	Near real time alerts	2.6	2.8	3.0	2.8	0.5	0.70
25	BAYTS		2.8	2.5	2.3	2.5	2.0	5.09
26	DETER		2.2	3.0	2.3	2.5	0.5	0.63

Based on this benchmarking matrix analysis, the preliminary selection of the most appropriate products/ datasets for the learning exercises are:

1. Remote Sensing Data: Sentinel-2 cloud-free composites S2GM and JRC-L1C-S2 (the S2GM approach was kept for comparison reasons during the Learning Exercises even though it was originally ruled out due to fact of being an already existing service),
2. Forest Status Map: Tree Cover Density (TCD), Tropical Moist Forest (TMF), Forest Type (FTY),
3. Forest Change Maps: Tropical Moist Forest (TMF), BFAST (Breaks For Additive Season and Trend), FCDM-optical/radar,
4. Near Real Time Alerting: RADAR Forest Cover Loss Alerts.

2.3 Description of the Pre-selected Forest Monitoring Products/ Datasets

The technical services or products that would be provided under a REDD+ component should support (or even enable) a country to undertake national forest monitoring for REDD+ implementation and, potentially, be applicable for monitoring SFM practices. The benchmarking analysis allowed the selection of the most appropriate products/datasets fitting the REDD+ requirements. These products/datasets will be showcased during learning exercises with local stakeholders involved in the forest sector to collect their feedbacks on the contents.

This Section 2.3 describes the technical specifications of the products/datasets that have been identified through the benchmarking analysis (as described in previous Section 2.2).

2.3.1 Sentinel-2 Imagery and Composites

As the IPCC recommends both the use of a wall-to-wall and a sample-based approach (such as the FAO FRA2020 RSS approach described in D2.2), there is a need to offer various types of Sentinel-2 imagery products from single scenes to monthly or annual composites. Such data (imagery and composites) are, apart from being used as a basis for wall-to-wall mapping, of particular importance as a reference or for visual interpretation of sample plots for a sample-based approach. By having access to the whole Sentinel-2 archive the User will be able to track specific sample plots over time, providing valuable information under a sample-based monitoring approach whether a change in the satellite signal relates to a mere seasonal effect (e.g. shedding of leafs) or was caused by anthropogenic interference. While the former does not result in land cover change, the latter represents AD that is relevant under REDD+ monitoring.

This Section specifies the Sentinel-2 imagery and cloud-free composite products. This offers composites of Top Of Atmosphere (TOA) products derived from the Sentinel-2 A and B platforms. Input to the processing are the Level 1C (L1C) products provided by the Copernicus Ground Segment, i.e. ESA Sentinel-2 core products. The service generates regional and temporal composites at global scale and produced on-demand over specific areas of interest. This approach to derive Sentinel-2 composites, as alternative to the Sentinel-2 Global Mosaic (S2GM), has been developed by the Joint Research Centre (JRC) using Google Earth Engine tool.

Annual Sentinel-2 L1C cloud-free composites over the tropical belt have been produced based on Sentinel 2A and 2B imagery from October 2015 to December 2017, Jan-Dec 2018 and Jan-Dec 2019. The spectral value of each composite pixel is calculated as the 'median' of all Sentinel-2 data (imagery available for each respective pixel) after cloud masking. The documentation about the processing algorithm will be freely available in due time from JRC (already partly available at https://forobs.jrc.ec.europa.eu/recaredd/S2_composite.php).

2.3.1.1 Output and Input Specifications

The detailed Sentinel-2 cloud-free composite Output and Input Specifications are defined in Annex 1.

2.3.1.2 Processing Specifications

While the single-date data can be proposed without any cloud-removal processing, for all other composites, the underlying algorithm to identify and remove cloud contamination is described in detail in Simonetti et al. (2015) and relies on knowledge-based rules, which are based on empirically derived spectral signatures collected globally. In contrast to the S2GM approach, Level 1C data (not atmospherically corrected) is used instead of L2A for the composites. Finally, a compositing step calculates the median over all available cloud-free pixels. As key feature, a newly developed cloud and shadow masking approach has been integrated and successfully tested at local/regional scale, leading to a significant improvement in sharpness by removing even smallest cloud remnants. The prototyping and the processing is running under Google Earth Engine (GEE). Options for downloading the S2 mosaic (GeoTiff) will be available soon.

2.3.2 Tree Cover Density

This Section specifies the Tree Cover Density product. The TCD product is a spatially explicit wall-to-wall representation projective tree canopy cover, expressed in percent. The Copernicus Land Monitoring Service (CLMS) defines Tree Cover Density (TCD) as the “vertical projection of tree crowns to a horizontal earth’s surface”. It provides information on the proportional crown coverage per pixel in a range of 0 to 100%. The product became operational in 2012 as part of the Copernicus High Resolution Layers (HRLs). It is based on optical Sentinel-2 satellite imagery and can be provided on a regular basis (e.g. every 12 months). The TCD product is a key input/ precursor for deriving forest maps as it allows the flexible application of a Forest Definition (e.g. FAO, National Definitions) in order to produce e.g. a forest cover mask, or other forest cover products. It can also be used as an input variable to spatially explicit modelling of forest biomass.

2.3.2.1 Output and Input Specifications

The detailed TCD Output and Input Specifications are defined in Annex 2.

2.3.2.2 Processing Specifications

The Tree Cover Density Product is based on time series Sentinel-2 multispectral satellite imagery, which is pre-processed (atmospheric correction, cloud masking). The product is generated based on a 2-step procedure: First, a tree cover mask is produced by pixel-based classification of dense time series data and then a multiple linear regression is used to correlate spectral properties to tree cover density reference data and derive a TCD model. TCD Reference data is generated from VHR satellite imagery by systematic sampling of 1 ha plots in a 10x10m sampling grid and is used for calibration of the TCD model as well as for model validation. Ideally, the Tree Cover Density is assessed on VHR sources by visual interpretation following a point grid approach (e.g. 10 x 10 point grid) for each Primary Sampling Unit (PSU). The assessed density information is linked with the spectral information of the satellite data and transferred to a multiple linear regression estimator.

2.3.3 Forest Seasonality/ Type

This Section specifies the Forest Seasonality/ Type product which shows the extent of forests based on the FAO forest definition and distinguished the forest into sub-classes according to their seasonality in evergreen and deciduous forest. The product is based on optical Sentinel-2 (and optionally Sentinel-1) time series data, which is derived by pixel-based classification of time features analysing the variation of spectral reflectance of the forest vegetation throughout the phenology season.

2.3.3.1 Output and Input Specifications

The detailed Forest Area and Seasonality Output and Input Specifications are defined in Annex 3.

2.3.3.2 Processing Specifications

The Forest Seasonality/Type product is based on dense time series of optical Sentinel-2 (and optional SAR Sentinel-1) imagery and pixel-based classification techniques using machine learning methods. The pre-processing for the optical imagery consists of radiometric correction, topographic normalisation, cloud and cloud shadow removal and calculation of indices. Analysis ready data, e.g. from the Synergise SentinelHub can also be used for analysis. SAR data is pre-processed using the Sentinel Application Platform (SNAP) employing processing to Gamma0, subset, thermal noise removal, radiometric calibration, terrain flattening and terrain correction and multi-temporal filtering.

The pre-processed images are stacked into dense time series for the defined observation period, usually the target year +- 1 year. Temporal statistical parameters from the time series, referred to as “Time features” are calculated which describe the temporal characteristics of the different land cover categories (e.g. mean, median, variance). Statistical time series properties can be flexibly computed from reflectance or index data of optical imagery, or backscatter information in radar imagery.

Classification of forest seasonality/ Type is conducted by the Random Forest (RF) Classification algorithm (Breiman 2001, Liaw and Wiener 2002). The RF algorithm generates multiple decision trees with randomly drawn subsets, instead of using all variables from the available data. Classification is done in a two-step procedure, first creating a binary Forest Mask (distinguishing forest and non-forest) and then further splitting the forest class into the sub-classes evergreen and deciduous forest according to the seasonality of their spectral patterns. Training data for the classification is derived from VHR data, aerial imagery, field data or other reference data available on forest types (e.g. forest inventory plot data).

2.3.4 Tropical Moist Forest

This Section specifies the Tropical Moist Forest (TMF) products. The TMF dataset (being continued) makes use of 38 years of Landsat individual images from 1982 to 2019 (about 1 250 000 scenes), mapping the tropical evergreen forest cover and forest cover dynamics such as deforestation, degradation and regrowth over the entire pan-tropical region. This multi-temporal analysis allows obtaining globally consistent and locally relevant information on the TMF extent and changes at 30m spatial resolution. Degraded forests and deforested land have been discriminated based on the duration and the intensity of the observed disturbance events.

The TMF dataset depicts the (semi-)evergreen forest extent and patterns of disturbances through two complementary layers: (a) a transition map and (b) an annual change dataset described hereafter. Each disturbance has been characterized in terms of timing (start and end dates of the disturbance and duration), sequential dynamics (e.g. deforestation after degradation), intensity (number of disruption observations) and extent.

2.3.4.1 Output and Input Specifications

The detailed Tropical Moist Forest product Output and Input Specifications are defined in Annex 4 for the transition maps and for the annual change product.

2.3.4.2 Processing Specifications

In order to map the area dynamics (extent and changes) of the tropical evergreen forests on a long-term period, an expert system has been developed to exploit the multispectral and multi-temporal attributes of the Landsat archive (since 1982) and uses ancillary information.

The mapping method includes four main steps: (A) single-date multi-spectral classification, (B) analysis of trajectory changes using the temporal information and production of a transition map, (C) identification of sub-classes of transition based on ancillary data (tree plantation and water surface datasets) and visual interpretation, (D) production of annual change maps.

In the first step (A), each pixel of the Landsat archive were classified on a single-date basis. Each pixel within the archive was initially assigned through single-date multi-spectral classification to one of three following classes: (i) potential evergreen forest cover, (ii) potential disruption, and (iii) invalid observation (cloud, cloud shadow, haze and sensor artefacts). The temporal sequence of classes (i) and (ii) was then used to address the uncertainty of the single-date spectral classification and to determine the target transition classes.

In the second step of the mapping approach (B), the temporal sequence of single-date classifications at pixel scale was analysed to first determine the initial extent of the tropical evergreen forest domain, by selecting pixels without any disruption for a minimum of four years from the first available valid observation. Then, from this initial delineation, five main transition classes have been identified.

The third mapping step (C) allowed to identify three sub-classes from the deforested land class. We geographically assigned deforestation to the conversion from evergreen forest to tree plantations - mainly oil palm and rubber, water surface (discriminating permanent and seasonal water)- mainly due to new dams, and other land cover - agriculture, infrastructures, etc. using ancillary information completed by visual interpretation of high-resolution imagery.

Each TMF disturbed pixel (degraded forest, deforested land, or forest regrowth) was characterized by the timing and intensity of the disruption events. The start and end dates of the disturbance allows identifying in particular the timing of creation of new roads or of logging activities and the age of forest regrowth or degraded forests. Three decadal periods have been used in the transition map to identify sub-classes of degradation and forest regrowth with ages: (i) before 2000, (ii) within 2000-2009 and (iii) within 2010-2019. The number of annual disruption observations combined with the duration, constitute a proxy for the disturbance intensity and impact level.

In the last mapping step (D), a collection of 30 maps is derived to provide the spatial extent of the evergreen forest and disturbance classes on a yearly basis from 1990 to 2019.

2.3.5 Forest Canopy Disturbance Monitoring

The FCDM tool developed at the JRC supports the detection of forest canopy disturbance from satellite remote sensing and can provide indication on forest degradation processes. The freely available FCDM (Forest Cover Disturbance Monitoring) tool comprises two monitoring approaches to detect disturbances in the forest canopy cover from satellite remote sensing: (a) the FCDM-optical approach based on the Delta-rNBR (self-referenced Normalized Burn Ratio) methodology, based on optical satellite imagery and (b) the FCDM-radar approach based on the Delta-SPE (Single Polarization Enhancement) methodology that is based on radar imagery only. The detection of forest canopy disturbance within forest canopies ('forest remaining forest') result for instance from tree removal, felling damages or from logging trails and thus can provide indications on forest degradation processes. Both monitoring methodologies are based on a multi-temporal change detection approach between an analysis and a reference period. The tool is running under Google Earth Engine (GEE) on a specific user-interface that allows working with the tool without the need of scripting knowledge.

2.3.5.1 Output and Input Specifications

The detailed Forest Canopy Disturbance Monitoring product Output and Input Specifications are defined in Annex 5.

2.3.5.2 Processing Specifications

The FCDM-optical (also named as Delta-rNBR methodology) is based on the analysis of optical satellite imagery (Landsat 4, 5, 7 and 8 as well as Sentinel-2 data) at medium spatial resolution (10m). The Normalized Burn Ratio (NBR) vegetation index, which is – beyond being able to detect burn scars – sensitive towards bare soil and non-photosynthetic vegetation, is used to detect openings in the canopy cover after clouds and cloud shadows have been removed. A self-referencing step is introduced in order to ensure the inter-scene comparability. Due to the fact that the signal of forest canopy disturbances (for example after the felling of a tree) is faint and especially in the humid tropics often short-lived because the soil or non-photosynthetic components are quickly overgrown by a fast growing layer of herbs and saplings, the Delta-rNBR methodology works with all images available in the Landsat or Sentinel-2 archives for longer periods such as seasons (several months) or whole years. In this way it allows capturing canopy disturbances with higher consistency and reliability even if occurring only occasionally. Finally, an aggregation step memorizes the worst (most disturbed) canopy cover condition per pixel location over the analysis and reference periods. These canopy cover composites are eventually used to calculate the difference between both periods, which indicate the canopy disturbance events (activity data) that occurred within the analysis period but showed undisturbed canopy cover during the reference period (Langner et al., 2018).

The FCDM-radar (also called as Delta-SPE methodology) is based on the analysis of Sentinel-1 radar satellite imagery at medium spatial resolution (10 m). As Sentinel-1 data (C-band) has a wavelength of about 5.5 cm it is able to penetrate the upper leave layers of the forest canopy and is mainly backscattered by the smaller and medium sized branches of the upper canopy. As result, the removal of a single tree for example due to selective logging is captured by the single bands, to a larger part independent of the polarization. However, due to the overall high level of backscatter noise the actual disturbance event – especially if small-scale such as a single tree removal – cannot be separated from the noise. Therefore, a multi-temporal filtering of the single polarized bands is performed over the analysis and reference periods. In order to be able to distinguish signal from noise, the disturbance event has to be observed at least for a certain duration of the analysis period. As a next step, the band-wise difference between the analysis and reference period is calculated, and these intermediate single band results are combined to better highlight areas of canopy cover change.

2.3.6 Breaks For Additive Season and Trend

This Section specifies the Breaks For Additive Season and Trend (BFAST) methods and software. In this case, the product described is produced by applying the BFAST algorithm on the Harmonized Landsat Sentinel2 data product (HLS) (https://hls.gsfc.nasa.gov/) and by using training and validation data sets to convert the BFAST change monitoring outputs into a specific product *e.g.* deforestation (year and time of deforestation).

More generally, BFAST integrates the decomposition of time series into trend, season, and remainder components with methods for detecting and characterizing change within time series. Essentially this method can be used to detect changes in remote sensing data and has most commonly been used to detect forest loss and gain. There are two components BFAST & BFASTmonitor.

BFAST iteratively estimates the time and number of abrupt changes within time series, and characterizes change by its magnitude and direction. BFAST can be used to analyse different types of time series (*e.g.* Landsat, MODIS) and can be applied to other disciplines dealing with seasonal or non-seasonal time series, such as hydrology, climatology, and econometrics. The algorithm can be extended to label detected changes with information on the parameters of the fitted piecewise linear models.

BFASTmonitor provides functionality for monitoring disturbances in time series models (with trend/season/regressor terms) at the end of time series (*i.e.,* in NRT). Based on a model for stable historical behaviour, abnormal changes within newly acquired data can be detected. Different models are available for modelling the stable historical behaviour. A season-trend model (with harmonic seasonal pattern) is used as a default in the regression modelling.

2.3.6.1 Output and Input Specifications

The detailed BFAST Output and Input Specifications are defined in Annex 6.

2.3.6.2 Processing Specifications

The algorithm is well developed and is available on r-forge (http://bfast.r-forge.r-project.org/), as well as in SEPAL (www.sepal.io). The speed of the algorithm is currently being optimized by using GPU processing capacities.

BFAST can be run on a desktop, mobile or cloud computing platform, from any computer platform (Windows, Linux etc.). It is available offline, and a single machine has sufficient CPU (depending on the area of interest). There are no specific storage requirements for hardware.

Pre-processing is carried out using well-established packages within the bfast r code. This includes for example adjustment for surface reflection and cloud masking (LEDAPS and FMASK) – and this differs depending on the input data. Outliers are removed, and data are mosaiced as required.

Then the algorithm is applied to the time series following an identification of the stable forest in the historical period. Generic Disturbances (e.g. deforestation) can then identified using the BFASTmonitor algorithm, which removes seasonality using a first-order harmonic seasonal model.

Training and validation data is required to train and classify the changes detected (significant change, and characterized change magnitude) towards specific disturbances e.g. deforestation events.

Spatial and thematic accuracy of these changes and e.g. specific disturbances is then the next critical step. More information on the methods can be found in an example of use of BFAST in practice (Devries et al., 2015).

2.3.7 RADAR Forest Cover Loss Alerts

This Section specifies the Radar Forest Cover Loss Alerts product. In this case the BAYTS methodology has been applied on the ESA Sentinel-1 radar data. Satellite radar remote sensing uses long-wavelength energy that penetrates through clouds and is sensitive to changes of forests physical structure, major advantages for NRT monitoring. With Sentinel-1, temporally dense and high spatial resolution 10 m radar data are available free and open globally for the first time. Sentinel-1 provides guaranteed observations every day in Europe and every 6-12 days in the tropics, independently of weather, season, and location. This is in particular useful in the context of monitoring forest loss in the tropics, where persistent cloud cover is limiting the ability to track forest change events consistently on a near real-time.

BAYTS is a probabilistic machine-learning-based method to detect forest cover loss in NRT using satellite data (e.g. Sentinel-1). The method is also capable of combining data from multiple satellites, such as Sentinel-1 (Radar) and Landsat (optical). Each new observation is converted to forest probabilities based on pixel-based time series metrics describing stable forest conditions for the period of interest. In case that the forest probability is smaller than 0.5, forest cover loss events are flagged and the change probability is calculated. Future observations are used to update the change probability and confirm or reject a forest cover loss alert event. The core information on the methodology is presented in Reiche et al, 2018.

This approach has been used to provide **forest cover loss alerts**, which can provide inputs into monitoring efforts or more typically, for law enforcement efforts which target illegal activities. The method is open source and available for all, and has already been operationalized at the national level in several countries (in an operational service context in Ecuador and Indonesia).

2.3.7.1 Output and Input Specifications

The detailed RADAR Forest Cover Loss Alerts Output and Input Specifications are defined in Annex 7.

2.3.7.2 Processing Specifications

The processing chain is well developed, and is semi-automated, meaning that regional tuning is required by the end user if alerts are to be prioritized for action.

The alerts can be run from any computer platform (Windows, Linux, cloud and desktop etc.). It is available offline, and a single machine has sufficient CPU (depending on the area of interest). There are no specific storage requirements for hardware.

Pre-processing is carried out on individual images as required depending on the sensor, mostly using ESA’s SNAP toolbox, corrupted images are removed, and data are mosaicked. In the case of Sentinel-1 image pre-processing, this includes geocoding, topographic normalisation and speckle filtering.

The NRT detection is then applied on each pixel within the forest mask. Firstly, forest seasonality is removed using harmonic model filtering, then the forest and non-forest distributions are derived, and a probabilistic approach is used to detect forest loss.

Spatial and temporal accuracy is then assessed as required. More information on the methods can be found in a scientific article from Reiche et al. (2018).

2.4 Preliminary Definition of Potential Forest Monitoring Concepts

The key elements necessary for a future Copernicus REDD+ Service Component were identified in the benchmarking analysis (in Section 2.2) based on existing products/datasets and the pre-selected products/datasets were described in details (Section 2.3). Based on these results, this Section provides a preliminary definition of the potential REDD+ Forest Monitoring concepts for the future Service Component. The specifications are based on the Stakeholder and Policy Review Requirements and the review of the FM capacities (D1.1 and D2.2) and will be consolidated with the outcomes of the learning exercises (D4.2). As pointed out in D1.1, the preliminary design of GIS analytical tools, providing some basic GIS functionalities that allow the user to handle and analyse the various potential future Copernicus REDD+ datasets, is described below in Section 2.4.6. These preliminary functionalities are extracted from the analysis of available toolbox options provided in D2.2.

The consolidated detailed technological specifications will be produced in D8.1 for the core service, and downstream potential associated service will be further detailed.

2.4.1 General Principles

The products as well as the GIS analytical tools to be provided under a potential REDD+ Service component should support (or even enable) a country to undertake national forest monitoring for REDD+ and/or be applicable for preparing and monitoring SFM practices. This REDD+ component aims at providing base layers for Forest Measurement and Reporting to tropical countries and should contain a list of standardized products to support the REDD+ implementation.

In the Roadmap for Future Copernicus Service Component for REDD+ Service (JRC concept note, 2016), it was clearly identified that a new dedicated REDD+ Copernicus service component should address high resolution forest area delineation and disturbance indicators. Such component should aim at providing in an automated way **annual forest maps at 10 m resolution. These maps should display main land cover classes with at least forest/ non-forest distinction at an accuracy of more than 85%,** potentially also including a few forest types, i.e. supporting the assessment of a "natural forests" class as defined and operationalized by UNFCCC Parties to comply with UNFCCC Decision 11/CP.19 (JRC, 2016). The baseline for the production of a REDD+ service component is the exploitation of the Sentinel EO data, mainly Sentinel-2 optical images, complemented by Sentinel-1 radar data.

The preparation of detailed product specifications for a REDD+ service component is a crucial task in the view to provide fit-for-purpose products to REDD+ users. In this Section, we provide a preliminary description of concepts that are matching the REDD+ policy requirements and, at the same time, are sufficiently mature for implementation within an operational service.

Figure 2 depicts an example of five basic building blocks, which could eventually be made available under a future Copernicus REDD+ Service, thus assembling a potential future REDD+ Service Portal. These building blocks include:

a) Analysis ready EO data for Forest monitoring (Remote Sensing imagery composites),

b) Forest Cover Status/ Condition maps (Tree cover/ Forest Type status maps),

c) Forest Cover Change information (Deforestation),

d) Forest Disturbance information (Canopy Disturbance that allows deducing Forest Degradation information),

e) EO & GIS Toolbox.

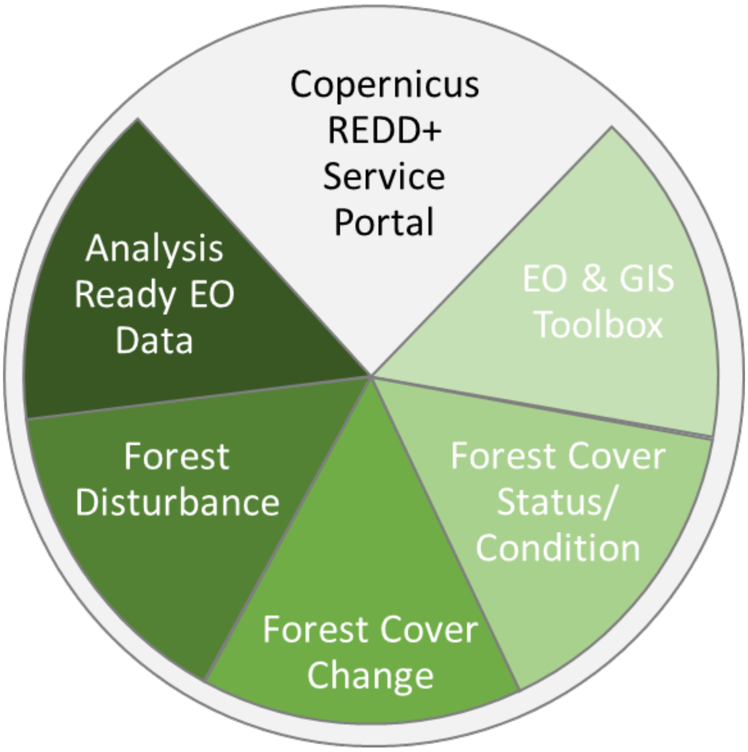

Figure 2: Building Blocks of a potential future REDD+ Service Portal.

The Forest Monitoring concepts that have been selected to fit these potential building blocks for a future REDD+ Service Portal are described hereafter in this Section:

1. Sentinel-2 imagery and composites,
2. Pan-Tropical Tree Cover Density for the reference year 2020,
3. Pan-Tropical Annual Tree Cover Change ,
4. Pan-Tropical Tree Cover Disturbance Alerting,
5. GIS analytical tools.

2.4.2 Sentinel-2 Imagery and Composites

While providing single date imagery for which no cloud removal processing is necessary and which mainly aim for visual interpretation activities as needed for example for sample-based monitoring approaches, the main focus of this Section is on the technical specifications of a potential improved Sentinel-2 cloud-free composite.

Such concept is aimed at allowing generating regional and temporal composites at global scale, produced on-demand over specific areas of interest. The specifications of such improved product are based on the experience derived from two existing products/datasets: S2GM and JRC-L1C-S2 products. The main differences of these products are presented in Table 5. While S2GM composites are derived from S-2 Bottom of Atmosphere (BoA) reflectance data (L2A), the JRC-L1C-S2 is derived from S-2 Top of Atmosphere (ToA) data (L1C). The cloud and shadow screening is also different: S2GM is relying on the ESA products-embedded cloud mask for the identification of the dense and cirrus cloud pixels when JRC-L1C-S2 is using the ESA L1C cloud mask with an additional step to better remove opaque and cirrus clouds. Finally, the compositing algorithm differs for the two approaches: S2GM is using the ‘medoid’ approach, which is conceptually similar to a centroid approach that selects single-date observations when JRC-L1C-S2 applies the median independently for all bands, and consequently does not necessarily select all spectral bands of a single pixel at a unique date.

Table 5: Main differences between S2GM and JRC-L1C-S2 products

	S2GM	JRC-L1C-S2
S-2 processing level	L2A (BOA reflectance)	L1C (TOA reflectance)
Cloud Mask	ESA L2A cloud mask	ESA L1C + JRC cloud mask
Compositing algorithm	Medoid	Median
Initial Potential Global Coverage	December 2018	October 2015

Figure 3 shows the results of different compositing algorithms (geometric median, median and medoid) applied to the same Landsat 8 data conducted by Roberts et al. (2017). The comparison shows that the geometric median has the highest spatial homogeneity and the Medoid approach leads to the highest spatial variability. More observations over longer compositing periods lead to better spatial homogeneity for all algorithms.

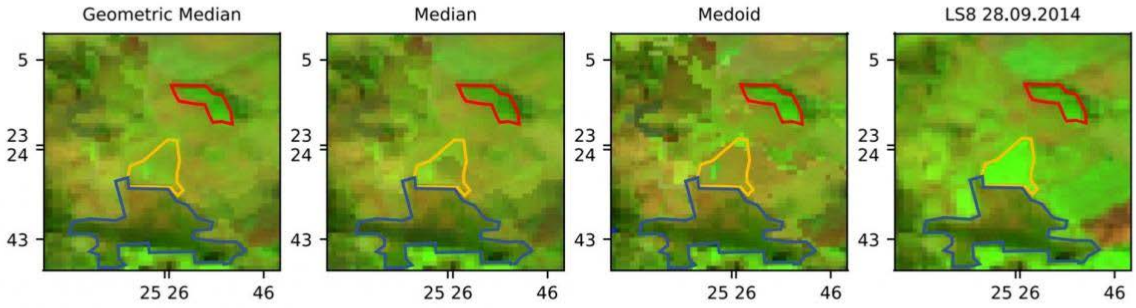

Figure 3: Comparison of geometric median, median and medoid against single clear observation

(different LC features marked in red, orange and blue). (Source: S2GM website modified after Roberts et al. 2017)

For the REDD+ Copernicus service component, an annual S-2 cloud-free composite is expected to support the production of detailed thematic maps (Tree Cover Density, Annual Tree Cover Change and Tree Cover Disturbance Alerting) by national institutions. The two products (S2GM and JRC-L1C-S2) will be assessed during the learning exercises (WP4) in order to potentially improve the S2GM component of the Copernicus Land Service.

2.4.3 Pan-Tropical Tree Cover Density for the 2020 Reference Year

A Pan-Tropical Tree Cover Density (TCD) product is proposed as a tree cover status layer, based on the specifications of the HRL-TCD product (See Section 2.3.2) that is implemented since 2012 within the pan-European component of the CLMS. This TCD product will be based on optical Sentinel-2 satellite imagery for the reference year 2020. The combination with Sentinel-1 imagery can also help improving the quality, e.g. especially in areas with high cloud coverage.

According to the UNFCCC definition (2001), ‘Forest’ is a minimum area of land between 0.05 to 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 to 30 per cent, where trees are higher or have a least the potential to reach a minimum height of 2 to 5 meters at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10-30 per cent or tree height of 2-5 meters are included under forest, as are areas normally forming part of the forest area which are temporarily un-stocked as a result of human intervention, such as harvesting or natural causes, but which are expected to revert to forest.

Tree Cover Density, defined as the “vertical projection of tree crowns to a horizontal earth’s surface”, includes “Forest” and “Other Wooded Land” areas as defined by FAO and provides information on the proportional crown coverage per pixel in a range between 0% to 100%.

The TCD product is considered to be a key input/ precursor for deriving forest maps as it allows the flexible application of a forest definition (e.g. FAO, national definitions). Such product can also serve as key input variable to spatially explicit modelling of forest biomass.

2.4.4 Pan-Tropical Annual Tree Cover Change

This Section specifies the "Pan-Tropical Annual Tree Cover Change" product. This product makes use of the Sentinel-2 and Sentinel-1 time series, as primary and ancillary datasets respectively, to detect forest cover dynamics such as deforestation, forest degradation and forest regrowth over the pan tropical belt. This multi-temporal analysis allows obtaining globally consistent and locally relevant information on the tree cover changes at 10m spatial resolution.

2.4.5 Pan-Tropical Tree Cover Disturbance Alerting

An important requirement for a forest monitoring system is the detection of small-scale forest canopy disturbances based on a continuous and frequent service provision. The temporal resolution of tracking forest change events is therefore directly linked to the repetition frequency of satellite data acquisitions. The Pan-Tropical Tree Cover Disturbance Alerting product is considered as an important Near Real Time (NRT) alerting system to allow identifying frequently logging activities (legal and illegal), on-going forest management activities and burned forests.

This product makes best use of the high temporal frequency of Sentinel-1 and -2 to detect forest cover dynamics such as deforestation, degradation and regrowth over the entire world within a bi-monthly revisit.

2.4.6 GIS Analytical Tools

In addition to the four proposed REDD+ Service building blocks dealing with datasets/ products, a further component with GIS analysis tools is necessary, in order to complement a future REDD+ Service Portal offering the User a certain degree of GIS analysis functionality. These GIS analytical tools would allow connecting and further analysing the single REDD+ Service products and provide the User a set of tools with GIS and data manipulating functionalities.

From an organizational point of view, these analytical tools could be made available both, as a desktop version as well as a web-based portal in order to provide flexibility to the different Users/ Stakeholders. The web-based version could be similar to Global Forest Watch of WRI, but with the additional functionality to adjust various (e.g. country-specific) parameters such as forest definition, MMU and EF when using the Copernicus REDD+ Service for their national GHG reporting . The use of country-specific parameters for national reporting is important for country ownership and endorsement aspects. A good example for a desktop version is the TerraAmazon software developed by INPE or the IMPACT toolbox by JRC (both described in D2.2).

The requirements on the GIS analytical tools of a future Copernicus REDD+ Service Portal will be elaborated with the Users during the Learning Exercises in WP4, and further consolidated in the D8.1 report, describing in detail the technical specifications of the Copernicus REDD+ Capacity.

3 Main organizational Elements of the Service Component

The main organisational elements that have to be considered in relation to the design and implementation of a REDD+ Core Service Component are the existing European Union Regulations that govern the Copernicus programme; these include the six Core Services of Copernicus, the financial allocations for these programmes, and the roles/responsibilities of the Entrusted Entities who are responsible for managing the different programmes. Additional aspects that have to be examined are the available infrastructure capacities and gaps for the Copernicus Data and Information Access Services (C-DIAS) in Europe and their functionality in developing countries (issues of internet connection to be examined and recommendations made). The role of UN agencies in supporting or using a Copernicus REDD+ Service is also of importance. The issues of Intellectual Property Rights (IPR) for any specific code/algorithms developed by European EO industry for the REDD+ Service, as this will have an impact on any business models for Downstream Services. Finally, important organisational aspect to consider are the capacity building needs in developing countries related to REDD+ implementation, and how this will be addressed in a Copernicus service. This Chapter will aim to review these points in the subsequent Sections.

A new DG named Defence Industry and Space[6] (DG DEFIS) has been created from 1 January 2020 as a sub part of DG GROW and will include the Copernicus programme (in Directorate C “Space”). From this date, DG DEFIS will be referred to in the deliverables of the project.

The main organisational elements that have to be considered in relation to the design and implementation of a REDD+ Core Service Component are the existing European Union Regulations that govern the Copernicus programme; these include the six Core Services of Copernicus, the financial allocations for these programmes, and the roles/responsibilities of the Entrusted Entities who are responsible for managing the different programmes. In addition, the available infrastructure capacities candidates to support the expected service as well as known restrictive elements for the Copernicus Data and Information Access Services (C-DIAS) in Europe are examined. This Chapter will aim to review these points in the subsequent Sections.

Additional aspects should also be assessed at a later stage as part of WP7 and include (i) an assessments of the gaps if any for the C-DIAS infrastructure related to the implementation of the service (i.e. to determine whether C-DIAS is suitable or not to support/hold the intended core service) and their functionality in developing countries (issues of internet connection to be examined and recommendations made); (ii) clear criteria for the distinction between Core and Downstream services; (iii) the role of all international initiatives involved in REDD+ policy and specially of UN agencies in supporting or using a Copernicus REDD+ Service is also of importance, as well as (iv) the issues of Intellectual Property Rights (IPR) for any specific code/algorithms developed by European EO industry for the REDD+ Service, as this will have an impact on any business models for Downstream Services. Finally, important organisational aspects to be considered are the capacity building needs in developing countries related to REDD+ implementation, and how this will be addressed in a Copernicus service. These additional organisational aspects are partly covered by the specific objectives of WP5, which deals with the coordination with the international initiatives including the UN agencies, and specially of WP7, which has the objective to provide a proposition of organisational elements for a Copernicus FM and REDD+ service, in a three-version deliverable to be adjusted along the project life span (D5.1-3 and D7.1-2).

[6] https://ec.europa.eu/commission/presscorner/detail/en/mex_19_6747

It has to be noted, as part of the organisation elements, that a new DG named Defence Industry and Space[7] (DG DEFIS) has been created from 1 January 2020 as a sub part of DG GROW and will include the Copernicus programme (in Directorate C "Space"). From this date, DG DEFIS will be the one referred in the deliverables of the project.

3.1 Institutional Framework: Description of Copernicus Services and Integration of a Core REDD+ Service Component

3.1.1 Need for an Evolution of the Copernicus Programme

The UNFCCC policy process for REDD+ requires an assessment of national historical and projected deforestation/ degradation rates, regrowth rates and statistics for the tropical ecosystems. The UNFCCC Conference of Parties (COP) has noted that remote sensing technologies are a useful tool to provide forest information for REDD+ and countries are encouraged to use the technology for their national forest monitoring systems (FCCC/CP/2010/7/Add.1). Whilst the REDD+ process within the UNFCCC was initiated in 2006, the more recent Paris Agreement in 2015, requires countries to prepare their activities for reduction of GHGs in a post-2020 time frame as their Nationally Determined Contributions (NDCs). The cycle of reviews and updates of the NDCs are every 5 years. Many countries have included their national REDD+ activities within their NDCs. Transparency is a key element of these frameworks, which includes open and free data.

The need of EO data related to forestry management is especially true in Africa, where 28[8] countries are UN-REDD partners. The demand in Latin America is considered as being relatively important: it is perceived as being the second most important demand in terms of EO data after the defence sector. Countries such as Mexico and Brazil are expected to be the largest clients in order to improve their national forest monitoring programmes (PWC[9], 2016).

In a report from JRC (2016) about a future Copernicus Service component for REDD+ Service, it is highlighted that very few developing countries have operational National Forest Monitoring Systems (NFMS). It was noted that it is due to the critical issue of uptake by the countries of EO technologies, and the lack of capacities (infrastructural and human resources). The European Union (EU) and its Member States (MS) provided an estimated Euro 3 billion for REDD+ between 2006-2014; in this context the EU and MS are considered to be the second largest financier of REDD+ supporting about 30% of the total volume of funds (EU, 2015). From this perspective it is mentioned that it is important for the EC to ensure that Europe plays a lead role in the operationalization of NFMS in developing countries; which is going to be promoted in a Copernicus REDD+ programme (JRC[10], 2016). Part of the difficulty in establishing NFMS in developing countries is often the lack of sufficient capacity. The development of a Core Service component would contribute to addressing this issue.

[7] https://ec.europa.eu/commission/presscorner/detail/en/mex_19_6747

[8] https://www.unredd.net/documents/redd-papers-and-publications-90/17169-info-brief-africa-region-jurisdictional-approaches-to-redd-in-africa-emerging-lessons.html

[9] PricewaterhouseCoopers (2016): Study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus downstream sector and user benefits. Prepared for the European Commission. DG-GROW. Publication Office of the European Union (Luxembourg).

[10] JRC's "Concept Note: A Roadmap for Future Copernicus Service Component for REDD+ Service"

3.1.2 Description of Copernicus Programme

Copernicus[11] is the European Union's Earth Observation Programme. Its satellite data and related technologies, and also its free and open data policy provide excellent opportunities to support these forest policies and to enhance transparency in the sector. Copernicus offers information services to help service providers, public authorities and other international organisations to improve the quality of life for the citizens of Europe, based on global data from dedicated satellites (the Sentinel families) and contributing missions (existing commercial and public satellites), and also from ground-based, airborne and seaborne measurement systems.

In the European Union Regulation No 377/2014 which establishes the Copernicus programme (2014) the implementation of the Copernicus services was foreseen to be organised by the main Commission Entrusted Entities such as the European Environment Agency (EEA), External Borders of the Member States of the European Union (FRONTEX), the European Centre for Medium-Range Weather Forecasts (ECMWF), as well as the JRC. The regulations presented the service component which would focus on six different themes, called Core Services. Core services are funded by the European Union and thus public funds are considered as “public goods” and thus full/open access to the products and services are provided by the relevant Entrusted Entities. Downstream services are considered to be those that are based on the Core products/services which the EO value-adding industry can develop and provide at cost to end users. “Downstream services correspond to those services that will be implemented outside the scope of the Copernicus governance and without EU public funding. Downstream services will provide their users with added-value by combining the information provided by the Copernicus services with additional data (e.g. socio-economic data). Depending on the business model adopted by each service provider, these downstream services could be either free for the final user (e.g. funding through advertising) or associated to a fee (e.g. pay-per-use, recurrent fee, etc.)” (http://www.copernicus.eu/main/faqs). The Core Services are described in paragraphs below.

Copernicus Atmosphere Monitoring Service (CAMS): This service provides continuous data and information on atmospheric composition. It describes the current situation, forecasts the situation a few days ahead, and analyses consistently retrospective data records for recent years. The CAMS supports many applications in a variety of domains including health, environmental monitoring, renewable energies, meteorology and climatology. The service focuses on five main areas: Air quality and atmospheric composition, ozone layer and ultra-violet radiation, emissions and surface fluxes, solar radiation and climate forcing.

Copernicus Marine Environment Monitoring Service (CMEMS): This service provides regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. The observations and forecasts produced by the service support all marine applications, including marine safety, marine resources, coastal and marine environment, and weather, seasonal forecasting and climate. Many of the data delivered by the service (e.g. temperature, salinity, sea level, currents, wind and sea ice) also play a crucial role in the domain of weather, climate and seasonal forecasting.

Copernicus Climate Change Service (C3S): This service supports society by providing consistent and authoritative information about the past, present and future climate in Europe and the rest of the World. C3S relies on climate research carried out within the World Climate Research Programme (WCRP) and responds to user requirements defined by the Global Climate Observing System (GCOS). C3S provides an important resource to the Global Framework for Climate Services (GFCS).

Copernicus Security Service: This service aims to support European Union policies by providing information in response to Europe’s security challenges. It improves crisis prevention, preparedness and response in three key areas, which are border surveillance, maritime surveillance and support to EU External Action (SEA).

[11] Information from Copernicus programme website: https://www.copernicus.eu/en

Copernicus Emergency Management Service (Copernicus EMS): This service, already considered operational in terms of service provision, provides all actors involved in the management of natural disasters, man-made emergency situations, and humanitarian crises with timely and accurate geo-spatial information derived from satellite remote sensing and completed by available in situ or open data sources. The Copernicus EMS consists of two components: a mapping component and an early warning component. Early warning component includes the European Forest Fire Information System (EFFIS), which provides near real-time and historical information on forest fires and forest fire regimes in the European, Middle Eastern and North African regions. EFFIS system is completed with Global Wildfire Information System (GWIS) at global level.

Copernicus Land Monitoring Service (CLMS): This Service, already considered operational in terms of service provision, has three scales of operations-the global, Pan European and a local component. The objective of CLMS is “to provide users in the field of environment and terrestrial applications with relevant information based on space data combined with data from other sources. It addresses a wide range of policies such as environment, agriculture, regional development, transport and energy as well as climate change. At global level it answers to European commitments in International Conventions." (ANNEX to the Commission Implementing Decision on the adoption of the Work programme 2019 and on the financing of the Copernicus Programme, 2019). The JRC co-ordinates the Global component and the EEA is co-ordinating the Pan-European and Local components.

3.1.3 Integration of the Proposed REDD+ Service Component within the Copernicus Programme

In the annual work programme for 2019 adopted by the European Commission in conformity with Art. 12 of the Copernicus Regulation, which establishes for each Core services a list of activities for the year, a new Global Hot Spot monitoring service is indicated as part of the Global Land component to include support of forest monitoring activities. The objective is "to provide detailed land cover and thematic reference information on specific areas of interest outside the European Union territory, particularly in the domain of the sustainable management of natural resources. [This activity] will see a continuity of the […] 2017-2018 activities dealing with protected and key landscape areas in Africa. The activities will also be extended to the support to forest monitoring (Reducing emissions from deforestation and forest degradation, REDD+) […]. Coverage will not be limited to Africa. The list of areas of interest will be extended by assessing a set of criteria [presented to the User Forum on 30 June 2017] in collaboration with other Commission Directorate-General (DG DEVCO, DG CLIMA), EU Delegations and interested EU Member States and in partnership with relevant programs/institutions. Tailored land cover and land cover change maps will be produced on protected areas and their surroundings, to support development activities, and to areas of interest to REDD+ key user communities, including the Commission (DG DEVCO) interest. This REDD+ support exercise will follow international guidelines and agreed specifications (Global Forest Observations Initiative, GFOI). The products will also be assessed and will respect defined quality standard." (ANNEX to the Commission Implementing Decision on the adoption of the Work programme 2019 and on the financing of the Copernicus Programme, 2019).

The existing Copernicus Global Land Service (CGLS) products from the Core Land Monitoring Service (CLMS) provides products that are too coarse in terms of spatial resolution to be used for detailed forest and REDD+ reporting requirements. The IPCC GPG (2006) defines 3 Tiers or levels of accuracy for reporting which have to be considered for the REDD services; Tier 1 can use spatially coarse default data based on globally available data with large uncertainties, Tier 2 and Tier 3 require country specific data with higher accuracy values. However, Tier 2 accuracy is the minimum required for reliable estimates and therefore for the REDD+ process. Moving from Tier 1 to Tier 3 increases the accuracy and precision of the estimates, but also increase the complexity and the costs of monitoring (GOFC GOLD Sourcebook, 2013).

At this first stage of the project, based on the outcome of WP1 & 2, there appears to be three main group of users that can be identified and can be ordered in terms of priority in relation to the establishment of a core service component as part of the Copernicus Programme:

1. European Commission policy formulation and monitoring requirements: EC DG DEVCO & CLIMA, FLEGT,
2. International policy and scientific framework: support to UNFCCC, UNCBD, international scientific community
3. Developing and REDD+ countries requirements: this would mainly focus on the development of downstream services/

3.1.4 Distinction between Core and Downstream Services

The following initial recommendations in relation to the organisational aspects for the designing of the new Copernicus Service Component content can be made:

1. Provision of a Core products/ service to provide input to derived IPCC compliant products, with clear specifications in terms of thematic contents, temporal and spatial definition, accuracy and transparency, designed according to the REDD+ requirements. To comply with the Core Service Component concept, these products and services would need to have a global definition and coverage. Several scenarios can be envisaged in terms of deployment depending on resources and requirements:
   a. Global service for REDD+/ Developing countries,
   b. On-demand services activated for specific regions/ countries.
2. The specified global service should be adaptable to countries users' context to allow a derivation of downstream products. The delivery of downstream services could be envisaged as follows:
   a. An online on-demand service to comply with user/ national requirement by setting thresholds for a number of specified parameters to comply with national forest definitions,
   b. Dedicated downstream services to :
      i. Produce more advanced products (i.e. Land Cover/ Use) that would be based on the core service component,
      ii. Provide capacity building related to REDD+ implementation: this has already been identified as a real need in developing countries and is also an important organisational aspect to consider (as confirmed by many stakeholders in the comprehensive User Assessment from D1.1 of the current project).

At this stage, the distinction between Core and Downstream Services mainly focuses on the geographical scope of the service. As such a service that is applicable at regional/ Global level is considered as Core whereas any adaptation focusing on national circumstances should be considered as downstream. The Dedicated Downstream services should be developed through the establishment of partnerships/ collaborations with multilateral and bilateral donor organisations and will be deeper examined in WP7 (Organisational Specifications) of this project. In addition, even though it would seem that the envisaged core service component would be part of the Global component of CLMS, interactions with/ requirements from other Copernicus Core Services such as C3S could also be envisaged or sought.

3.1.5 Synergies with Other Land Sectors

Even though forests represent by far the largest carbon sink in the AFOLU/ LULUCF sector according to the UNFCCC and IPCC, increasingly REDD and the forest sector should not be considered as standalone but activities and requirements for the other land sectors should also be considered. The identification of deforestation drivers requires as a starting point the characterisation of IPCC categories. Even though this type of requirements cannot be directly addressed as part of a global forest layer, the definition of IPCC categories should be considered as part of potential additional land cover/ use products.

The synergies with the other land sectors was tested during the benchmarking analysis within in Section 2.2 by the inclusion the IPCC land use categories criterion. The thematic content of each product was assessed if it can support the mapping of IPCC categories. From the assessment, very few products can directly support IPCC LU mapping. Synergies with national IPCC Land use maps for REDD+ reporting will be further elaborated within the consolidated assessment of the Downstream services.

3.2 Financial Framework for a Core REDD+ Service Component

The European Union (EU) and its Member States (MS) provided an estimated EUR 3 billion for REDD+ between 2006-2014; in this context the EU and MS are considered to be the second largest financier of REDD+ supporting about 30% of the total volume of funds (EU, 2015). From this perspective it would be important for the EC to ensure that Europe plays a lead role in the operationalization of NFMS in developing countries; this can be promoted in a Copernicus REDD+ programme. The main source of financing for a Core REDD+ component will be from the overall Copernicus budget; however, as there is a risk that such funds may be insufficient for such a service and it is thus prudent to examine supplementary sources of funding. In this context the Local Copernicus Land Component of Urban Atlas is funded by the DG REGIO and therefore it would be pertinent to discuss the options of supplementary funding for the Core REDD+ Component with DGs who are interested to obtain the products. This is dealt with in more detail in WP5 “Coordination and Knowledge Exchange with International Initiatives” of this project.

3.2.1 Available Funding from DG DEFIS

One of the main objectives of the current project is to provide a potential blueprint or model for a Copernicus REDD+ component which could be presented to the European Commission by 2020. This is an important milestone as recommendations from this project could support the Commission’s Directorate Generals (such as DG DEFIS and DG CLIMA) in designing a Copernicus REDD+ proposal to access funds in the post-2020 Multi-annual Financial Framework of the European Union (2021-onwards). The European Commission is at the end of a funding cycle (7 years duration) and the new cycle (with related budget) will start in 2020 with a new Space Regulation to be released around mid-2019 (this regulation is about to be adopted by the EU Parliament). In the European Parliament and Council’s Proposal for the 2021 funding, the overall requested budget was EUR 16 billion for the space programme of which EUR 5.8 billion has been proposed for the Copernicus programme. In March 2019, The European Council asked for an increase of the budget, such that Copernicus would be allocated EUR 6 billion. See Figure 4 which illustrates the budget distribution between the different space components for the new funding cycle.

	Galileo and EGNOS	Copernicus	GOVSATCOM & SSA
Role	global navigation and regional satellite navigation systems	free and open Earth observation data of land, atmosphere, sea, climate change and for emergency management and security	access to secure satellite communications for national authorities and monitoring of space hazards
Budget	€ 9,7 billion	€ 5,8 billion	€ 0,5 billion
Goal	· ensure continuity in the operations · provision of high quality satellite navigation services · investment in ground infrastructures and satellites	· maintain leadership in environmental monitoring, emergency management and border & maritime security · grow range of satellites for new observation capacities · new data dissemination infrastructure for easier development of commercial applications	· develop GOVSATCOM through pooling of Member States capacities · under the SSA: - further develop space surveillance and tracking of space objects to avoid collisions - complementary activities to address other space hazards (space weather, asteroids)
Impact	· new, free of charge, service will allow users to know positions very precisely (error margin: 20 cm) · new applications and services, such as autonomous cars, drones, robots and internet of things	· environmental needs: focus on CO2 emission monitoring and climate change, land use to support agriculture, observations of Polar areas, forest and water management · security needs: improve detection of small objects (e.g. vessels) and monitor illegal trafficking	· GOVSATCOM: improve government action to increase citizens' security · SSA: more autonomy and capability to protect space infrastructure and Earth from space hazards

Figure 4: Budget request and overall goals for funding (EU, 2018)

The allocations of budget for the specific Land Monitoring Services has yet to be finalised and the current project can provide information to the Commission on potential cost elements for the REDD+ Component.

3.2.2 Additional Funding Available from Other DGs and IFIs

Given that the budget for a Core REDD+ Component would be only one budget line/element form an overall Global Land Service budget there is a high chance that additional funding would have to be obtained. In this context, it was noted that at the Workshop organised by the project for REA, DG GROW and ESA on the 14 November, M. Massart from DG GROW indicated that letter of request would be sent to the different DGs requesting additional financial support for the different Copernicus programmes. The Directorate-General for International Cooperation and Development (DG DEVCO) would be a primary target for securing additional funds as they have the overall mandate for "development policy in a wider framework of international cooperation, adapting to the evolving needs of partner countries"(https://ec.europa.eu/europeaid/mission-statement_en). In addition to approaching the different DGs there is a planned meeting of the Copernicus User Forum on 29 January 2020, where it would be pertinent to present the Core REDD+ Component, its value and contribution to the EU policy implementation as well as funding required.

Funding for downstream services could be further sourced from various International Financing Institutes (IFIs). For example, the EU and the World Bank co-operate on both sector specific and geographic regions both in technical assistance and funding; for example, between 2003-2016 the World Bank received funds from DG DEVCO of US$ 2.9billion (Baroncelli and Abingdon, 2019). The EU finances often contribute to Multi-Donor Trust Funds which can provide funding for sector specific projects to developing countries. Additional funding from national donors such as the Agence Française de Développement (AFD) and the German Development Bank-Kreditanstalt für Wiederaufbau (KfW) can also be sources of financing for downstream services.

The sourcing of additional financing for the Core REDD+ Component and downstream services should be further examined within the project life-span, such that recommendations can be provided to the DG DEFIS on possible scenarios. However, it should be noted that the accessing of such supplementary funding for the Core REDD+ Component is an administrative action for DG DEFIS.

3.3 Technical Framework

The organisational aspects should also cover the technical framework which is not related to the actual technical specification or methodological aspects of the service component, but ensures that an appropriate framework is established in terms of input data (e.g. the Sentinel constellation is in place and fully operational), solutions exist and are identified in terms of storage, processing and service delivery requirements.

3.3.1 Input Data

The Sentinel-2 constellation was designed to be the main source of data for such activities and can be complemented by Sentinel-1, Landsat 8 from NASA/USGS, and also potentially ALOS2-PALSAR from JAXA.

The annual work programme for 2019 adopted by the European Commission in conformity with Art. 12 of the Copernicus Regulation establishes for each Core services a list of activities for the year and mentions its Global Sentinel Analysis Ready Data component from the Global Land service as of interest for the REDD+ activities. The Global Land service includes:

1. **S2 Level-2A** operational pre-processing service started in 2017 by ESA and available at the pan-European scale with global production starting in Q4 2018. It includes a scene classification and an atmospheric correction applied to Top-Of-Atmosphere (TOA) Sentinel-2 Level-1C orthoimage products. Level-2A main output is an orthoimage Bottom-Of-Atmosphere (BOA) corrected reflectance product, obtained with Sen2Cor processor.
2. **S2 Level-3** products, based on the ESA Level-2A have been launched in the beginning of 2018. It has the main objective to produce and distribute these Sentinel-2 Level-3 product as part of the **S2GM project** (Sentinel-2 Global Mosaics) to produce mosaic images at the global scale. The service provides various high spatial and temporal (10-days to seasonal) mosaic surface reflectance images at global scale, covering also specific geographical areas of interest, that is operationally produced and made available to users. The prime users envisaged by this 'S2GM service' are the Commission the EU Member States and partner countries to satisfy their monitoring needs for environmental, and climate change policies including REDD+.

From the mid-March 2018, the Level-2A became an operational product[12], beginning with coverage of the Euro-Mediterranean region. Global coverage started in December 2018. However, this activity, as the S2GM one, are still under development and there still needs to be an assessment to be made on the fitness for purpose of the products being delivered for tropical forest monitoring activities.

Therefore, a specific activity was also developed by JRC to provide suitable country mosaics (JRC-L1C-S2) for selected REDD+ countries.

[12] ESA, read online on December 2019: https://earth.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-2a-processing

3.3.2 Storage and Processing of Data

Considering the large amount of data required the storage and processing of the data should be done in the same infrastructure.

In the Space Strategy for Europe (2016) it was noted that whilst Copernicus is a major provider of EO data, there are "technical barriers currently preventing users from fully exploiting the data and information Copernicus delivers". The Strategy recommended the provision of several Platform services, which would offer improved data access and "on-line processing capabilities in which European industry will take a leading role". ESA was commissioned to launch the first four C-DIAS Platforms in 2017. The overall aim of the ESA DIAS tender was to focus on the development of the DIAS back-office operations services to include in particular the following baseline activities:

1. "[…] setting-up and operating efficient interfaces to access the DIAS data,
2. Providing tools and services supporting the development and operations of the DIAS front-office services,
3. Ensuring the availability of scalable computing and storage resources for the development of the front-office services at competitive commercial conditions" (ESA ITT, 2016).

The Consortia implementing the C-DIAS Platforms have become operational by the end of 2018, and allow to access and to store many different data collections (with processing performed by ESA or other entities). The following Figure 5 provides an overview on the DIAS platforms.

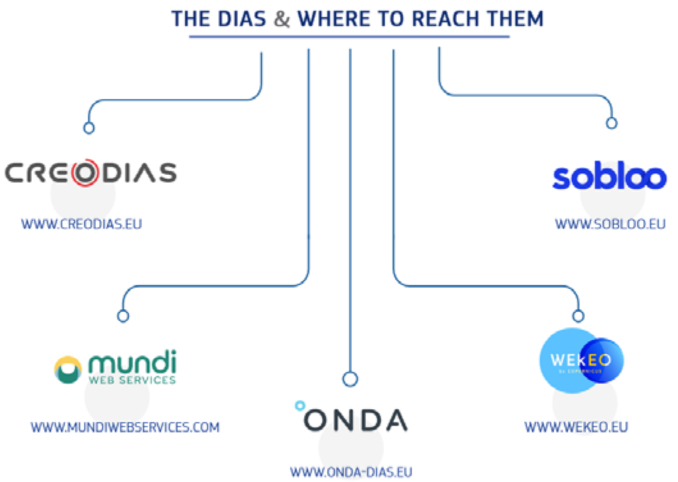

Figure 5: The DIAS and where to reach them

(https://www.copernicus.eu/sites/default/files/Copernicus_DIAS_Factsheet_June2018.pdf)

See also the status of DIAS platforms in Table 6 from EARSC, which has been working together with the commercial DIAS in order to publish a comparison table to highlight the main characteristics of the different platforms and make their features and functionalities clearer to users.

Table 6: DIAS Comparison (Source European Association of Remote Sensing Companies (EARSC) from February 2019)

	Copernicus Services available locally	EO processing tools	EO applications	Backend services for developers	Type of cloud offer
Mundi	**CLMS** **CEMS**	GDAL, Orfeo Toolbox, SNAP Toolbox	Geosigweb Land Consumption, Grassland Monitoring Egeos, KeyStone Copernicus Data Hub, ESA Web WorldWind, Eo4WildLife	Jupyter Note Book, Discovery API, Open search and OGCSW API, Download API, S3 Protocol, Reload Manager.	**Pay-per-use:** Applicable on all VM (VCPU, NVGPU), all storage component, network and services **Package offer:** From 30 to 60% off for 12 to 36 months subscription
Onda	**CMEMS** **CLMS** **CAMS**	Open source Software tools are available in our pre-configured virtual environments for data processing, software development, dissemination of value-added products and administration of front-end services. Our data processing tools include: SNAP, QGIS, Orfeo Libraries, ESA Toolboxes, GDAL.	ONDA is an "Enabler of Capabilities" and it serves a wide variety of users, regardless of what type of thematic application or business they are dealing with. In this context, ONDA provides: • The Marketplace for users to promote their own solutions • Managed Service, which benefit from our long-standing expertise in EO applications.	ONDA offers two APIs to access multi petabytes of data: OData (Open Data Protocol) and Advanced API (ENS - Elastic Node Server). • OData queries can be used directly in the Catalogue for data search, view and download • the Advanced API allows accessing any low level component of the product through ENS (Elastic Node Server). No download nor unzip are required to process the data. Both APIs can be used with any general programming or scripting language.	The ONDA Cloud provider is OVH. Two payment models are available: • pay per use (hourly) • subscription (monthly).
Creodias	**CAMS** **CMEMS** **CLMS** **CEMS**	Dedicated VM images with EO processing tools included, SNAP (s1tbox, s2tbox, sen2cor, gpt), OSGeo ready-to-use operating system images, e.g. including QGIS, FWTools, Mapserver, Python with GDAL , Mapnik, Geoserver. Batch Processing System **ArcGIS ESRI** (commercial software) - an innovative mapping and analytics platform with direct, local access to EO data.	EO Finder, EO Browser Sentinel-hub, The SPARQL interface	Possibility of customer's applications installation on CREODIAS platform with full root access to the system.	We offer pay-per-use and fixed term pricing billing models (https://creodias.eu/billing-modes). We provide discount for long term contracts and big value orders. We grant special discount for scientific institutions. The whole description and price list is available on: https://creodias.eu/price-list.
Sobloo	**CMEMS** **CLMS** **CAMS** **CEMS** **C3S**	We propose a customised "sobloo VM: " - VM pre-installed with a Virtual desktop, accessible from your favorite browser, which contains: - Processing environment: ESA Snap, BRAT, OTB, Sen2Cor - GIS solution: Qgis 2.18- GDAL 2.2 support - Development platform: Eclipse Neon with C, C++, Java, Python - Scientific computation: scilab, GNU Octave, ... - Jupyter notebook - Rstudio	All algorithms and libraries available in SNAP and OTB- Cloud coverage detection algorithm based on deep learning developed by Airbus Defence and Space (March 2019) - Change detection algorithms developed by Airbus Defence and Space (March 2019) - GeoRice - rice crop monitoring (March 2019) - GeoFire - fire damage monitoring (March 2019) - CNES LAI (June 2019)	On top of the IaaS features, sobloo offers the following services, upon request: - Ready to go K8S cluster- Apps deployment engine (Monocular), providing access to more than 150 pre-packaged apps such as ETCD, Redis, Kafka, RabbitMQ, ELK. Complete list available at https://hub.kubeapps.com	Both pay-per-use and package offers are available.
Wekeo	**CMEMS,** **CLMS** **CAMS** **C3S**	SNAP, QGIS, Panoply, Monteverdi, s3rgb	EO Workbench provides set of interactive applications like SNAP, Panoply and non-interactive processing services like NDVI generation, RGB generation. The users can also integrate their own processing service in the portal and can share the service/results with others.	-Discovery API (OpenSearch): Collection discovery and Search. -Harmonised Data Access UI & API (based on REST I/F): Search & Access of EO Data. -EO PaaS (EO Workbench): Enables users to apply pre-configured processing or their own custom processing algorithms to EO data. Using EO tools like SNAP, QGIS via browser. -Jupyter Hub: Jupyter notebooks can be developed making use of Harmonized Data Access (REST I/F); -Self provisioning of IaaS, PaaS (ranges from SDN, SDS, VMs, Docker, K8S)	**Pay per use:** A commercially attractive pay-per use will be offered on WEkEO V1 (started after summer 2019). **Package offer**: The v0 of WEkEO can host a limited number of Pilot Users free of charge ("Users to the data"). Packages are based on T-Shirt sizes for project sizes (XS, D, S, M, L).

However, it should be highlighted that from the start the C-DIAS were designed to break barriers to facilitate access and processing of Sentinel data, but it was not specifically envisaged that the C-DIAS would be used to produce Copernicus Core Services. In particular, it has to be ensured that the whole Sentinel-2 archive should be accessible through the selected infrastructure, thus allowing the screening of all single scenes as well as the on-the-fly access to imagery and composites for visual analysis to support sample-based visual interpretation approaches.

As demonstrated in initial attempts to implement some CLMS core service components on C-DIAS, there are a number of technical problems as well as contractual issues that still remain to be solved. In addition, a recent initiative was launched by DG for Communications Networks, Content and Technology (DG CNECT) in collaboration with the ESA EOP, the Geo AI Applications Facility (GAIA) which aims to (i) meet the infrastructure requirements of EO AI in research, services and industry and (ii) provide a potential central node of the European Open Science Cloud, powerful EO Applications data-ecosystem (> 100 Pbyte of data) and AI training- & meta-data, processing & tools, applications with European Centre for Medium-Range Weather Forecasts (ECMWF). This initiative is relatively new, but meetings are being held at DG Level to get GAIA started.

Dedicated thematic platforms such as the ESA Forestry-TEP could be considered as a model and it is interesting that the F-TEP is now connected with one of the C-DIAS. However, it remains to be seen whether this can sustain the implementation of a global service. SEPAL from FAO should also be considered if suitable for such an application.

Should any of the above infrastructure be considered unsuitable, the use of a dedicated private cloud infrastructure could be envisaged and tailored exactly to the need of the core service component implementation. The main drawback is that the input data would need to be downloaded into that infrastructure. However, for most of the platforms listed above, the Sentinel data available has yet to be fully ARD which means there is still a need to pre-process the satellite imagery resulting in duplicating the data and increase associated storage costs.

Finally, other existing non-European platforms could be used for storage and processing of data. Google Earth Engine (GEE) and Amazon Web Services (AWS) could be envisaged as they already offer the full Sentinel and Landsat archives together with scalable powerful processing capacities. In addition, there have already been examples of a number of global products already processed as part of these platforms. However, the pricing policies as well as the IPR issues would need to be carefully considered and would probably require some negotiations to ensure that these are compliant with the Copernicus data policies.

For the processing of data such as in the proposed analytical tools with GIS and data manipulating functionalities, options may need to be considered for users, for example to make it possible to select their own area of interest, and the possibility to adjust products to their own specific applications which may include adjustment of forest products to national forest definitions. In order to account for the different country-specific infrastructural conditions (e.g. access to and speed of internet) these GIS analytical tools of a future Copernicus REDD+ Service Portal would need to be made available both as a desktop version as well as a web-based version. Additionally, the service must be provided with detailed and clear documentation including user guide; but also, with a strong user support programme including materials guidance for example with documentation and examples for exports and extraction of statistics, interactions with users, learning exercises and online help desk.

3.3.3 Delivery of Data

The delivery of data products, which should be free of charge, can be integrated or separated from the storage and processing of input data. There are good reasons for integrating it with the storage and processing in terms of efficiency and duplication of infrastructure, but there may also be good reasons for having a separated dedicated platform to offer a wider range of functionality.

Considering that a large proportion of users will be in developing countries with unstable low bandwidth access, other means of data delivery should also be envisaged notably through physical media and desktop applications. At the very least bandwidth issues should be considered as part of the delivery platform to ensure that the maximum number of users can be reached.

Many options of data delivery should be considered: the provision of metadata with accuracy, the file type selection (i.e. tiff....), the possibility to download only a selected area of interest or all data as tiles.

Regardless of the platforms selected as part of a Core Service, data might also be made available through other platforms and infrastructures and within other tools making it easily available to more users.

4 Conclusions and Recommendations

The assessment of (i) the requirements for REDD+ FM in International and EU policy requirements, (ii) the Users requirements for REDD+ FM and (iii) the existing EO-based FM technical capacities, (see project deliverables (D1.1, D2.1 and D2.2, respectively) were used as starting point to produce the initial design of a future Copernicus Forest Monitoring (FM) and REDD+ Service Component. This initial design addresses the main technical and organisational elements of such a potential Copernicus REDD+ Service Component.

A benchmarking process proved to be an efficient approach to select the key technical elements from a list of 26 potential products/datasets that had been pre-identified from the EO-based FM Capacity Review. The benchmarking analysis allowed evaluating the potential datasets and concepts against a set of 15 different criteria and hence selecting the most appropriate candidates for a Copernicus REDD+ Service component. This was made possible because these criteria reflected a large range of requirements (that were grouped into four main categories: Technical REDD+ reporting requirements, User requirements assessment, Operating Requirements and Existing Service & Continuity). The application of a rating system for these criteria led to the reduction to 9 products/concepts (out of 26) that are identified as the most suitable and are consequently proposed for inclusion in 'Demonstration Cases' and 'Learning exercises'.

In total four remote sensing related building blocks of FM concepts are included in this initial proposal for a future REDD+ component, namely: (1) Sentinel-2 Image Composites, (2) Pan-Tropical Tree Cover Density (reference year 2020), (3) Pan-Tropical Annual Tree Cover Change and (4) Pan-Tropical Tree Cover Disturbance Alerting. The detailed technical specifications of these selected products/ concepts provide a strong baseline for the preliminary definition of potential FM products matching the REDD+ policy requirements and, at the same time, being sufficiently mature for implementation within an operational service. A fifth building block with tools having GIS analytical functionality interconnects above four FM concepts and thus complements the initial design of a REDD+ Service Portal.

A first assessment of institutional, financial and infrastructural frameworks allowed providing an initial design of the organisational elements of a new Service component within the Land Service. The institutional framework is essentially based on the existing EU Regulations that govern the Copernicus programme. The assessment of the infrastructural framework allowed ensuring appropriate solutions for data input, storage, processing and service delivery requirements, considering Sentinel-2 constellation as the main source of data. This assessment included the initial investigation of available infrastructure capacities and gaps for the Copernicus Data and Information Access Services (C-DIAS).

Our approach led to the provision of a solid baseline for designing the Copernicus FM/ REDD+ service component that needs to be presented to the Users during the Learning Exercises and subsequently consolidated during the second reporting period into an operational end-to-end Copernicus REDD+ service component. These "Learning Exercises" will permit assessing and consolidating the initial design with the following expected technical outcomes: (i) User validation and endorsement of products/services, and (ii) Recommendations for product/service evolution. It has not been possible to investigate in detail within this report several organisational aspects, especially specific issues related to developing countries (e.g. data access, platform functionality, capacity buildings, …), the role of UN agencies in supporting this service component, Intellectual Property Rights and clear delineation between the Core and Downstream Services. These important issues will further be analysed during the Learning Exercises and in the second phase of the Organisational Specifications Work Package.

Finally, a key conclusion is that it will be crucial to verify that the products/datasets are really fitting the requirements of the main targeted Users and that these users can effectively access such products/datasets.

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WRI Interactive Forest Atlas of Congo version

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6 Annexes: Detailed Specifications of Selected Products

Annex 1: Sentinel-2 Imagery and Composites Specifications

The detailed Sentinel-2 cloud-free composite Output Specifications are defined in Table 7.

Table 7: Output Specifications of Sentinel-2 cloud-free composite

Product Output: Sentinel-2 cloud-free composite	
Description and Utility	The Sentinel-2 cloud-free composite product is showing Sentinel-2 L1C cloud-free composites over the tropical belt produced based on Sentinel-2A/B imagery from 2015 to 2019. The spectral value of each composite pixel is calculated as the 'median' of all Sentinel-2 data (imagery available for each respective pixel) after applying a cloud masking algorithm developed at JRC.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	Default Spectral bands: SWIR (B11), NIR (B8), RED (B4) Or any user defined (up to 10 spectral bands, 10-20m)
Time Period - Update Frequency	Annual Composites (as default time period) from October 2015 onwards; Or any user defined period (e.g. single-date, monthly, quarterly, …)
Geographic Reference System	WGS84, UTM, National Systems – defined by the User
Spatial Representation	Raster product
Spatial Resolution	Up to 10 m resolution
Minimum Mapping Unit	0.01 – 0.05 ha
Format	Raster GEOTIFF file
Metadata	Text file including
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: - Compliancy of output with IPCC and user requirements, - Completeness, - Positional Accuracy. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery of services
Thematic Accuracy	N.A.
Positional Accuracy	< 1 pixel of source imagery (Sentinel-2)
Service Interface	Google Earth Engine Interface
Service Provision	https://forobs.jrc.ec.europa.eu/recaredd/S2_composite.php Online view via WMS (default products) and FTP
Service Delivery	In time period agreed with user
Conditions Applying to Access and Use	No restriction for the products
Archive	Online view and download service via WMS (default products), FTP

Customer Care	Contact is available on the Service Platform

The Sentinel-2 imagery and cloud-free composite products are produced by optical data. Table 8 shows the Input Data specifications that will be used to create these S2 composites.

Table 8: Input Data Specifications of Sentinel-2 cloud-free composite

Input Data	
Earth Observation (EO) Data	**Optical data:** • **~10m/20m/60m:** Sentinel 2 (since 2015).
Spectral Bands/ SAR Band and Polarisations	All Sentinel-2 spectral bands from B2 (Blue, 10m), B3 (Green, 10m), B4 (Red, 10m), B5 (Red edge, 20m), B6 (Red edge, 20m), B7 (Red edge, 20m), B8 (Near InfraRed (NIR), 10m), B8A (Narrow NIR, 20m), B11 (Short-Wavelength InfraRed (SWIR), 20m), and B12 (SWIR, 20m)
Time Period	Depending of the cloud coverage of the requested area (S2 minimum frequency is 5 days)
Auxiliary Data	Metadata of acquired EO data (existing cloud masks). Extent of Area of Interest

Annex 2: Tree Cover Density (TCD) Specifications

The detailed Tree Cover Density (TCD) Output Specifications are defined in Table 9.

Table 9: Output specification of Tree Cover Density

Product Output: Tree Cover Density (TCD)	
Description and Utility	The Tree Cover Density product shows the tree canopy density in terms of projective cover in percent per pixel at a given point in time. Tree Canopy Cover Density is directly derived from High Resolution (HR) satellite data (direct approach). This product forms the basis for generating Forest Area maps according to a National Forest Definition or other User requirements. It can further be used to as an input for Land Use/ Land Cover classification, and to distinguish between intact forest and degraded forest as well as between different levels of degradation which makes it valuable for stakeholders (public or private) involved in monitoring forest resources. It has a broad range of applications, including Sustainable Forest Management (SFM), REDD+ Measurement, Reporting, and Verification (MRV) activities, Forest Landscape Restoration (FLR), and the identification of High Carbon Stock (HCS) forests, especially when combined with other products such as the Land Cover/Use and Land Cover/Use Change.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	0 No Tree Cover 1 -100 - Tree canopy cover density per pixel in percent 255: No Data
Time Period - Update Frequency	Historic for a specific date (from 2018 onwards); temporal update frequency up to annual
Geographic Reference System	WGS84, UTM, National Systems
Spatial Representation	Thematic Raster
Spatial Resolution	10 m (Full resolution of Sentinel-2)
Minimum Mapping Unit	Minimum Mapping Unit (MMU) = 1 pixel Mapping Scale 1:25,000 - 1:50,000
Format	Raster
Metadata	ISO TC 211 compliant to ISO19115:2003 Metadata, INSPIRE on request
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: • Compliancy of output with user requirements, • Completeness, • Thematic accuracy, • Thematic completeness, • Positional Accuracy, • Product Utility. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery

	of services.
Thematic Accuracy	Overall accuracy > 85 - 90%
Positional Accuracy	< 1 pixel of source imagery
Service Interface	Dataset available via Pan-European Land Monitoring Services Website
Service Provision	Access to Service via Web Portal, Online view (WMS) & download service (WCS, direct download or FTP)
Service Delivery	Service can be provided on a regular basis (currently every 3 years)
Conditions Applying to Access and Use	No access restrictions.
Archive	Data stored on Service Platform
Customer Care	Contact form on the Service Platform

The TCD product is produced based on optical data from the Sentinel-2 satellite constellation. Table 10 shows the Input Data specifications that will be used to create the required map.

Table 10: Input Data Specification of Tree Cover Density

Input Data	
Earth Observation (EO) Data	**Optical data:** • **Sentinel 2** ~ 10m; from 2015 onwards
Spectral Bands/ SAR Band and Polarisations	All optical bands of Sentinel-2.
Time Period	Maximum +/- one year according to data availability and technical specifications.
Auxiliary Data	In-situ data Aerial Photos, VHR data, etc Metadata of acquired EO data. Extent of Area of Interest Forest maps, if existing

Annex 3: Forest Seasonality/ Type (FTY) Specifications

The detailed Forest Area and Seasonality Output Specifications are defined in Table 11.

Table 11: Output specification of Forest Seasonality/ Type

Product Output: Forest Seasonality/Type	
Description and Utility	The Forest Seasonality/Type product is a **status product** showing the forest extent (according to the FAO definition of forest with a minimum area of 0.5 ha and a tree cover density of 10% or more), distinguishing different forest ecosystem strata/ types in terms of their seasonality into evergreen forest and deciduous forest. The product is derived from High Resolution (HR) Sentinel-2 satellite data, Sentinel-1 SAR data can be used as an option. Knowledge about the locations of different forest types is important in order to apply specific forest management activities and conservation activities. Furthermore, this product can serve as input to forest biomass assessment, for stratification purposes (e.g. for the assessment of GHG emissions) and for planning Forest Landscape Restoration (FLR) activities.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	Class 1: Evergreen Forest, Class 2: Deciduous Forest, Class 3: Non-Forest, Class 255: No Data.
Time Period - Update Frequency	Historic for a specific date (from 2018 onwards); temporal update frequency up to annual
Geographic Reference System	WGS 84
Spatial Representation	WGS84, UTM, National Systems
Spatial Resolution	10m
Minimum Mapping Unit	0.25 – 0.5 ha
Format	Thematic Raster
Metadata	ISO TC 211 compliant to ISO19115:2003 Metadata, INSPIRE on request
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: • Compliancy of output with user requirements, • Completeness, • Thematic accuracy, • Thematic completeness, • Positional Accuracy, • Product Utility. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery of services.

Thematic Accuracy	Overall accuracy > 85 - 90%
Positional Accuracy	< 1 pixel of source imagery
Service Interface	Dataset available via Pan-European Land Monitoring Services Website
Service Provision	Access to Service via Web Portal, Online view (WMS) & download service (WCS, direct download or FTP)
Service Delivery	Service can be provided on a regular basis (currently every 3 years)
Conditions Applying to Access and Use	No access restrictions.
Archive	Data stored on Service Platform.
Customer Care	Contact form on the Service Platform

The Forest Seasonality/Type product is produced with optical data. Table 12 shows the Input Data specifications that will be used to create the Forest Seasonality/ Type map.

Table 12: Input specification of Forest Seasonality/Type

Input Data	
Earth Observation (EO) Data	**Optical data:** • **Sentinel 2** ~ 10m; from 2015 onwards **SAR data:** • **Sentinel-1** ~10m (since 2014)
Spectral Bands/ SAR Band and Polarisations	All optical bands of Sentinel-2. SAR: Dual Polarization recommended.
Time Period	Maximum +/- one year according to data availability and technical specifications.
Auxiliary Data	In-situ data Aerial Photos, VHR data, etc Metadata of acquired EO data. Extent of Area of Interest Forest maps, if existing

Annex 4: Tropical Moist Forest (TMF) Specifications

The detailed Tropical Moist Forest product Output Specifications are defined in Table 13 for the transition maps and Table 14 for the annual change product.

Table 13: Output Specifications of Tropical Moist Forest – Transition map

Product Output: (a) Tropical Moist Forest (TMF) transition map	
Description and Utility	The transition map of the TMF dataset captures the forest cover changes within the Tropical Moist Forest (TMF) at the end of the observation period (i.e. December 2019) by depicting five main classes with a few sub-classes.
Service Area	Pan-tropical Coverage
Mapping Classes and Definitions	1: **Undisturbed Tropical Moist Forest** (TMF) with closed canopy cover including areas without any disturbances observed over the whole Landsat historical record. 2: **Degraded TMF forest**. Two levels of degradation have been empirically identified: (a) degradation with short-duration impacts (observed within a 1-year maximum duration); which includes the majority of logging activities, natural events and light fires, and (b) degradation with long duration impacts (between one and 2.5 years) which mainly corresponds to strong fires (burned forests). All disturbances events for which the impacts were observed over more than 2.5 years were considered as deforestation processes. 3: **TMF regrowth**, which corresponds to a two-phase transition from TMF to deforested land, and then vegetation regrowth (at least 3 years of regrowth). It includes three sub types corresponding to three different ages of regrowth (between 3 and 10 years, between 10 and 20 years, and more than 20 years). 4: **Deforested TMF** areas including subcategories of converted land cover: (a) water bodies, (b) tree plantations, (c) other land cover that includes infrastructures, agriculture and mining. 5: **Other land cover** (non-TMF cover as baseline) includes savannah, deciduous forest, agriculture and non-vegetated cover. A specific transition class has been identified, i.e. from other LC to vegetation regrowth (with 3 to 10 years of regrowth).
Time Period - Update Frequency	Historical (up to 1982) & Update: Flexible to the user request (e.g.: every 6 or 12 months)
Geographic Reference System	Lat Long, WGS84
Spatial Representation	Thematic Raster
Spatial Resolution	Output pixel size of 30m (Landsat TM: 30 m)
Minimum Mapping Unit	0.09 ha
Format	GEOTIFF *.tif (All standard raster data formats available, original 8 bits per pixel)
Metadata	INSPIRE compliant metadata as Annex to the product
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: • Compliancy of output with IPCC and user requirements, • Completeness, • Thematic accuracy, • Thematic completeness, • Positional Accuracy,

	• Utility for REDD MRV. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery of services
Thematic Accuracy	The performance of the disturbance detection has been validated against 12 235 sample plots resulting into 9.4% omissions, 8.1% false detections and 91.4% overall accuracy.
Positional Accuracy	< 1 pixel of source imagery (Landsat 8: 12m)
Service Interface	Will be publicly accessible in 2020
Service Provision	Online view and download service via WMS, FTP
Service Delivery	Yearly updated, and available online
Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Upon user request, data storage is possible on the Service Platform
Customer Care	Contact is available on the Service Platform

Table 14: Output Specifications of Tropical Moist Forest – Annual change dataset

Product Output: (b) Tropical Moist Forest (TMF) annual change dataset	
Description and Utility	The annual change dataset is a collection of 30 maps depicting – for each year between 1990 and 2019 – the spatial extents of undisturbed Tropical Moist Forests and TMF disturbances.
Service Area	Pan-tropical Coverage
Mapping Classes and Definitions	1: Undisturbed Tropical Moist Forests, 2: New degradation (disruptions detected for the first time during the considered year), 3: Ongoing degradation (disruptions started before the considered year and are still detected), 4: Degraded forest (disruptions started before the considered year and are not detected anymore), 5: New deforestation (disruptions detected for the first time during the considered year), 6: Ongoing deforestation (disruptions started before the considered year and are still detected), 7: New regrowth (deforestation occurred the year before and disruptions are not detected anymore), 8: Regrowth (deforestation occurred at least one year before and disruptions are not detected anymore), 9: Water (permanent or seasonal), 10: Other LC, 11: Invalid observations.
Time Period - Update Frequency	Historical (up to 1990) & Update: Flexible to the user request (e.g.: every 6 or 12 months)
Geographic Reference System	Lat Long, WGS84

Spatial Representation	Thematic Raster
Spatial Resolution	Output pixel size of 30m (Landsat TM: 30 m)
Minimum Mapping Unit	0.09 ha
Format	GEOTIFF *.tif (All standard raster data formats available, original 8 bits per pixel)
Metadata	INSPIRE compliant metadata as Annex to the product
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: • Compliancy of output with IPCC and user requirements, • Completeness, • Thematic accuracy, • Thematic completeness, • Positional Accuracy, • Utility for REDD MRV. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery of services
Thematic Accuracy	The performance of the disturbance detection has been validated against 12 235 sample plots resulting into 9.4% omissions, 8.1% false detections and 91.4% overall accuracy.
Positional Accuracy	< 1 pixel of source imagery (Landsat 8: 12m)
Service Interface	Will be publicly accessible in 2020
Service Provision	Online view and download service via WMS, FTP
Service Delivery	Yearly updated, and available online
Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Upon user request, data storage is possible on the Service Platform
Customer Care	Contact is available on the Service Platform

The Tropical Moist Forest product is produced by optical data. Table 15 shows the Input Data specifications that will be used to create the required Forest Status/Change map.

Table 15: Input Specifications of Tropical Moist Forest

Input Data	
Earth Observation (EO) Data	**Optical data:** **Landsat** L1T archive (orthorectified top of atmosphere reflectance) acquired between July 1982 and 31 December 2019 from the following sensors: Thematic Mapper (TM) onboard Landsat 4 and 5, Enhanced Thematic Mapper plus (ETM+) onboard Landsat 7, and the Operational Land Imager (OLI) onboard Landsat 8
Spectral Bands/ SAR Band and Polarisations	Mostly the SWIR2, NIR, Red, and TIR bands have been used in the expert system developed.
Time Period	1982-2019
Auxiliary Data	User defined auxiliary data: - The Global Surface Water (GSW) dataset derived from Landsat time series (Pekel et al. 2016) has been used to identify conversion from moist forests to water bodies (e.g creation of a dam), - Two external data have been used to identify the tree plantations classes: (i) the tree plantations dataset from the World Resources Institute (WRI) (Petersen et al. 2016), which covers seven countries (Brazil, Cambodia, Colombia, Indonesia, Liberia, Malaysia and Peru), and (ii) the oil palm dataset from Duke University (Vijay et al. 1999), which covers a few plantation zones in the tropics.

Annex 5: Forest Canopy Disturbance Monitoring (FCDM) Specifications

The detailed Forest Canopy Disturbance Monitoring product Output Specifications are defined in Table 16.

Table 16: Output Specifications of Forest Canopy Disturbance Monitoring

Product Output: Forest Canopy Disturbance Monitoring (FCDM)	
Description and Utility	The Forest Canopy Disturbance Monitoring (FCDM) product observes forest disturbances. A forest disturbance means a decrease in canopy cover happening during an analysing period (P2) compared to a reference (historical) period (P1). The temporal resolution is directly linked to the frequency of satellite data acquisitions starting from 15 days.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	- Class 0: Non-Forest (derived from the Forest Mask), - Class 1: Change (decrease in canopy cover) , - Class 2: No change (Forest remains forest and no change of canopy cover). Date of change in separate layer as Day of the year. Disturbance severity in separate layer (radar only).
Time Period - Update Frequency	Provided on a bi-monthly basis but it will depend on the EO data availability,
Geographic Reference System	Lat Long, WGS84
Spatial Representation	Thematic Raster
Spatial Resolution	Output pixel size ranging from 10 to 30 m dependent on EO input data (Sentinel-1/2: 10 m, Landsat TM/ETM+/OLI: 30 m)
Minimum Mapping Unit	0.05 to 0.5 ha MMU
Format	GEOTIFF (*.tif) (All standard raster data formats available, original 8 bits per pixel)
Metadata	INSPIRE compliant metadata as Annex to the product
Quality Assurance	All Quality relevant information and Quality checks are documented and cover the categories: • Compliancy of output with user requirements, • Completeness, • Thematic accuracy, • Thematic completeness, • Positional Accuracy, • Utility for REDD MRV. Quality Management Systems are applied to cover non-conformance issues, timely corrective actions, and customer services related to reliability, flexibility and timely delivery of services
Thematic Accuracy	The service provides evidence on Thematic Accuracy, defined on the basis of documented procedure with defined sampling scheme, size, unit, criteria, reference data and evaluation process. The thematic accuracy figures are presented in error (confusion matrices), overall class accuracy, user and producer accuracies for each class and overall. The feasible overall

	accuracies with current sensors range from 75 to 85%.
Positional Accuracy	Geometric accuracy is dependent on the geometric resolution of the input EO data. Presented as RMS error. With current sensors feasible RMS errors range from 0.5 to 2.5 pixels.
Service Interface	User is responsible for the service activation Service Provider is responsible for EO data acquisition and data provision
Service Platform	Google Earth Engine
Service Provision	Online view and download service via WMS, FTP
Service Delivery	In time period agreed with user
Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Upon user request, data storage is possible on the Service Platform
Customer Care	Contact is available on the Service Platform

The FCDM product is produced by optical and radar data. Table 17 shows the Input Data specifications that will be used to create the Forest Disturbance map.

Table 17: Input Specifications of Forest Canopy Disturbance Monitoring

Input Data for Forest Canopy Disturbance Monitoring (FCDM)		
Earth Observation (EO) Data	**Optical data:** • **~ 30m:** Landsat-4/5 TM, Landsat-7 ETM+, Landsat-8 OLI • **~10m/20m:** Sentinel 2 (since 2015).	**SAR data:** • **~10m:** Sentinel 1 (since 2014).
Spectral Bands/ SAR Band and Polarisations	Optical: NIR/SWIR2 SAR: C Band	
Time Period	Maximum +/- one year according to data availability and user specifications.	
Auxiliary Data	Metadata of acquired EO data (existing cloud masks). Digital Elevation Models (for slope extraction). Extent of Area of Interest Forest mask	

Annex 6: Breaks For Additive Season and Trend (BFAST) Specifications

The detailed BFAST Output Specifications are defined in Table 18.

Table 18: Output Specifications of Breaks For Additive Season and Trend

Product Output: Breaks For Additive Season and Trend (BFAST)	
Description and Utility	The Breaks For Additive Season and Trend (BFAST) product shows primarily the year of change (in this case deforestation). This information is useful for the generation of activity data, and can also be used as an input for policy development.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	- Class 1+: Year of change (time of change can also be given on sub-yearly intervals potentially), - Class 2: No change. Separate layer can show magnitude of change (there are no units, and this depends on the input time series)
Time Period - Update Frequency	Dependant on input data – technically the entire Landsat archive can be exploited. Data can be provided on an annual or sub-annual basis.
Geographic Reference System	Can be defined by the User, mostly WGS84.
Spatial Representation	Thematic Raster and Vector
Spatial Resolution	Output pixel size depends on EO data used – when based on HLS, resolution is 30 m/ 10 m
Minimum Mapping Unit	1 pixel
Format	*tif and *shp (standard raster/ vector formats)
Metadata	All documentation are available, and code is open.
Quality Assurance	All Quality relevant information and Quality checks are documented. These checks can include: • Compliancy of output with User requirements, • Thematic accuracy, • Temporal accuracy, • Utility for REDD MRV. Quality Management Systems can include checks on delivery of data, and customer service.
Thematic Accuracy	Thematic accuracy assessments require VHR data, which cannot be retrieved for the entire product. But assessments can be carried out to provide overall thematic accuracy or class specific accuracies for an area of interest.
Positional Accuracy	<1 pixel of source imagery
Service Interface	Currently BFAST products are not produced operationally. An interface can be developed by the Service Provider in collaboration with the User.
Service Provision	Flexible options will be possible – including online view and download service via WMS or FTP. The BFAST software has been implemented within the FAO SEPAL platform and can be used for operational scaling by any interested user.

Service Delivery	Annual (or sub-annual) change maps can be produced as soon as possible after the last data acquisition.
Conditions Applying to Access and Use	Data will be made freely available and open to all.
Archive	Data can be stored on the Service Platform, and archived data can remain available to all.
Customer Care	To be determined with the Service Provider.

The BFAST product is produced in this case with the HLS multi-sensor optical data set. Table 19 shows the Input Data specifications that will be used to create the required Forest Change map.

Table 19: Input Specifications of Breaks For Additive Season and Trend

Input Data	
Earth Observation (EO) Data	**Optical data:** • Generally, BFAST is applied on Landsat data, and in future Sentinel-2 can be incorporated – for example using HLS (resulting in 30 m/ 10 m outputs), or products can be based on Sentinel-2 data alone (for 20 m resolution products). • In this case, Harmonized Landsat and Sentinel-2 (HLS) Surface Reflectance Product is at 30 m spatial resolution, but data at 10 m are available on request from NASA) • Other harmonized Sentinel-Landsat products may also be used including: Sen2like. • Other potential datasets include: Sentinel 1, Sentinel 2, Sentinel 3, Landsat 1-5, Landsat 7 & 8, MODIS, ALOS-PALSAR (many are ~ 30m, and this can accommodate a range of data).
Spectral Bands/ SAR Band and Polarisations	Commonly BFAST is carried out using NDVI or NDMI. In this demonstration case NDMI is used.
Time Period	Covering the output time period plus an additional 2 years for training the algorithm.
Auxiliary Data	In-situ data, Aerial Photos VHR data etc, for cal/val. EO data and Metadata of acquired EO data. Extent of Area of Interest. User defined auxiliary data (e.g. protected areas, road networks, urban and infrastructure).

Annex 7: RADAR Forest Cover Loss Alerts Specifications

The detailed RADAR Forest Cover Loss Alerts Output Specifications are defined in Table 20.

Table 20: Output Specifications of RADAR Forest Cover Loss Alerts

Product Output: RADAR Forest Cover Loss Alerts	
Description and Utility	The Radar Forest Cover Loss Alerts product primarily shows deforestation (loss of forest canopy cover). The temporal resolution is directly linked to the availability of new satellite data acquisitions. This information is thus important for decision makers where a fast response is needed being an important resource to protect forests from illegal logging. Furthermore, it allows monitoring of on-going logging activities in forest concessions, for example in the context of Zero Deforestation and Sustainable Supply Chain initiatives.
Service Area	Defined by the User (wall-to-wall, regional, national, sub-national)
Mapping Classes and Definitions	- Class 1: Deforestation, - Class 2: No deforestation. Separate layers can show (1) priority (inside or outside of protected forest), (2) date of the alert (3) area of connected deforestation pixels
Time Period - Update Frequency	Dependent on required confidence, and on EO data availability. Alerts can be generated for any time period. In the case of the product developed for this project, Sentinel 1 data is acquired every 6-12 days. Alerts can be provided for the entire length of the input data time-series monitoring period.
Geographic Reference System	Can be defined by the User, mostly WGS84.
Spatial Representation	Thematic Raster and Vector
Spatial Resolution	Output pixel size depends on EO data used – when based on Sentinel 1, resolution is 10 m
Minimum Mapping Unit	0.01 ha (one S1-pixel)
Format	*img/*tif and *shp (standard raster/ vector formats)
Metadata	Documentation is available, and code is open.
Quality Assurance	All Quality relevant information and Quality checks are documented. These checks can include: • Compliancy of output with User requirements, • Thematic accuracy, • Timeliness (time-lag of alert). Quality Management Systems can include checks on delivery of data, and customer service.
Thematic Accuracy	Thematic accuracy assessments require VHR data, which cannot be retrieved for the entire product. But assessments can be carried out, and overall accuracy in a tested case study (Ecuador) has been >85%.
Positional Accuracy	<1 pixel of source imagery (Sentinel-1)
Service Interface	Alerts are sent directly to end User (i.e. Palm Oil Producer). Prioritized alerts can be sent depending on their needs, and generic alerts are made openly available. In future, the system will be made available via the Global Forest Watch website, and will be freely available and easily accessible to all interested Users.

Service Provision	Online view and download service i.e. via WMS, FTP or via USB hard disk etc.
Service Delivery	Continuously updated, and available online.
Conditions Applying to Access and Use	Openly available, no restrictions.
Archive	Dependent on User needs: it can be made available upon user request, as data storage can be stored on the Service Platform, or all historical data can remain available on the platform.
Customer Care	Contact through GFW will be made available.

The RADAR Forest Cover Loss Alerts product is produced using RADAR data in this case. Table 21 shows the Input Data specifications that will be used to create the maps have the proposed specifications for this project.

Table 21: Input Specifications of RADAR Forest Cover Loss Alerts

Input Data	
Earth Observation (EO) Data	**SAR data:** • **~10m:** Sentinel 1A and B (since 2014), • The method can be applied on other data.
Spectral Bands/ SAR Band and Polarisations	C band, duel-polarisation (VH, VV), where available
Time Period	Covering the output time period plus a training period (15 months was used in the recent case study in Indonesia (https://www.mdpi.com/2072-4292/10/5/777/htm).
Auxiliary Data	In-situ data, Aerial Photos VHR data etc, for cal/val. EO data and Metadata of acquired EO data. Extent of Area of Interest. User defined auxiliary data (e.g. protected areas, oil palm concessions, road networks, and logging infrastructure).