Proposal to support:

Natural Wealth and Sovereign Risk

Final Report

Support requested by:
World Bank Group (WBG) - EFNLT

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PURPOSE

This document compiles the objectives and achievements of the Project together with the conclusions and findings. It will present how to support a larger service over other regions, countries and indicators. The potential of the methodology applied during the project will be described, but also its limitations, for EFNLT and other stakeholders to be aware of the working flow and it's potential.

It is also intended for dissemination purposes, and provision of great potential of using EO for mapping the crop types and their indicators.

1 DEVELOPMENT CONTEXT AND BACKGROUND

1.1 Introduction

Services based on Earth Observation (EO) are useful tools for providing a wide range of past and present environmental information through the analysis and processing of historical information, present status and analytical data available.

Technology has now achieved the capacity of processing large amounts of data within a time frame and inside an affordable budget.

The particular advantages of EO in this context are the non-intrusive, objective and globally consistent nature of the information and the use of satellite mapping services provides many opportunities for the management and verification of the environmental practices associated with the development projects the banks are helping.

Through unique EO products, it is possible to map agriculture, land use and environment, water quality, energy availability. food security, coastal subsidence and forest state among other equally important data, which EO can gather effectively in areas with little ground information.

ESA's Copernicus programme is aimed to make environmental monitoring a reality, delivering near-real-time data on a global level which can also be used for local and regional needs.

Through its own dedicated Sentinel satellites, various contributing missions and on-ground stations that collects information from in situ systems such as ground stations, which deliver data acquired by a multitude of sensors on the ground, at sea or in the air, Copernicus programme allows us to create value-added information by processing, comparing and analysing data that stretches back for years, and from this monitor changes, create forecasts, analyse patterns and generate maps that identify anomalies and features.

Over this, ESA has been collaborating with Banks and International Financial Institutions for a long time on monitoring development projects and its impact on the environment.

This collaboration has demonstrated the relevance of EO for Development projects, and has proven that it is a valuable tool for make cost effective, quick and incontrovertible assessments, that help to manage urban growth, protect forest, monitor water quality and broadly provides evidence of progress or baselines for remediate actions whenever an environmental transformation occurs as result of a development project.

Although larger initiatives and programmes are currently on execution (like EO4SD, an ESA initiative to support the uptake of EO-derived information in sustainable development), there is a need to cover small-scale and exploratory uses of EO products as a response to short-term, ad-hoc requests from Banks and international institutions. These requests demand an innovative approach and capacity to deliver within a short time frame, a solution that goes beyond standard product generation and that links the EO data with underlying statistical and geographic information in a creative way.

To achieve this, ESA is funding a Framework Contract (named: EO-Clinic) scheme to which this project belongs to.

Under this Framework Contract, several "Request for Proposal" are be issued to the contractors from different end users (banks and International Finance Institutions). These Requests can vary largely on its purposes and will address any or several of the following Thematic Groups: Agriculture, Climate Change, Coastal Zone Management, Disaster Risk Management, Energy and Natural Resources, Forestry, Marine Environment Management, Transport, Urban, Water Resources Management and Non-EO Information and Analytics.

This document is a result from Request for Proposal 8 (RFP008) of the EO-clinic Frame Contract, requested by the World Bank Group (WBG) – EFNLT.

1.2 Request for proposal 008: Natural Wealth and Sovereign Risk

This chapter summarises the objectives and approach of the requested EO support dealing referred in the Request for Proposal 8 (RFP008) of the EO-clinic Frame Contract, requested by the World Bank Group (WBG) - EFNLT

The **main initial objective of this Request for Proposal number 008 (RFP008) is to provide crop health indicators for selected countries on crop type maps generated for various crop types**. Indicators are to be aggregated to administrative levels, presented back until 2005 and provided with a frequency ideally monthly or finer. The indicators should be suitable to explain crop health and therefore be presented within a short time period after observation.

The RFP008 describes 15 countries and their top 5 crops (in TABLE 1 below), from which at least 2 countries of the same region should be chosen to show the feasibility of the RFP. Major aim of the study is to make all information consistent for entire countries rather than to provide single results within selected regions.

The results of this study are to be delivered to the World Bank Group in the form of tables and build upon existing EO datasets and data processing and visualization capabilities.

The World Bank launched the Sovereign ESG Data Portal in October 2019, a free and easy to use online platform that provides users with environmental, social and governance data. In the environment group some agricultural related indicators are already available, like share of agricultural land and share of GDP. The ESG data portal as part of the World Bank's Global Program on Sustainability (GPS) aims to provide policy makers and the financial sector with the necessary metrics. In this context, gaps are identified concerning to agricultural crop health and status information regarding granularity and frequency of data. Consequently, the need for cross-country consistent data, which is available long-term and over large areas is clearly visible. Our solution proposed in this project will add an important added value to the ESG data portal to improve the situation and provide a source of valuable information.

GREENSPIN launched a web application (CROPTIFY, available under https://app.greenspin.de) visualizing several indices for monitoring vegetation development and crop health with focus on wheat, which also includes early estimations for wheat production at the end of the season. The Consortia will benefit from the availability of this Web application with which the results of this project will not only be delivered as table files at the end of the project summarizing the findings to administrative levels. They will also be incorporated into the existing application giving the project partners a unique and valuable tool to assess crop health and vegetation development status of several crop types in various countries over a long time period immediately. CROPTIFY will be available for project partners and stakeholders until 31th of October. This will put the World Bank Group and possible stakeholders in the position to immediately visualize and start working with the results of this project and to assess the potential impact of such information for their daily work.

As an example of outcomes of this project, we presented below in the initial proposal the situation for wheat in Germany in 2019 (see figures below). At an early stage in the season, official forecasts indicated a second drought year after 2018, with a great decline of wheat production values. Analysing the vegetation indices in CROPTIFY at this stage however, led to the conclusion that a decline was only to be expected in a select number of federal states in Germany, whereas the others showed average production values. Overall, this assessment was highly valuable for a better evaluation of the official production forecasts released during the season.

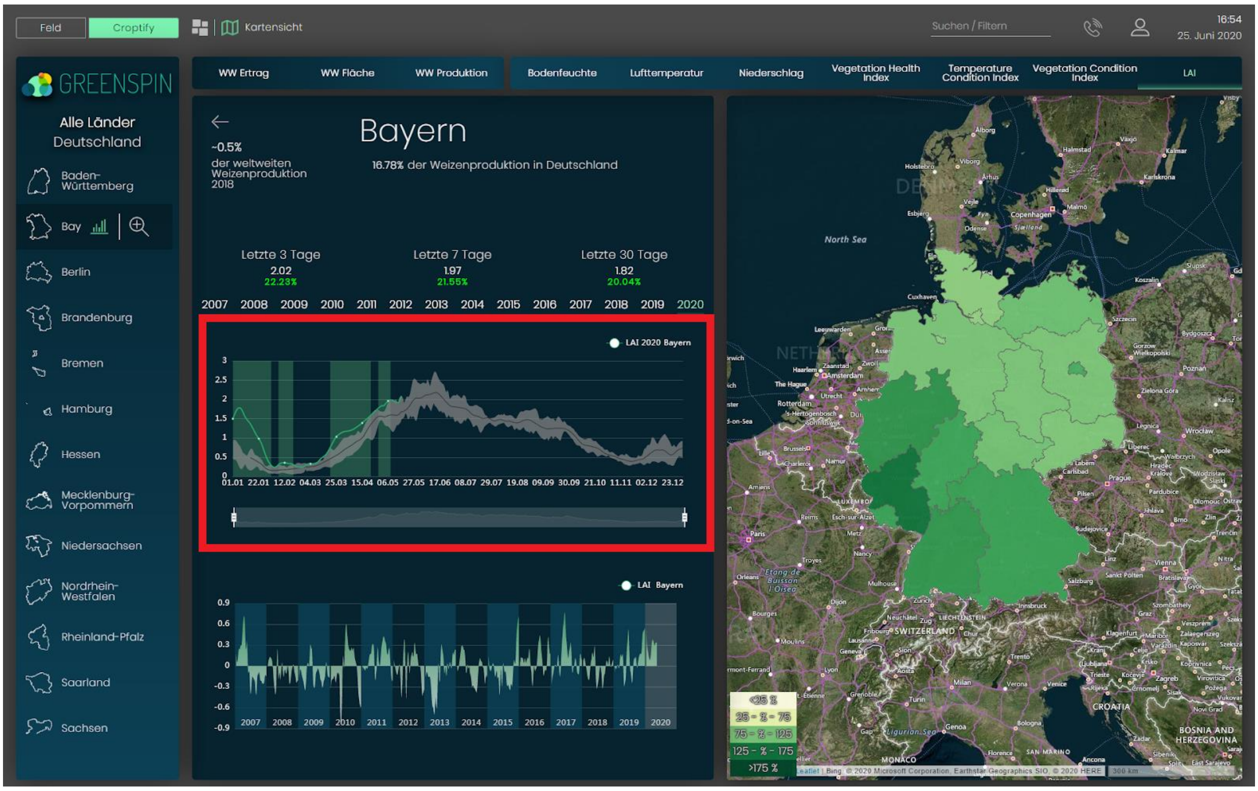


FIGURE 1 *CROPTIFY map view showing the Leaf Area Index for wheat areas at the level of federal states in Germany for 2020. Index data is available and can be selected back to 2007. In the diagram framed in red, significant deviations of the current season values (green line) from long term mean value (dark grey line on grey background) are highlighted in green indicating an early vegetation grow up in this spring and early summer in Bavaria.*

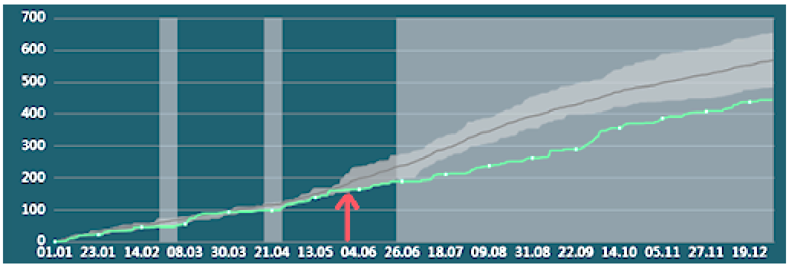


FIGURE 2 *Precipitation sum for 2019 in Saxony-Anhalt, the lack of precipitation starting end of May (red arrow) is clearly visible and highlighted. This has resulted in a noticeable reduction of yield in this year.*

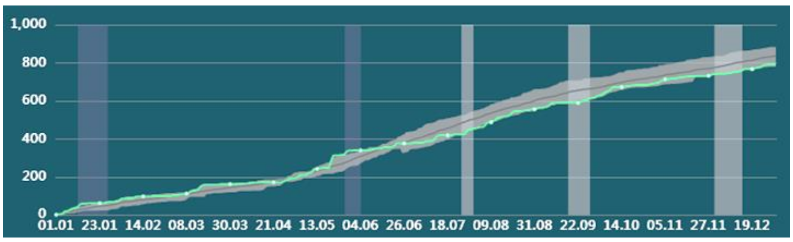


FIGURE 3 *Precipitation sum for 2019 in Bavaria. In contrast to Saxony-Anhalt, no precipitation decline was recorded, leaving the state at normal wheat production values in this year.*

CROPTIFY was covering most European countries, the Ukraine, Russia's main wheat growing regions and the US. After this project is now complemented with rice and maize and many more administrative areas and for many more years, complemented by many crop quality criteria and statistics.

In the World Bank's purpose to use above data and analyse it in combination with e.g. data on food prices from the Food and Agricultural Organisation (FAO) and World Food Programme (WFP), we proposed extra global analysis that may further support this analysis: In particular weather effects to crop health. Increasing variability of weather and intensified (local) weather extremes are environmental risks every country faces nowadays due to climate change. This clearly leads to the need of a continuous monitoring program of crop health within regions of a country. Long-term comparison of several vegetation related indices (so called time series) is needed to rank the current year's situation within past seasons and to evaluate eventually the current season's output. With Coronavirus induced changes nowadays, cropping patterns adaptations and possible cropping management changes should be monitored thoroughly.

1.3 Initial request: Objectives, Work Logic and Expected Outputs

1.3.1 Problems to be Addressed and Geospatial Information Gaps

The World Bank launched the Sovereign ESG Data Portal in October 2019, a free and easy to use online platform that provides users with environmental, social and governance data. In the environment group some agricultural related indicators are already available, like share of agricultural land and share of GDP. The ESG data portal as part of the World Bank's Global Program on Sustainability (GPS) aims to provide policy makers and the financial sector with the necessary metrics. In this context, gaps are identified concerning to agricultural crop health and status information regarding granularity and frequency of data. Consequently, the need for cross-country consistent data, which is available long-term and over large areas is clearly visible. Our solution proposed in this project will add an important added value to the ESG data portal to improve the situation and provide a source of valuable information.

The information gaps to focus on the present World Bank support request are related to agricultural crop status and crop health, compared across countries. At the moment the related data available to the bank team is often inconsistent, not sufficiently granular and not made available with a sufficient frequency. The bank team currently only has country-level wealth data on an annual frequency to compare crop data to. These are highly aggregated and modelled such that direct comparisons are difficult.

1.3.2 Information services to be delivered: Crop Types and Crop Health

This service shall consist of mapping the most important crop types together with their crop health indicators, for several countries, at national or sub-national level, for a number of priority crops for each country. This data will be used by the bank team in combination with e.g. data on food prices from the Food and Agricultural Organisation (FAO) and World Food Programme (WFP).

The data the bank team would find most useful is ideally aggregated to an administrative level, e.g. the first or second administrative divisions of a country, so that the bank team can explore different custom aggregators for bringing the data to country-level (i.e. administrative level 0). Data could of course also be provided based on a fixed grid, with the possibility of aggregation to an arbitrary level of administrative divisions.

The bank team is primarily interested in cross-country comparison. Hence, rough analyses of many countries are deemed more useful than detailed analyses of a few countries.

TABLE 1 presents a list of 15 countries with their top 5 crops that the bank team has proposed as possible country-crop combination candidates. Countries marked as *high* priority are central to the bank study. Within this priority band, the bank's top priority is in the LAC (Latin America and the Caribbean) and SEA (South-East Asia) regions. Countries with *medium* priority are a few selected European countries that will serve as benchmarks in the study. These are included given the bank's donor structure, the EO Clinic consortia's expertise.

Of the crops listed in table below the bank team has very high preference for the ones highlighted in green. In orange are alternative options or additions.

The following additional countries are part of the bank study, but are considered low priority for the purpose of the present RFP: South Korea, Australia, Japan, New Zealand, China, Finland, Norway, Sweden, Austria, Switzerland, Czech Republic, France, United Kingdom, Hungary, Portugal, Slovakia, Ireland, Bulgaria, Brazil, Canada, USA, India. Results for these countries shall be included only if useful existing datasets can be identified and exploited, or easily generated in some other way.

Priority	Region	Country	1	2	3	4	5
high	LAC	Colombia	Coffee, green	Maize	Rice, paddy	Sugar cane	Plantains and others
high	LAC	Mexico	Maize	Sorghum	Beans, dry	Sugar cane	Coffee, green
high	LAC	Peru	Maize	Rice, paddy	Coffee, green	Potatoes	Plantains and others
high	SEA	Indonesia	Rice, paddy	Oil palm fruit	Maize	Rubber, natural	Coconuts
high	SEA	Malaysia	Oil palm fruit	Rubber, natural	Rice, paddy	Oilseeds n.e.s.	Coconuts
high	SEA	Philippines	Rice, paddy	Coconuts	Maize	Vegetables, fresh n.e.s.	Bananas
high	SEA	Thailand	Rice, paddy	Rubber, natural	Cassava	Sugar cane	Maize
high	Other	South Africa	Maize	Wheat	Sunflower seed	Soybeans	Sugar cane
high	Other	Turkey	Wheat	Barley	Olives	Sunflower seed	Maize
medium	EEA	France	Wheat	Barley	Maize	Rapeseed	Grapes
medium	EEA	Germany	Wheat	Barley	Rapeseed	Rye	Maize
medium	EEA	Netherlands	Potatoes	Wheat	Sugar beet	Barley	Onions, dry
medium	EEA	Italy	Wheat	Olives	Maize	Grapes	Barley
medium	EEA	Spain	Barley	Olives	Wheat	Grapes	Sunflower seed
medium	EEA	Poland	Wheat	Triticale	Barley	Rye	Grain, mixed

TABLE 1. *Countries and crops of interest.*

Given the short turnaround requirement of the present RFP, and taking in account the resources available, the exact choice of countries (or administrative regions) and crops to be demonstrated is left to the discretion of the Contractor (see below proposal and achievements): this project is requested to be performed in 6 weeks at a maximum of 40 K€.

The Contractor is invited to evaluate the feasibility of mapping the crops in the countries shown in Table above. The Contractor shall thereafter propose a selection of at least two countries (preferably more countries of the same group, e.g. 2 LAC countries are preferred over 1 LAC and 1 SEA country), in which at least one of the top-priority crops will be mapped.

For each mapped crop type, suitable crop health indicators shall also be provided, with a frequency that shall be consistent across all mapped areas and crops, ideally monthly, and at least quarterly. The crop health indicator shall be based on one or more suitable parameters, preferably simple and close to the observation (such as NDVI). More complex parameters, modelled or based on retrievals in different domains or at coarser scales (soil moisture, precipitation, evapotranspiration, evaporative stress index, etc.), can also be considered as alternatives.

The bank is interested in consistent data for entire countries. Mapping major administrative divisions instead of entire countries is acceptable only as an extreme measure to mitigate processing of large data volumes, and only if thoroughly justified.

The mapping shall be done continuously from at least 2010 to present (ideally from 2005 until present). A larger number of countries with a shorter time period (e.g. LAC and SEA countries for 2010 to present) is preferred over a longer period with fewer countries (e.g. LAC countries only for 2005 to present). Consistency over the years and comparability between the countries are very important.

The spatial resolution at which the analysis shall take place shall follow what is feasible, accurate, efficient and meaningful with freely-available EO data (e.g. Sentinel-2 and Landsat).

To meet the Work Completion Deadline (WCD), the Contractor is encouraged to investigate and fully exploit any possible pre-existing EO-based datasets (use off-the-shelf or build on), taking stock of efficient data processing infrastructure. If not freely accessible, the proposed solution shall clearly list the costs of using such processing infrastructure, for the proposed country-crop combinations, and for a possible scale-up including what is feasible and meaningful in more countries listed in **¡Error! No se encuentra el origen de la referencia.** above.

Table below presents the corresponding FAOSTAT crop codes which may assist the Contractor's work.

15	Wheat	156	Sugar cane	403	Onions, dry
27	Rice, paddy	157	Sugar beet	463	Vegetables, fresh n.e.s.
44	Barley	176	Beans, dry	486	Bananas
44	Grain, mixed	236	Soybeans	489	Plantains and others
56	Maize	249	Coconuts	560	Grapes
71	Rye	254	Oil palm fruit	656	Coffee, green
83	Sorghum	260	Olives	836	Rubber, natural
97	Triticale	267	Sunflower seed		
116	Potatoes	270	Rapeseed		
125	Cassava	339	Oilseeds n.e.s.		

TABLE 2. *FAOSTAT crop codes.*

2 WHAT WAS PROPOSED TO BE PERFORMED

2.1 Understanding of the requirements and proposed approach

From a technical point of view, the core concept of the RFP is a crop growth monitor at administrative level, applicable in all major cropping regions of the world. The first requirement is therefore a consistent mapping approach to identify the overall area of a crop within an administrative area. Secondly, the monitoring takes place to assess crop health within administrative areas.

The data pool necessary for this RFP has to be standardized, objective and consistent for several years and over large regions. Therefore, we will utilize an ensemble of different datasets from different sources fulfilling these requirements. All of these datasets are freely accessible, available for a large period of time and have a focus on vegetation development.

The RFP mentions 15 high and medium priority countries (see TABLE 1 above) as possible country-crop combination candidates. In this project, we are proposing to cover approximately 70% of the originally highlighted country-crop combinations required, as indicated in the table. These 70% cover the bank's top priority countries (and the medium priority ones) and the crops with very high preference. The other part of 30% are the crops intended as alternative options. However, we will focus on the high preference countries due to the short turnaround requirement of the RFP, in a following step after successful finishing this proposal, the alternative crops can be managed in the same way we propose in this project.

In addition, and in TABLE 3 below, the crop types to be analysed in this project are highlighted, fulfilling more than the minimum crop types requested in the RFP: wheat, maize and rice.

Priority	Region	Country	1	2	3	4	5
high	LAC	Colombia	Coffee, green	Maize	Rice, paddy		
high	LAC	Mexico	Maize	Sorghum			Coffee, green
high	LAC	Peru	Maize	Rice, paddy	Coffee, green		
high	SEA	Indonesia	Rice, paddy		Maize		
high	SEA	Malaysia		Rubber, natural	Rice, paddy		
high	SEA	Philippines	Rice, paddy		Maize		
high	SEA	Thailand	Rice, paddy	Rubber, natural			Maize
high	Other	South Africa	Maize	Wheat			Sugar cane
high	Other	Turkey	Wheat	Barley			Maize
medium	EEA	France	Wheat		Maize		Grapes
medium	EEA	Germany	Wheat	Barley			Maize
medium	EEA	Netherlands	Potatoes	Wheat		Barley	
medium	EEA	Italy	Wheat		Maize		
medium	EEA	Spain	Barley		Wheat		
medium	EEA	Poland	Wheat		Barley		

TABLE 3. *Countries and crops of interest focussed on very high preference and alternative options according to the RFP. Highlighted crops (green) will be covered in this project.*

However, mapping different crop types in several countries with a comparable quality over the years is a challenging task in terms of data availability, processing costs & processing time and classification algorithms. We propose therefore a mixed approach using freely available EO data in combination with existing crop type maps of different, individual years. In this approach, areas for each administrative unit will eventually be estimated using similarity measures based on vegetation time series. The approach has already been successfully applied for 13 years at administrative levels on soft wheat in nearly all European countries as well as in the Ukraine, Russia and United States. The main advantage of this approach is due to the use of medium resolution satellite imagery (e.g. MODIS and partially Sentinel-3) which is available for a long time period at regular time intervals. This guarantees a consistent data availability and resulting quality and leads to a manageable amount of data and processing time. The adaptation and further development of this approach within this project will consider maize and rice, allowing us to evaluate the feasibility of mapping the major crops in all requested countries in the RFP. However, due to the short turnaround requirement of this RFP, we will focus on wheat, maize and rice in these countries, which represent approximately 70% of all possible country-crop combinations given in TABLE 1 of the RFP008 (as already mentioned above).

Suitable crop health indicators will be provided on a regular basis, ideally monthly or below. With our long experience in Remote Sensing with focus on agriculture, we propose a compilation of time series of several datasets, including EO data and weather information, to set up a comprehensive and detailed view on all country-crop combinations. TABLE 4 below summarizes these datasets are (with sources and temporal resolution).

Index family	Index	Source	Availability since	Temporal coverage
Soil water	Soil water Index (SWI)	Copernicus Global Land Service	2007	daily
Air temperature	DWD ICON WORLD	DWD open data service	2015	daily
	ECMWF ERA-interim	ECMWF open data service	1979	daily
Precipitation	DWD ICON WORLD	DWD open data service	2015	daily
	ECMWF ERA-interim	ECMWF open data service	1979	daily
Global Vegetation Health Products	Vegetation Health Index (VHI)	NOAA STAR Global Vegetation Health Products	1981	7-day frequency
	Temperature Condition Index (TCI)	NOAA STAR Global Vegetation Health Products	1981	7-day frequency
	Vegetation Condition Index (VCI)	NOAA STAR Global Vegetation Health Products	1981	7-day frequency
Vegetation indices	Leaf Area Index (LAI)	NASA MODIS MCD15A3H.006	2001	7-day frequency
	OLCI terrestrial chlorophyll index (OTCI)	ESA Sentinel-3	2016	2-day frequency

TABLE 4. *Indices being provided in this project to evaluate crop health and crop status.*

All data sources have been widely used in global and regional studies and are generally considered of a high quality[1].

The above-mentioned datasets are extracted pixel-wise using the previously described crop maps and aggregated to administrative level as requested. Due to the varying temporal resolution of the datasets, we propose a solution using a 10-day time frame for data delivery in order to ensure a consistent update interval.

According to the requirements of the RFP to provide continuous time series, all datasets will be provided from 2005 to present, except the proposed Sentinel-3 index which starts in May 2016.

2.2 The partners

The overall EO-Clinic frame contract consortium is composed by thirteen companies. Twelve EO service providers, expert in a specific thematic group, but also, with expertise in most of them. And the prime contractor, everis aerospace and defense, an entity which primary expertise in management of challenging international

[1] see for example: Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M., & Rudolf, B. (2014). GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. Theoretical and Applied Climatology, 115(1-2), 15-40.
or: Chen, C. F., Son, N. T., Chen, C. R., Chiang, S. H., Chang, L. Y., & Valdez, M. (2017). Drought monitoring in cultivated areas of Central America using multi-temporal MODIS data. *Geomatics, Natural Hazards and Risk*, *8*(2), 402-417.

development projects. This way, the key of the success lies on a well-structured and collaborative team, which members supporting each other in order to achieve outstanding results.

It is a **well-balanced team** formed by **one (1) multinational entity** leading the consortia, expert in managing international projects, **two (2) research organization** which provides state of the art techniques in term of EO solutions and **ten (10) SMEs** entities highly dynamic and specialized on EO solutions.

The main principles of the consortium are:

- **Highly reactive and dynamic structure** – for accommodating short-term, small and exploratory request from the end user.
- **Deep understanding and expertise on thematic EO products** – providing a wide coverage of range of skills and capabilities in terms of different EO study areas and products generation.
- **Client-oriented solutions** – always keeping in mind the scope and the necessities of the end-users. Their business activity and aiming to provide the best suited EO solutions for them.
- **Time-oriented project** execution – It is essential in this environment to deliver EO information on time against deadlines. This is the only approach for achieving what it is called "rapid-response" capability to the Bank users.
- **High quality assistance for end users** – usually, final users are not familiar EO technologies, even less, when innovative methodologies and techniques are applied. It is essential to provide assistance on final information for its correct exploitation.
- **Expand the knowledge through Europe** – thirteen companies, nine different countries. The consortium aims to promote European missions, generate value-adding services, and take European EO capabilities to the next step.

The complete thematic groups required by ESA for different Request for Proposals are fully addressed by the consortium members.

This project in particular is performed by the following partners providing the best expertise for the specific purpose of the project:

Everis Aerospace and Defense S.L.	Prime Contractor: EO-clinic Frame Contract and project management and technical Coordination
everis is a multinational group that offers to its clients services and solutions that add high value covering all the value chain areas of a company, from defining the strategy, to design, development, integration, implementation and maintenance of technological solutions. **everis Aerospace and Defence**, the **everis** Group's Aerospace and Defence Division, offers global solutions for implementing critical systems in aerospace, defence, security and simulation sectors, integrating reliable and innovative technologies though proprietary development and through the SMEs with which the Group has strategic alliances as leading partners.	
Green Spin GmbH	Subcontractor: Thematic Group 1- Agriculture Leader
GREENSPIN is a spin-off company from the Department of Remote Sensing at the Institute of Geography, University of Würzburg, with close ties to the German Aerospace Agency. The largest part of GREENSPINs team of six consists of remote sensing and data scientists. Over the last 4 years, we specialized in data analytics and service development in digital agriculture. They successfully developed and launched our web-based Agri Analytics application for B2B customers in agriculture in 2017. GREENSPIN has broad experience in developing agricultural applications based on remote sensing for industrial and institutional customers. They include automated solutions for mapping, monitoring and yield modelling for a wide range of crop types. Their web-based GIS for agricultural applications automatically processes satellite imagery and can, for example, detect crop types on agricultural parcels. GREENSPIN's	

key personnel for this RFP has long standing experience in working with development organizations and institutional partners in agriculture-related development research projects in Central Asia.	
World from Space S.r.o	Subcontractor: Thematic Group 9-Urban Leader
World from Space (WFS) is a start-up company established in September 2017, currently incubated in the South-Moravian Innovation Centre, Brno, Czech Republic. WFS is a company building on experience of its founders in the field of EO and environmental science. The company builds its core business around the interpretation of satellite data for various users. So far, we cooperate especially with cities. Our vision consists of two main product lines of the company - Smart Cities and Smart Agriculture, with ongoing R&D bringing new topics according to customer needs. We want to put stress on transfer of knowledge and know-how from the scientific community to real use. Therefore, we intend to preserve our cooperation with universities and research institutions. The company was awarded the Seal of Excellence under the Horizon 2020 SME instrument in 2018 for the project of vegetation dynamics and drought monitoring. WFS is a winner of ESA BIC Prague EOVation Masters 2018, ESA BIC EOVation Masters Scientific Article 2018 and it won the second place at the ESA BIC Prague City and climate hackathon 2018. We were part of the winning team of the ESA BIC Prague Agricultural hackathon 2017. World From Space (WfS) is an Earth Observation company active in the agricultural sector, urban and land monitoring and management with focus on climate change adaptations. Core of the company's business is DynaCrop service, an API for agricultural software serving monitoring and analytical information based on satellite data. WfS is part of ESA's start-up ecosystem, member of ESA BIC Czech Republic, winner of the Copernicus Masters - Government Challenge 2018 and took part in Copernicus accelerator in 2019. The team of WfS consists of people from multiple domains: remote sensing, geoinformatics, IT, environmental management and smart agriculture. WfS is covering a wide range of skills including satellite data processing and interpretation (optical and radar systems), cloud computing, AI, backend development, GIS that are combined with agricultural, environmental and urban expert knowledge.	

2.3 Work Logic proposed

The work logic of this particular Work Order has been defined to ensure the provision of an efficient service to EFNLT and ESA, maximizing added value outputs, delivered on time and in the required format. Indeed, the work for this RFP is organized around five work packages (WP).

- **WP0**: the overall management and the successful implementation of the work as well as the delivery of the results. (Everis)
- **WP1**: This working package is focused on generating and providing crop type maps at administrative levels and pixel-level as input for WP2. (GREENSPIN)
- **WP2**: This working package includes generating time series of crop health indicators and conducting data delivery to the World Bank via a web-based application and downloadable datasets. (GREENSPIN)
- **WP3**: This working package includes a comprehensive assessment of available (global) datasets that can support interpretation and bring context to data produced in WP1 and Wp2. This work package (WP3) also includes two case studies. (World From Space)
- **WP4**: This working package contains the final report, recommendations, technical verification and quality assurance of the results of WP 1, 2 and 3. (Everis)

The high level work logic is described in the following Figure:

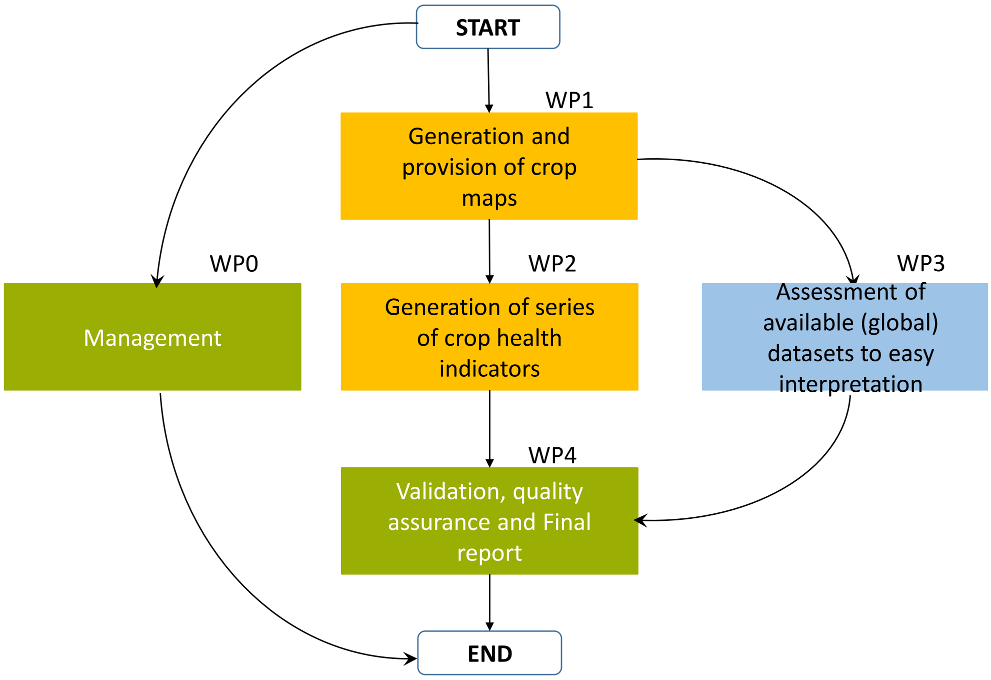


FIGURE 4 *Work Logic of Work Order*

2.4 Description of Work packages.

2.4.1 WP0 - Management.

Management activities of this project will be performed by everis. Management processes will follow the ones described in reference Management Proposal. In this proposal, only specific management aspects for this RFP are described. In order to control the progress of the work order with respect to cost, schedule and technical objectives, the following milestones are set up:

Milestones		Date
Kick-off Meeting (KOM)	Once the Work Order (WO) is launched, a KOM will be held by ESA, EFNLT and Everis to review schedule, scope of the work and deliverables. It will be agreed the crop type selected, the Countries and the health indicators to be analysed.	T0
Acceptance Review	A final meeting with ESA, EFNLT and Everis will be performed to review and accept the work done along the work order.	T0+6w

TABLE 3. Milestones management.

Other management-related tasks such as cost control procedures, progress reporting, meetings management, actions management and so on will be carried out as stated in Management Proposal. Moreover, the proposal manager will contribute to the final report with the conclusions obtained during the Work Order, and related to the estimation of feasibility, conditions and cost of an extended service.

2.4.2 WP1- Crop type maps.

2.4.2.1 Objectives, tasks and methodology

The main objective of Work Package 1 (WP1) is to generate maps of the following crop types: wheat, maize and rice. Considering the information and the requests in the RFP, this WP1 has the following tasks:

1.A. Data download and preparation: Identify and obtain available crop type maps, provide time series of vegetation indices

1.B. Extract templates of vegetation time series for each administrative unit and crop type

1.C. Generate cropping areas of wheat, maize and (paddy) rice

Task 1.A - Data download and preparation:

Available raster-based global (e.g. SPAM[1]) and local (e.g. maps of grain maize in Mexican states[2]) crop type maps are evaluated according to the year of origin and eventually downloaded. These crop type maps act as a template to gather the time series of vegetation indices in the next step.

Time series of either one or a maximum of two vegetation indices retrieved from medium resolution satellite imagery are downloaded for each year considered in this project. Due to the requirements of the RFP to include long time series starting ideally in 2005, we will mainly use the LAI & FAPAR vegetation index from the MODIS MCD15A3H.006 product. If feasible and valuable we additionally will include Sentinel-3 based indices like OLCI starting from mid 2016.

Task 1.B - Extract templates:

Using the crop type maps as masks, we extract crop type specific time series of the vegetation indices for each administrative unit and year a mask exists. These crop type specific time series serve as templates which will represent a typical temporal sequence of a vegetation season from sowing to harvest.

Task 1.C – Generate cropping areas for crop types:

The templates correspond to pixel based single-year crop masks and are used to identify similar developments in other years. Based on these templates, the time series of pixels of the remaining years are analyzed applying similarity and distance measures (e.g spectral angle mapper[3], dynamic time warping[4]) in order to find corresponding pixels to the respective crop type.

2.4.2.2 Outputs

The main outputs will consist of:

1) Pixel based crop type maps as delivery to WP2 for each administrative unit and all years
2) Table of aggregated cropping areas for each administrative unit and all years.

2.4.2.3 Boundary conditions

Building crop type masks on medium resolution EO data has advantages over finer resolution EO data especially in terms of processing time & costs. This medium resolution data is available with a high temporal frequency with proven and consistent quality over the last 20 years, and has been used commonly for large area estimations on higher levels.

However, crop type maps on higher resolution data -e.g. Sentinel-2 data sets- have other advantages like a more accurate detection of distinct crop types. Nevertheless, consistent data availability and -quality within a year or during the last 13 years is not given using only Sentinel-2 and Landsat-8 EO data. This drawback will lead to a highly fragmented availability of single crop type maps.

[1] Spatial Production Allocation Model (2005 & 2010): https://www.mapspam.info/

[2] Gobjerno de México - Estimación de superficie agrícola para el ciclo primavera - verano (2015): http://infosiap.siap.gob.mx/gobmx/datosAbiertos.phphttp://infosiap.siap.gob.mx/gobmx/datosAbiertos.php

[3] Demonstrated on Landsat-7 reflectance time series: Yan, L. and Roy, D.P. (2015). Improved time series land cover classification by missing-observation-adaptive nonlinear dimensionality reduction. Remote Sensing of Environment, 158, 478-491.

[4] Wegner Maus, V., Câmara, G., Appel, M., & Pebesma, E. (2019). dtwsat: Time-weighted dynamic time warping for satellite image time series analysis in r. Journal of Statistical Software, 88(5), 1-31.

Therefore, we propose using medium resolution EO data to fulfil the requirements of this RFP, which clearly gives preference to consistent cross-country comparison over single highly accurate crop type maps.

2.4.3 WP2 – Crop health indicators and data delivery

2.4.3.1 Objectives, tasks and methodology.

The main objective of Work Package 2 (WP2) is to generate the time series of crop health indicators, finalising with the delivery to the World Bank via a web-based application and downloadable datasets.

The tasks to be performed within this WP2 are:

2.A. Generate time series data for crop health indicators for each administrative unit

2.B. Data delivery and adaptation of the web-based application

Task 2.A – Generate time series data for crop health indicators for each administrative unit:

Pixel based crop type maps delivered by WP1 are used as masks to extract corresponding values from each parameter listed in above section 2.1. Specifically, that means that we build time series (a series of index values in time order) of all indices given in TABLE 4 above only on pixel were we identified the corresponding crop. Since all parameters have different temporal resolutions (data acquisition frequency), the next step to be performed in this task is to harmonize all time series towards 10-day time series by interpolation. All administrative units will be treated equally so that all parameter time series are standardized and available for each unit.

Task 2.B – Data delivery and adaptation of web-based application:

We will deliver all results generated in WP1 & WP2 in table format, separated into:

1. a boundary table including name, country and unique identifiers for each administrative unit used in the project.
2. single tables for each parameter time series using the same unique identifier to match the tables with each other.

Additionally, a vector file will be delivered containing all administrative units with their corresponding unique identifier for visualization purposes.

Besides the delivery of tables, all results of this project will be incorporated into the web application available at https://app.greenspin.de. This means, the proposed crop health indicators will be visualized immediately and can be assessed without time delay directly inside the application, for each desired administrative unit. In order to be able to include the additional crop types and country coverage, the web-application must be adapted by:

- including new country boundaries
- defining styles and symbology for new parameters
- creating custom text labels
- providing a data download option directly in the diagrams.

2.4.3.2 Outputs

The main outputs will consist of the following information:

1) Tables of 10-day time series of at least 5 crop health indicators for each country-crop combination for which crop type masks from WP1 are generated
2) PDF reports of which the content is visualized and also made available via a data download option within the existing web-based application (CROPTIFY) in order to facilitate a direct evaluation of the health indicators in each region.

2.4.4 WP3 – Datasets assessment and case studies.

2.4.4.1 Objectives, tasks and methodology.

Work package 3 serves as an added value to the main RFP request: crop mapping and crop health condition. We believe that there are other datasets (e.g. global ones) that can improve the understanding of agriculture in countries and their crop production. To be more specific, there are different levels of vulnerability of the national agro-sector towards both actual/short-term extreme climate-related events (such as drought) and long-term climate change. In order to perform such analyses, this work package will be performed throughout the following tasks:

3.A) Assess the relevant global datasets to support context for crop data

3.B) Promote the drought indicator from GDO (Global Drought Observatory) as additional crop health measure

3.C) To show how additional datasets can serve the purpose - two case studies.

Task 3.A) Assess the relevant global datasets to support context for crop data

Within this task, available global datasets relevant to crop monitoring and health status on national level available globally will be reviewed (extracted from the Climate Data Store from Copernicus Climate Change Service[1]).

It will include a study of the factsheets and derivation procedures used for obtaining the data. This will be evaluated in the context of the possibility to conduct automated processing and also its relevance for the aim.

The datasets, data storages and services that will be minimally considered for this Task 3.A can be found in below section 2.5.

This task will:

- Review of datasets,
- Downloading test samples,
- Preprocessing the data in a GIS software (QGIS).
- Expert interpretation of the information in the context of crop production and climate change.
- Feasibility of using the dataset for automation, assessing data access and formats, evaluating possible implementation costs.

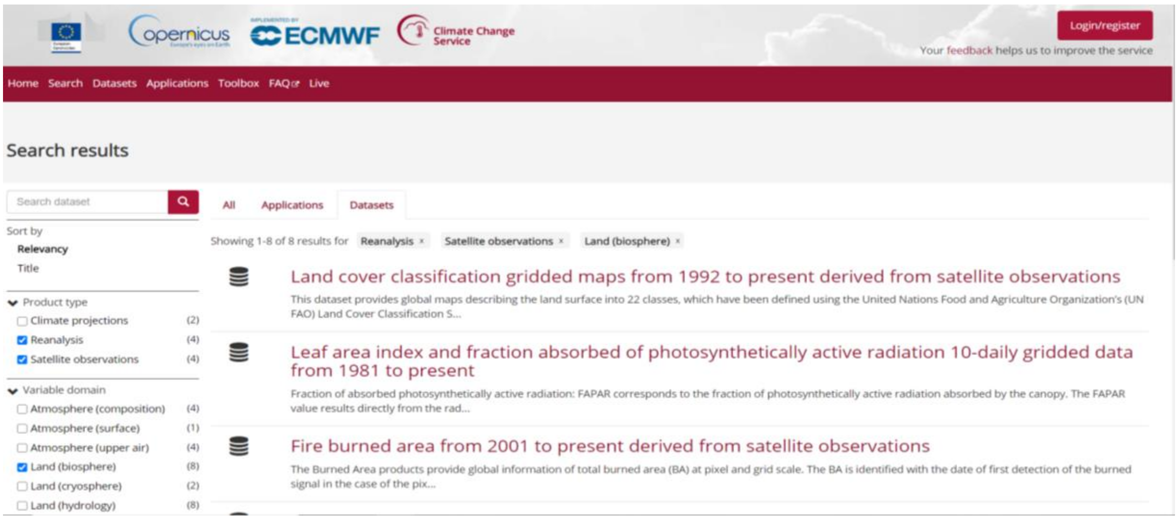


FIGURE 5 *Climate Data Store from Copernicus Climate Change Service*

[1] https://climate.copernicus.eu/the-climate-data-store

Task 3.B) Promote drought indicator from GDO[1] (Global Drought Observatory) as additional crop health measure

For Task 3.B), data from GDO will be downloaded and processed for all countries of the RFP (see TABLE 3). For data automation, Python scripts will be written as dedicated tools are not provided. We will write a script for semi-automated download of Risk of Drought Index (RDrI) time series data in JSON/CSV format from country reports available in the GDO. Another Python script with be written to automatically process this data files to generate outputs for this report.

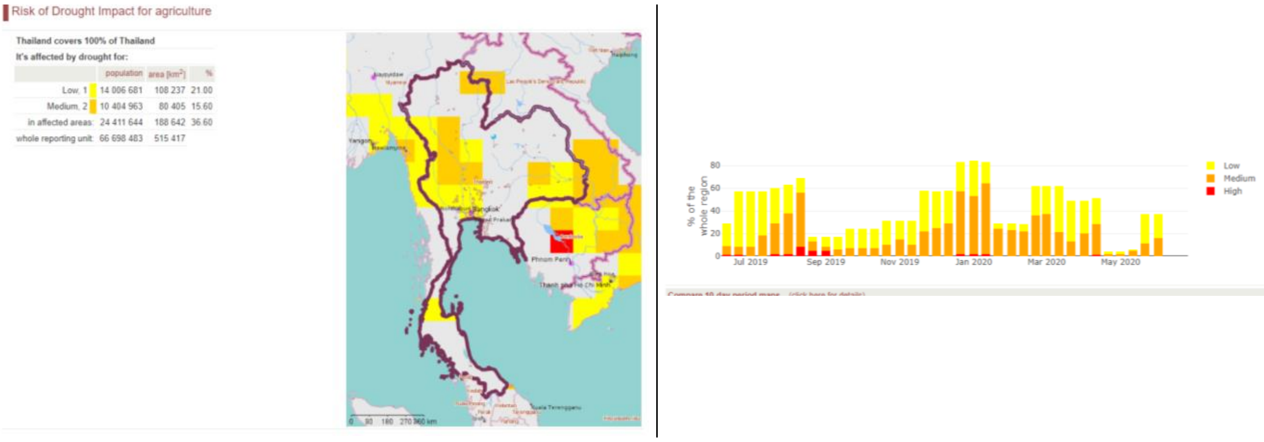


FIGURE 6 *Actual map and time series graph of Risk of Drought Index (RDrI) from Global Drought Observatory*

Task 3.C) To show how additional datasets can serve the purpose - two case studies

Within this task, data from Task 3.A will be processed in the QGIS software for the sample countries: <u>Thailand and Indonesia</u>. Together with all outputs from WP1, WP2 and Task3.B, a comprehensive interpretation will be done by putting crop type and area into context with health status and overall situation.

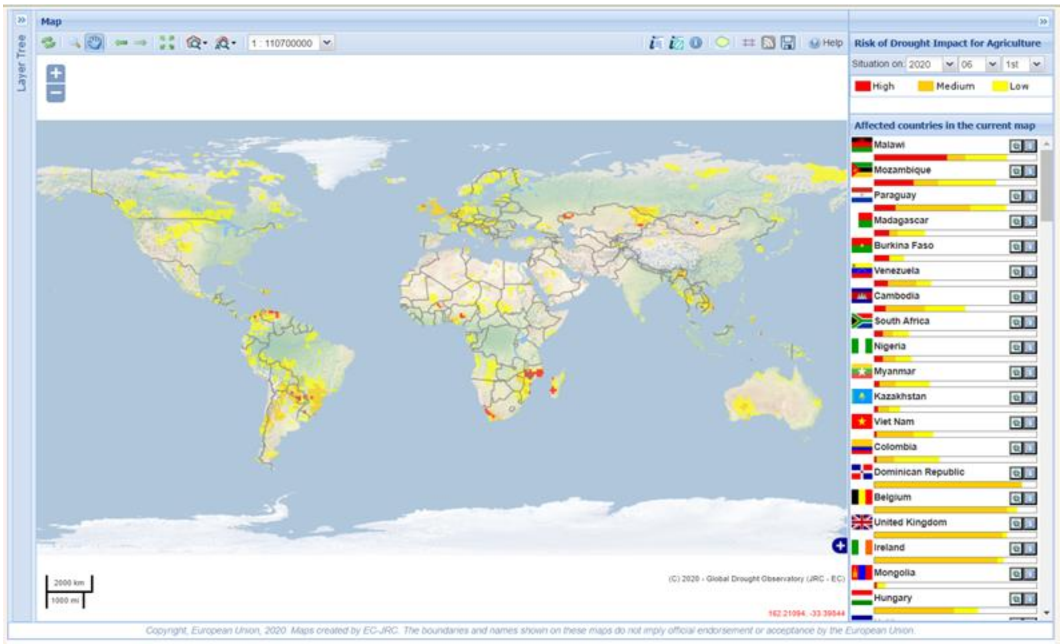


FIGURE 7 *Global Drought Observatory from Copernicus Emergency Management Service*

[1] https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000

2.4.4.2 Outputs

There are four deliverables from WP3, all to be documented together in the Technical Note 2:

1) **Assessment report**, including a comprehensive **table** of global datasets relevant for crop status and health monitoring that are not included in the outputs of WP2 (thus not part of the web-based application). The table will include nominal identification of the dataset and its initials (coverage, resolution, update frequency, data source, timespan) and relevant information/indicators. This will be completed with feasibility measures for implementation, automated monitoring and interpretation remarks as a part of the report and recommendations for possible use.
2) **Drought indicator** for all countries included in this RFP in the form of **time series** (table and graph) with usage manual for interpretation. Timespan for this is 2013-mid 2020.
3) **Thailand case study** - showcase information given for the selected country within WP1 and WP2 and add text interpretation of the health status indicators. Moreover, it adds additional information from the dataset assessed in Task A of WP3. It also discusses feasibility of datasets and information gathered.
4) **Indonesia case study** - showcase information given for the selected country within WP1 and WP2 and add text interpretation of the health status indicators. Moreover, it adds additional information from the dataset assessed in Task A of WP3. It also discusses feasibility of datasets and information gathered.

2.4.5 WP4 - Technical Verification, Quality Assurance, and Final Report Creation

2.4.5.1 Objectives and tasks.

Main objectives of WP4 will be dedicated to ensure the overall quality of the service and report findings and conclusions acquired during the WO execution. An independent technical verification will be performed over the generated outputs. Moreover, quality assurance principles such as those described in the management section of the management proposal will be followed. Those procedures will be tailored to fit into the 4-week time frame, and then ensuring that a minimum quality is reached.

The second objective of WP4 will be the creation of a final report that states the guidelines for the success of the project. Conclusions and findings will be compiled in this report, and then well support a larger service over other regions, countries and indicators. The potential of the methodology applied during the WO will be described, but also its limitations. Then, EFNLT and other stakeholders will be perfectly aware of the working flow and it's potential.

It is also considered to work with EFNLT on dissemination activities, and support for determining the viability of using EO for mapping the crop types and their indicators.

To achieve the objectives, following tasks are identified, and will be agreed with ESA and EFNLT:

- Task 4.1 - Independent Quality and Verification Check of the output products (according to the RFP requests in what concerns the Countries and crops combination).
- Task 4.2 - Final Report, which includes conclusions and guidelines to an extended project over a larger area.

2.4.5.2 Outputs.

The outputs of this working package will be compiled into the Work Order Final Report. It will include the verification and quality assurance metrics, but also the conclusions and findings of the performed services. It will also include guidelines and limitations of the services, and results from added value analysis defined in WP3, for the analysis of the future expectations based on current crop data and Sentinel based climate data expectations.

2.5 Input dataset required

Due to the requirements of this RFP, we focus on EO and secondary data with high temporal resolution, long history and consistent quality. Some countries to be covered are located in the tropical hemisphere with an expected extensive cloud coverage. Therefore, high temporal resolution is needed to fill the time series of crop health indices with as much valid values as possible.

Based on these characteristics we decided for WP 1 and WP 2 to use -among others- EO data from the MODIS sensor in addition to Sentinel-3. All images and datasets which will be used in this project are freely available.

Image data and weather data procurement will be depending on the dataset. Corresponding sources are listed in TABLE 5.

Index family	Index type	Download source
Soil water	Soil water Index (SWI)	Copernicus Land Service https://land.copernicus.eu/global/
Air temperature	DWD ICON WORLD	DWD open data service https://opendata.dwd.de/
	ECMWF ERA-interim	ECMWF open data service https://www.ecmwf.int/
Precipitation	DWD ICON WORLD	DWD open data service https://opendata.dwd.de/
	ECMWF ERA-interim	ECMWF open data service https://www.ecmwf.int/
Global Vegetation Health Products	Vegetation Health Index (VHI)	NOAA STAR https://www.star.nesdis.noaa.gov/star/index.php
	Temperature Condition Index (TCI)	NOAA STAR https://www.star.nesdis.noaa.gov/star/index.php
	Vegetation Condition Index (VCI)	NOAA STAR https://www.star.nesdis.noaa.gov/star/index.php
Vegetation indices	Leaf Area Index (LAI)	USGS Earth Explorer https://earthexplorer.usgs.gov/
	OLCI terrestrial chlorophyll index (OTCI)	Sentinel Hub https://www.sentinel-hub.com/

TABLE 5. *Sources of data acquisition for WP1 & WP2*

For additional information and statistical verification, FAO statistics will be used (http://www.fao.org/statistics/en/).

Concerning the input data needed in order to execute the tasks of WP3, the required data will be obtained at no cost from the following sites:

- Global Drought Observatory (GDO) as an part of the Copernicus Emergency Management Service (https://edo.jrc.ec.europa.eu/gdo)
- GloFAS - The Global Flood Awareness System as an part of the Copernicus Emergency Management Service (https://www.globalfloods.eu/)
- European Forest Fire Information System (EFFIS) - (https://effis.jrc.ec.europa.eu/)
- Catalogue of the European Centre for Medium-Range Weather Forecasts (ECMWF) real-time products
- Copernicus Global Land Service, theme Vegetation (https://land.copernicus.eu/global/)
- Climate Data Store (https://cds.climate.copernicus.eu/) run by Copernicus Climate Change Service
- NASA Open Data Portal (https://data.nasa.gov/)

2.6 Proposed Schedule

The planned schedule for the delivery of the services, counting from the release of the Work Order is presented below (duration 6 weeks):

WP	Description	Leader	Start	End	Duration
WP0	Managemet and Procurement of Satellite Images	everis	To	To+6	30 days
WP1	Crop type maps	Greenspin	To	To+4	20 days
Task 1.A	Data preparation and download: Identify and obtain available crop type maps, provide time series of vegetation indices	Greenspin	To	To+1	5 days
Task 1.B	Extract templates of vegetation time series for each administrative unit and crop type	Greenspin	To+1	To+2	5 days
Task 1.C	Generate cropping areas of wheat, maize and (paddy) rice	Greenspin	T0+2	T0+4	10 days
WP2	Crop health indicators and data delivery	Greenspin	T0+3	To+6	15 days
Task2.A	Generate time series data for crop health indicators for each administrative unit	Greenspin	T0+3	To+5	10 days
Task2.B	Data delivery and adaptation of web-based application	Greenspin	To+5	To+6	5 days
WP3	Datasets assessment and case studies	Worldfrom	To	To+6	24 days
Task3.A	Assess the relevant global datasets to support context for crop data	Worldfrom	To	To+2	14 days
Task3.B	Promote drought indicator from GDO (Global Drought Observatory) as additional crop health measure	Worldfrom	To+2	To+4	14 days
Task3.C	To show how additional datasets can serve the purpose - Two case studies	Worldfrom	To+4	To+6	10 days
WP4	Validation and Quality Assurance	everis	To+3	To+6	12 days

T0 = 20 July 2020

3 RESULTS AND CONCLUSIONS

3.1 WP0 – Management Conclusions

The project was managed following the initially planned schedule although some of the initial tasks were not easily performed, delaying the project few days from its initial schedule.

The initial Kick-off meeting plus three bi-weekly progress meetings were held, sending all Minutes of meeting by email to al participants just after the meeting.

A final acceptance review and close out meeting is also held 4 days after the initially planned end of the project.

3.2 WP1 – Crop type maps

The solution presented in this work package aimed the evaluation of the feasibility of mapping crop types in all countries requested in the RFP. For the cross-country comparison envisaged, a global usable approach was implemented taking advantage of available crop type maps from several countries as references. Such a reference data base -incorporating several countries and years- was not implemented before and represents a novelty. A global year-by-year mapping approach for different crops at pixel sizes below a kilometre is not known in literature by now. Therefore, the efforts in this work package can be seen as a successful feasibility study with valuable outcomes in terms of requirements for basic data and processing steps. Several examples are given in technical Note 1, describing the potential but also hurdles to overcome towards a continuous classification scheme in the future. A continuation of the work is recommended.

The crop type maps to be generated for all countries and in different years was a difficult task. As described in the proposal, this requirement was addressed using reference spectra created from time series of a vegetation index based on existing crop type maps.

Reference spectra are typical courses of a vegetation index for a crop in a country. These reference spectra vary between countries but also within a country for several years (e.g. different courses of vegetation indices for a dry and a normal vegetation season). To generate reference spectra for single countries, existing crop type maps have been analysed and downloaded if appropriate. To fit the conditions of the RFP, the crop type maps must indicate correctly at least areas of similar crop types. For South East Asia and South America, available maps from satellite image classification include many errors. Therefore, in this project, these maps were visually verified and sometimes even dismissed. An optimal case of crop type maps are field boundaries with information on the field crop per year, which were found only in France and The Netherlands. Overall, the following data sets were found and used in the project (see below TABLE 6). For crops with multiple growing seasons, time periods specified in the analysed crop type maps are recorded as well.

Country	Years, coverage and type of crop
Colombia	2014, 2016, 2018, selected regions, Rice (no distinction of seasons)
Ecuador	2014, 2015, 2016, 2017, 2018, 2019, countrywide, Rice (season 1 to season 3) and Maize (season 1 and season 2)
France	2010 - 2017, countrywide, Wheat and Maize
Germany	2016, countrywide, Cereals and Maize
Indonesia	2009, 2011, 2017, countrywide, Rice (no distinction of seasons)
Italy	2012, 2014 - 2019, selected region, Rice and Maize
Mexico	2015, countrywide Maize (spring season only)
Netherlands	2009 - 2019, countrywide, Wheat and Maize
Peru	2019, selected region, Rice (no distinction of seasons)
Philippines	2017, selected region, Rice (semester 1 and semester 2)
South Africa	2006, 2007, selected regions, Wheat (only 2007) and Maize
Thailand	2020, countrywide, Rice (season 1 and season 2, north and south)

TABLE 6. *Acquired crop type maps used to generate reference spectra*

But it is clear that the process of acquiring crop type maps is a long-term process of communication and processing with different National responsibles who reply in different timely order. As shown in above TABLE 6, not all countries are covered with in-situ maps and some data sets are only available at a regional level.

In addition, none of the countries had maps available for the complete intended investigated time period (2007 until 2020). For the Philippines, data sets were requested from an official source[1] which provided parts of the data after 4 weeks (and the total project duration was 6 weeks). On the other hand, since no in-situ maize data could be obtained for Peru, additional data sets from Ecuador were acquired and found partly usable to detect maize areas in Peru. Processing of the data included re-projection, transformation to raster, rescaling to a uniform raster size and extraction of respective crop types.

Additionally, the following problematic issues came up during the processing of reference spectra:

a) in South America, several growing seasons for maize are common, often distinguishable in terms of the elevation of the growing region. Suitable data was not found for all growing seasons, especially concerning maize growing areas in lowland regions in Peru.
b) In South East Asia, several rice growing periods are common but most of the data sets found do not distinguish between them.
c) Finally, the application of reference spectra retrieved from the in-situ crop type maps is carried out on a global cropland layer. This cropland layer distinguishes between areas used for growing crops and other land uses/ land covers. Three different sources were downloaded and compared in order to cover most of the global crop land without obtaining too many cases of misclassifications (e.g. indicating settlements as cropland). The sources were:
    - GlobCover[2] (version 2.3, 300m pixel resolution, 2009)
    - the Land Cover product from the Copernicus Global Land Service[3] (Version 2.0, 100m pixel resolution, 2015)
    - the GFSAD[4] data set (Global Food Security-Support Analysis Data, Version 001, 30m pixel resolution, 2015).

All of the products were found useful in the northern hemisphere (especially Europe and the western part of Russia), useful with restrictions in South East Asia but not useful in Central & South America.

In addition, other common problems with the data available are about the over-classifications (e.g. savanna and tropical forest as cropland in GlobCover) or under-classifications (missing large parts of agricultural systems in Peru, Ecuador and Colombia in the Copernicus product). The quality of the cropland layer determines, among other factors, the quality of the retrieved crop area raster maps, thus leading to an unstable final quality.

The second part of the data download process was the collection of official area statistics for each country at the lowest administrative level possible. For all countries in scope, these data sets were acquired and used to compare with in-situ crop type maps and crop area raster maps.

In order to be able to create crop area maps of the crops of interest from the extracted reference spectra, Change-Vector Analysis (CVA) was performed in which multiple similarity measures were evaluated: Spectral

[1] https://prism.philrice.gov.ph/
[2] http://due.esrin.esa.int/page_globcover.php
[3] https://land.copernicus.eu/global/products/lc
[4] https://www.usgs.gov/centers/wgsc/science/global-food-security-support-analysis-data-30-m-gfsad

Angle Mapper (SAM)[1], Spectral Information Divergence (SID)[2], Spectral Correlation Mapper (SCM)[3], Euclidian Distance (ED)[14] and Chebyshev Distance (CD)[4]. All measures are calculated between a time series of a reference spectrum and a time series of a cropland pixel. The Enhanced Vegetation Index (EVI) is used as vegetation index for the analysis.

The proposed measures also differ in terms of sensitivity to the properties of analysed time series. For example, ED and CD are both very sensitive to differences of gain and as well as of offsets between time series. SAM and SID are sensitive to differences in gain, whereas SCM is insensitive to differences of both properties.

During the analysis of the different country-crop combinations, it turned out that the suitability, selection and applied threshold of a similarity measure depends on the one hand the examined crop and on the other hand on the availability of reference spectra. It was proven to be essential to have a large absolute number of individual spectra as well as a good coverage of not only average crop development cycles but extreme/differing development cycles as well (e.g. heat periods in Europe, elevation levels in South America, multiple rice growing cycles in Southeast Asia).

In summary, depending on the analysed crop and available reference spectra, a different selection or combination of similarity measures turned out to be the most suitable one in order to generate crop area maps. The temporal distribution of crop cycles between different countries and regions is another important parameter influencing the quality of the resulting crop area maps.

Another factor that turned out to be an influencing parameter on the extracted reference spectra is the differing geographic distribution of individual crops and their impact. Figure 2 shows two extracted spectra of maize from the EVI index in France. The two of the three main crops grown in France are wheat and maize. Therefore, many agricultural areas in France contain a mixture of areas consisting of maize and wheat. The “pure” spectrum was sampled in a department in which maize represents about 33% of the sown area with crops, wheat only 1%. The “mixed” spectrum was taken from a department in which maize is grown on 7% of the agricultural areas, whereas wheat covers around 21%. As a result of the described difference of individual crop area distributions, the mixed spectrum in this example bears a greater resemblance to a wheat spectrum. As a consequence, depending on the spectra which are used to classify maize pixels, the resulting crop area maps are containing the areas having a similar distribution of crop types.

FIGURE 8 below is showing the effect of the occurrence of different growing patterns of the same crop (rice) in different regions, in particular in Philippines and Indonesia. The spectrum from the Philippines is clearly showing two crop cycles whereas the spectrum from Indonesia is showing a smoother EVI curve. The latter is either the result of a single crop cycle or the overlap of many different growing patterns of rice inside the extracted pixels. Therefore, the accuracy of the resulting crop area maps is also influenced by the time period which is used in the CVA. Time periods of interest can be approximated by existing crop calendars of the individual countries, but especially in areas with multiple overlapping seasons of the same crop (as it is the case for rice in Southeast Asia), the actual growing cycles of the rice are not necessarily correlating with the theoretical crop calendars.

[1] Weyermann et al. (2009): Spectral Angle Mapper (SAM) for anisotropy class indexing in imaging spectrometry data. Proc. SPIE 7457, Imaging Spectrometry XIV. DOI: 10.1117/12.825991.
[2] Du et al. (2004): New hyperspectral discrimination measure for spectral characterization. Opt. Eng. 43(8). DOI: 10.1117/1.1766301.
[3] Carvalho Júnior et al. (2011): A New Approach to Change Vector Analysis Using Distance and Similarity Measures. Remote Sensing 3(11). DOI: 10.3390/rs3112473.
[4] Deborah et al. (2015): A Comprehensive Evaluation of Spectral DistanceFunctions and Metrics for HyperspectralImage Processing. Remote Sensing 8(6). DOI: 10.1109/JSTARS.2015.2403257.

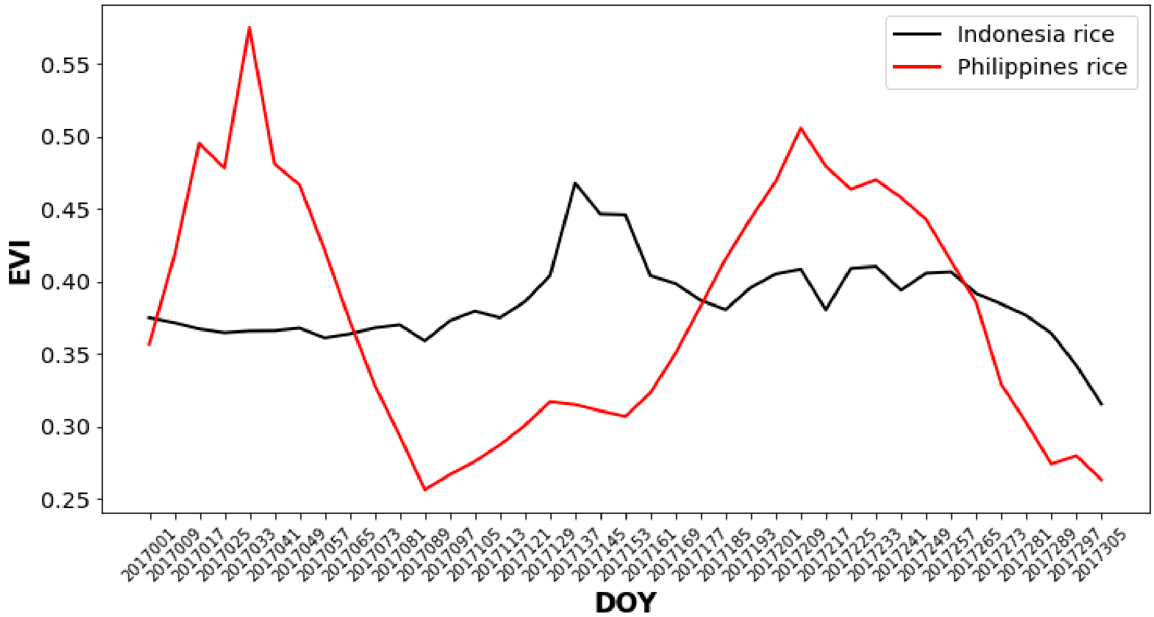


FIGURE 8 *Rice spectra from Indonesia and Philippines 2017 (Indonesia: South Kalimantan province, Philippines: Nueva Ecija province)*

In summary, when acquiring reference spectra, one must consider the actual distribution of different crops not only inside the analysed geographical unit from which the reference spectra are extracted but also inside the geographical unit in which the crop area maps shall be generated.

Another point to be considered is the occurrence of multiple seasons for the same crop, which limits the transferability of reference spectra from one country to another and data is not always available.

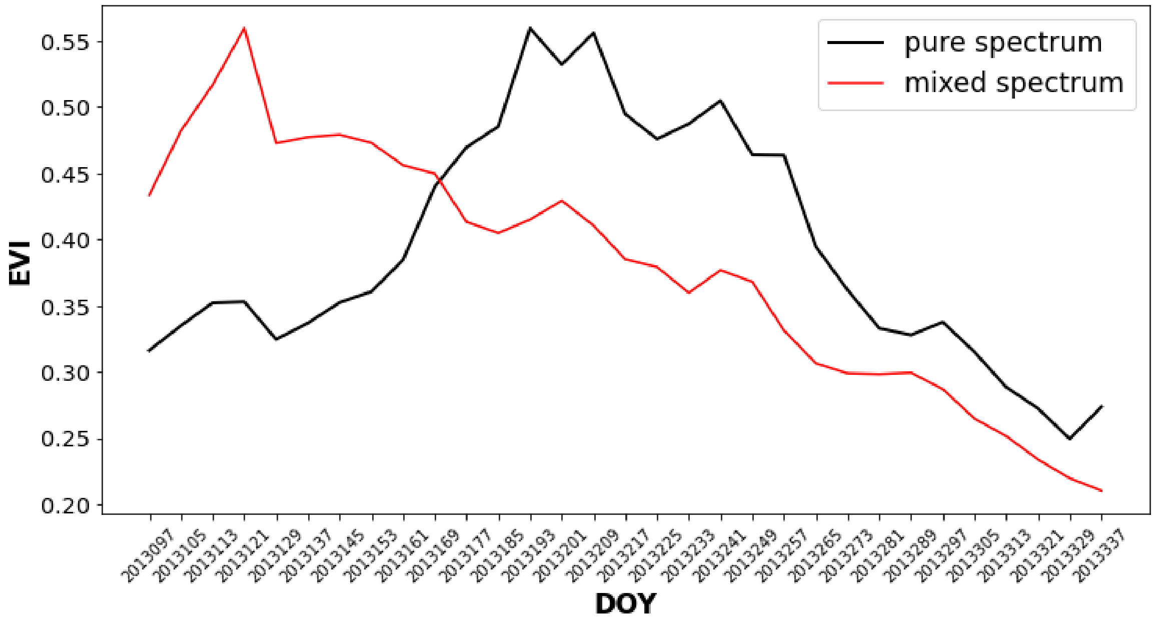


FIGURE 9 *Pure and mixed spectra of maize in France 2013 (pure spectrum: department Landes; mixed spectrum: department Loiret)*

The transferability of spectra between neighbouring countries is also important to consider but it is not only limited by the general distribution of crops and the linked extraction of spectra but also caused by differences of altitudes at which the crop is grown. This is a challenge particularly for maize classification in South America where elevation patterns strongly vary between and inside individual countries.

At last, to achieve the goal of continuous time series from different indicators, one should consider the availability of valid pixel values for a certain place and time. Within this work package it was intended to review the number of valid pixels for each country to eventually assess the quality and usability of derived time series.

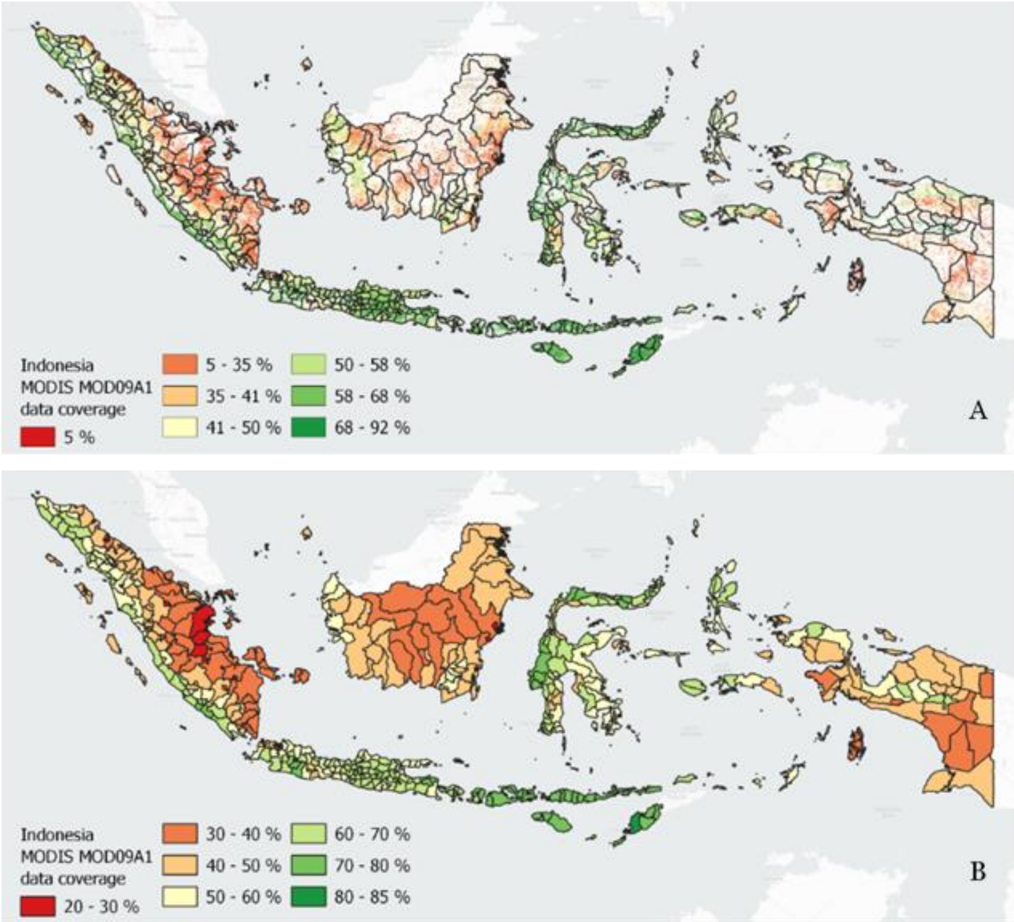


FIGURE 10 *Coverage of Satellite imagery in Indonesia. A) at pixel level and B) averaged at administrative level.*

FIGURE 10 above is example of the assessment carried out for all countries at the lowest possible administrative level. For this examination, all MODIS data for all years were examined at pixel level, valid pixels were counted and finally divided by the overall number of satellite data acquisitions (FIGURE 10, A). The result was then averaged on the lowest administrative level (FIGURE 10, B). As expected, the results show the relatively low amount of data coverage in some areas of Indonesia, Malaysia and Thailand. All other countries are covered with a minimum of 40% (e.g. Peru) or even 60% (e.g. France). Additionally, a time-relevant perspective is necessary: for France most of the cloud coverage is during the off-season and therefore not relevant for crop detection. Since countries like Indonesia show several (and overlapping) crop seasons during a year, cloud coverage in optical data is very relevant and must be taken into account when classifying crop patterns using only optical satellite data. Alternatives are RADAR satellite data, which will not (or only in exceptional cases with very thick and high clouds) be influenced by cloud occurrence. Especially for field-based crop classification approaches, this data type must be part of the implementation in selected areas.

All above data files are part of the deliveries of the project (see Chapter 4 below).

3.3 WP2 – Crop health indicators and data delivery

Secondly, several crop health indicators are provided in the deliveries summarised in Technical Note 1, with a 10day frequency across all mapped areas and crops. The indicators have been selected thoroughly in terms of simplicity and update frequency. As a result, all of indicators are available on a daily basis and the majority of indicators are updated daily (some in a 10day frequency) but all of them are available since 2007 and therefore present a comprehensive and consistent base for further investigations. All parameters are based on global data sets making them comparable between countries and through time.

The time series of parameters were extracted based on the GlobCover product and scaled up based on an additional globally available land use data set. The "Spatial Production Allocation Model" (SPAM[1]) provides raster-based information about the coverage of selected crop types with a pixel size of 10 by 10 km based on the year 2010 (see an example in FIGURE 11. below for rice areas and size in South East Asia according to the SPAM data set from 2010).

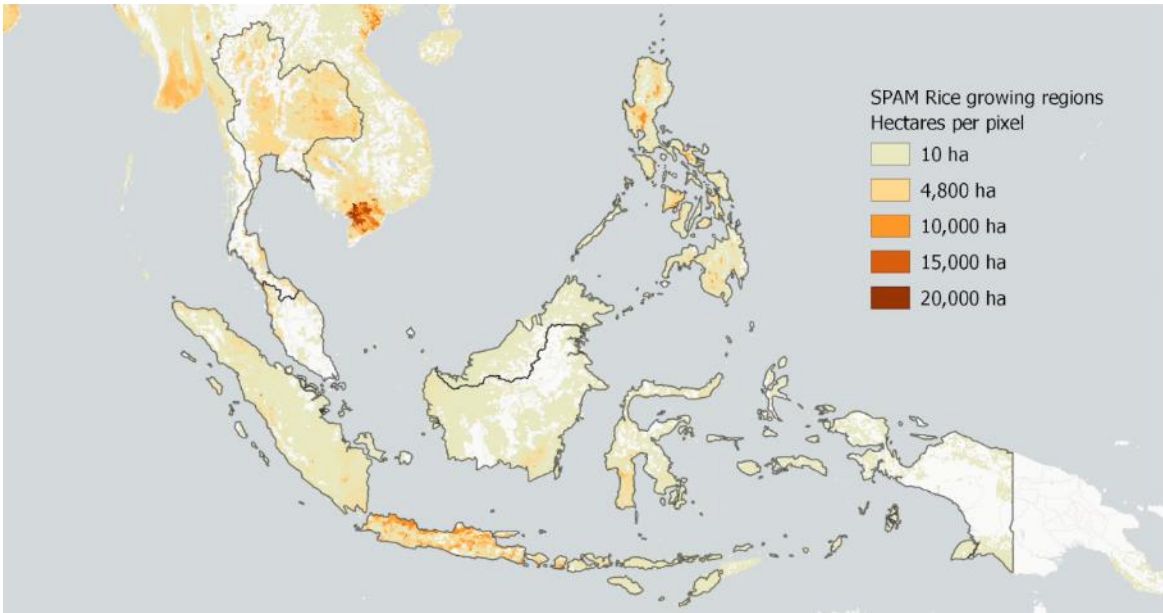
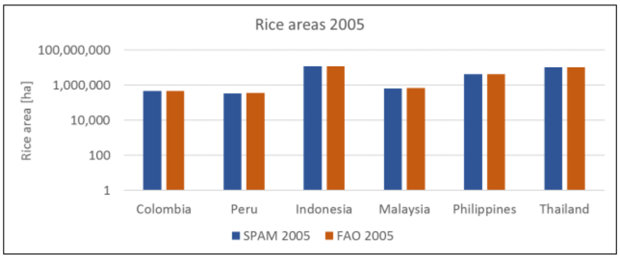
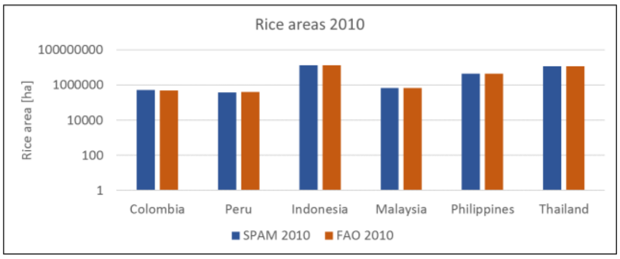


FIGURE 11 *Rice areas and size in South East Asia according to the SPAM data set from 2010*

Despite the coarse resolution, the data set is globally available with a reported good quality (see FIGURE 11 above) and therefore valuable for this application. Statistical values at country scale, calculated for different years and crop types -shown in FIGURE 12 for rice and maize - in the countries of the RFP confirm the good quality.





[1] https://www.mapspam.info/about/

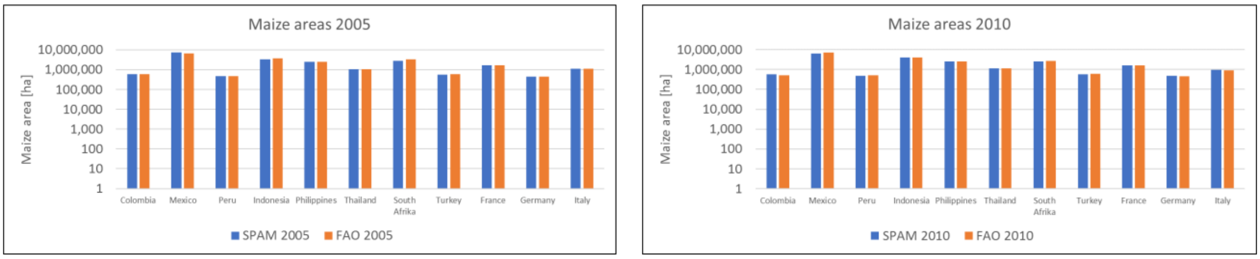


FIGURE 12 *Rice (above) and Maize (below) area at country level from SPAM (left: 2005, right: 2010) in comparison to FAO statistics. Logarithmic scale.*

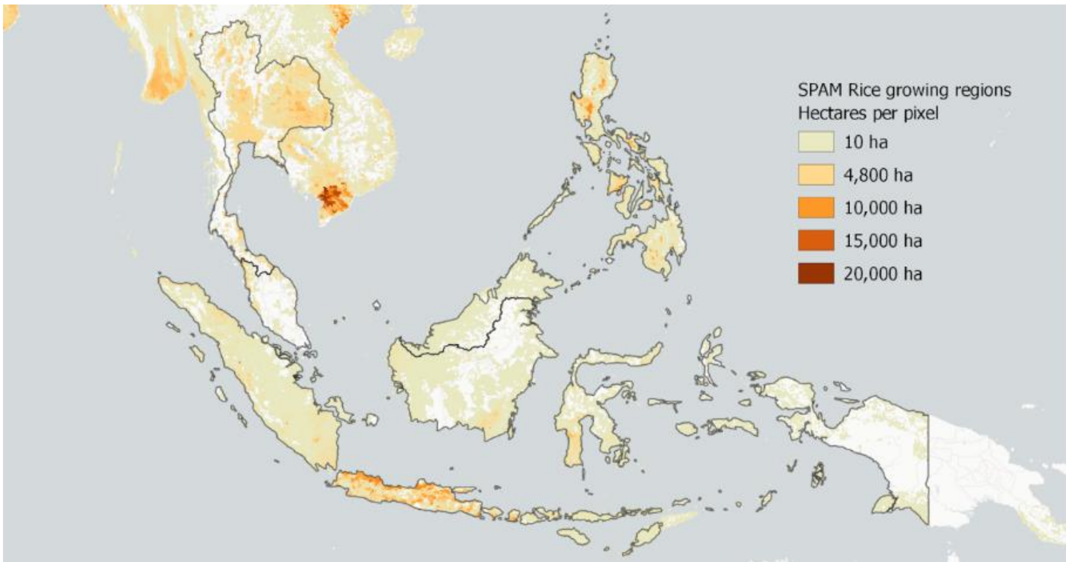
Data for all parameters were downloaded and processed into a consistent and standardized form. Processing include changing the data type (e.g. climate files in grib-format into geographically positioned GeoTiff files), extracting the required values (e.g. extracting precipitation of a set of hundreds of climate variables within each of the grib files, selecting cloud free pixels with satellite observations) and a re-projecting them into globally usable WGS84 projection (if needed). An overview of the amount of data used in this project is given in TABLE 7.

Data type	Number of files processed for monitoring
SWI - Soil Water Index	> 4,900 files
Air temperature / Precipitation	> 10,000 files
Global Vegetation Health Products	> 2,000 files
Leaf Area Index	> 95,000 files

TABLE 7. *Number of files processed for monitoring during the project*

All parameters were extracted and averaged on the lowest possible administrative unit of a country and only on cropland using the GlobCover data set. The upscaling of these values towards country level was done using the crop coverage values of the SPAM data set.

The "Spatial Production Allocation Model" (SPAM[1]) provides raster-based information about the coverage of selected crop types with a pixel size of 10 by 10 km based on the year 2010 (see an example in FIGURE 13 below for rice areas and size in South East Asia according to the SPAM data set from 2010).



[1] https://www.mapspam.info/about/

FIGURE 13 *Rice areas and size in South East Asia according to the SPAM data set from 2010*

This procedure ensures that administrative units with a high value of crop area are given a higher weight in the upscaling process than units with less or no area of the corresponding crop.

The proposal to this RFP suggested the use of a web application (CROPTIFY) for visualization, data download and interpretation of the results. Following the requirements, the application was adapted to fulfil the needs of the RFP by implementing the following options:

- PDF download of diagrams and raw data download for all parameters
- Introducing maize and rice as crops
- Covering all required countries

To indicate the potential of such a global available indicator summary and visualization for further use in combination with e.g. data on food prices or questions of food security, several examples are given in the following sections.

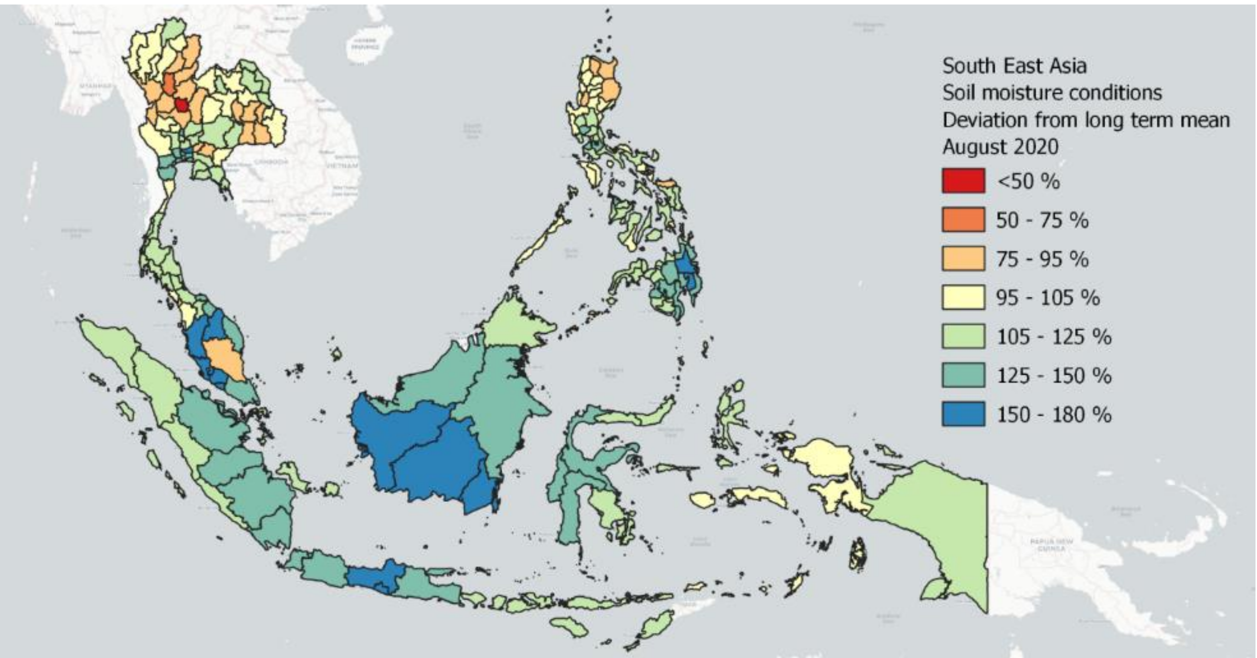


FIGURE 14 *Soil moisture conditions for rice growing regions as deviations from long-term average in South East Asia for August 2020.*

FIGURE 14 above shows the condition of soil moisture in South East Asia in August 2020 as a deviation of long-term average. The differences in the first administrative unit below the nation unit are clearly visible and indicate good conditions in most of the Indonesian rice growing regions, moderate conditions in Malaysia and diverse conditions in Thailand. Especially, the situation in the mainland of Thailand coincides with the official news from the region from April to May 2020 (Global Drought Observatory Analytical Report[1] from JRC), which indicated a higher risk of drought for the region due to a lack of precipitation and a poor start of the monsoon 2020.

FIGURE 15 below goes a little deeper and compares two regions in Thailand by daily values. The diagram shows a clear distinction between a normal year for the southern part of the country and a start of a dry situation in the northern part. A less-than-normal SWI is visible with the start of 2020 which shows very good the potential of a continuous monitoring for early warning applications.

[1] http://edo.jrc.ec.europa.eu/gdo

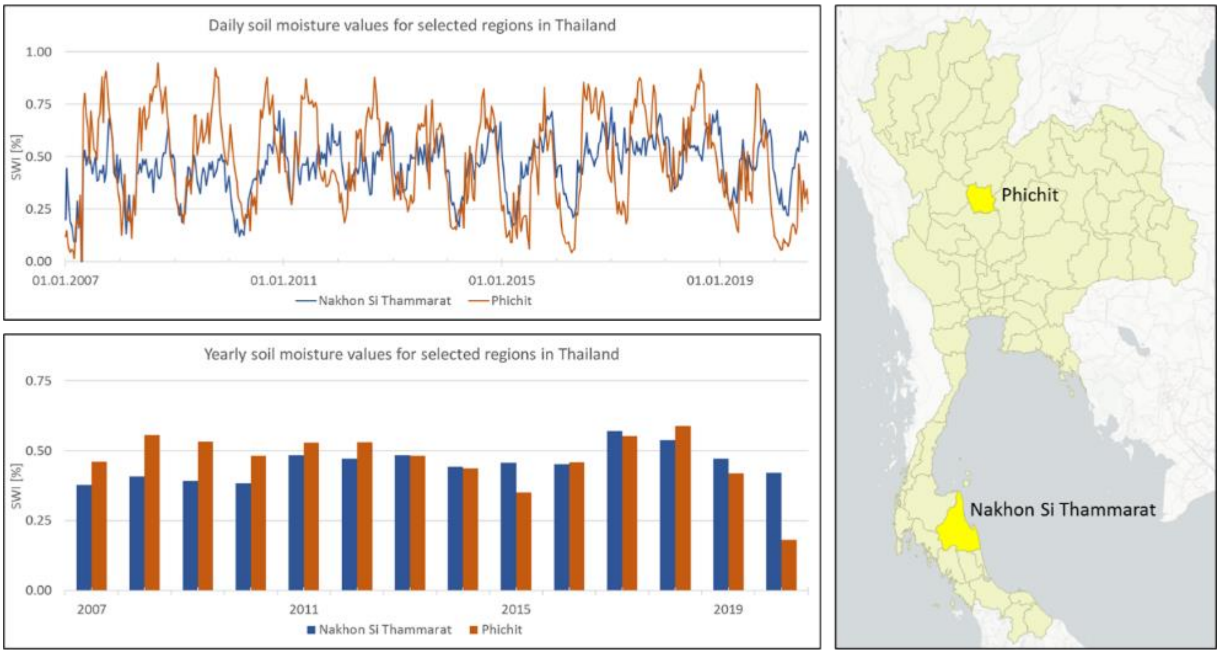


FIGURE 15 *Daily soil moisture for two regions in Thailand.*

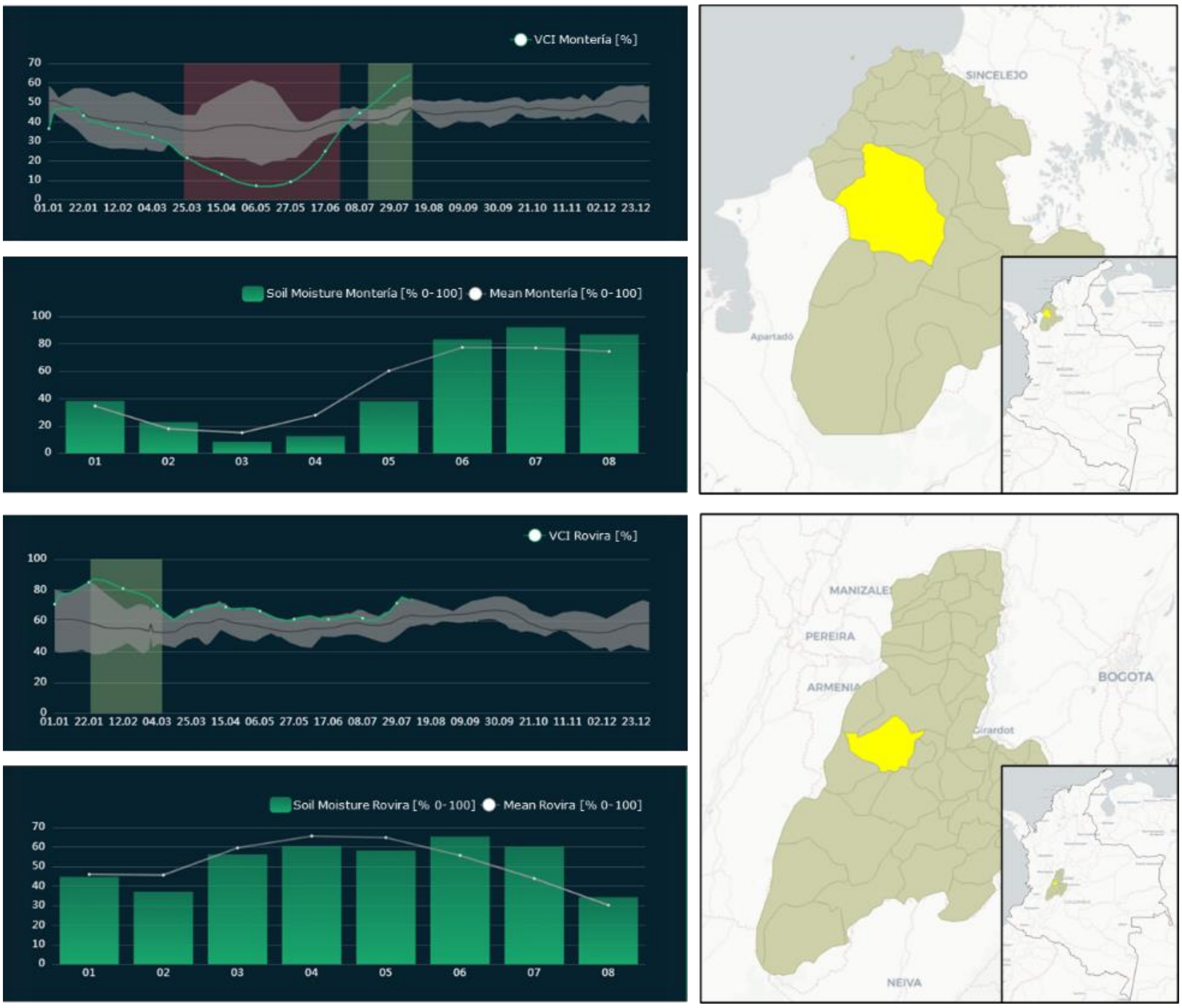


FIGURE 16 *The vegetation condition index in two maize growing provinces of Colombia for 2020. Diagrams were taken directly from the web application.*

FIGURE 16 above shows the vegetation condition index for two maize growing provinces in Colombia for 2020 with a clear decline of the index in March - June in the norther Caribbean part of the country. This coincides with official news from FAO GIEWS[1] (Global Information and Early Warning System, reference date: 15-July-2020) referring to dry weather conditions and high temperatures during planting and crop development stages (e.g. in Montería). At the same time, the report neutralized the negative effects on nation-wide maize harvest based on the favourable conditions in the producing areas of Central Andean (e.g. in Rovira) and the Llanos. Again, the continuous monitoring allows for

- an early recognition not optimal conditions of crop development,
- an estimation of the duration of the corresponding conditions and
- a nation-wide classification of the situation.

The potential of such a global continuous monitoring can be summaries into

- early detection and regional assessment of possible non-optimal plant-relevant growth conditions
- assessment of a duration of non-optimal growth conditions and effects on food security in the region
- usage of indicators as input data for further investigations in a combination with e.g. food prices, future climate models or for the implementation and control of regional supportive activities to counteract negative climate impacts.

Additionally, main growing areas of individual crops do not show considerable variations between single years due to climatic and environmental conditions. FIGURE 17 shows the differences between three years of rice growing areas in Indonesia, indicating the essential parts of growing areas (three years of rice growing) in black.

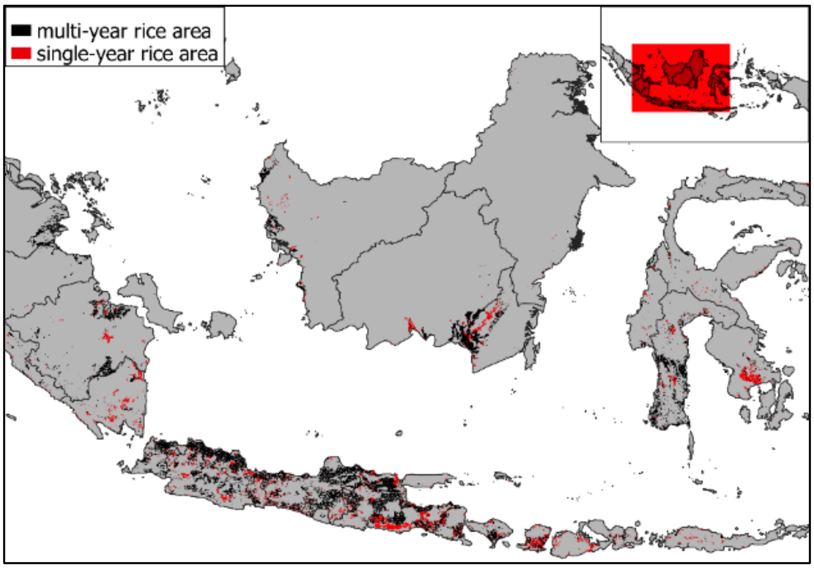


FIGURE 17 Differences in rice growing areas in Indonesia between 3 years (2009, 2011, 2017). Black areas indicate the main growing areas where rice is grown in all three years. Red areas indicate areas where rice is growing only in one of the three years.

To improve the situation, additional data sets can improve the overall capability of the system towards a comprehensive tool covering land and water related aspects of crop growth conditions. Such data sets can be related to water (e.g. evapotranspiration, soil water depletion, evaporative stress, drought indicators -see work package 3 below-), land related (e.g. soil types as static parameter, changes in land use) or price related (e.g. estimation of crop area, yield and production for all administrative units, visualization and incorporation of world market prices).

The present activity has laid a foundation for further processing and enhancement of a global monitoring system. Examples of some of the mentioned enhancements are already part of the web application (CROPTIFY)

[1] http://www.fao.org/giews/countrybrief/country.jsp?code=COL

for wheat: continuous forecasting of wheat area, yield and production, stock exchange prices and comparison with official estimations).

3.4 WP3 – Datasets assessment and case studies

As mentioned before, besides the immediate crop production measurement data, there are a number of auxiliary resources with regard to environmental, climate, or soil conditions, which are closely related to agricultural performance. The main advantage of such data lies in a long tradition of collection, thus wide time-span and diversity of choice.

This data can improve the understanding of agriculture in countries and their crop production. To be more specific, there are different levels of vulnerability of the national agro-sector towards both actual/short-term extreme climate-related events (such as drought) and long-term climate change.

The data sources in TABLE 8 below have been considered as providers of potentially valuable data to support analyses and results from WP1 and WP2 of this project. They are comprehensively described in the following chapters along with identification of considerable datasets.

Climate Data Store run by Copernicus Climate Change Service	https://cds.climate.copernicus.eu/
GloFAS - The Global Flood Awareness System as a part of the Copernicus Emergency Management Service	https://www.globalfloods.eu/
European Forest Fire Information System (EFFIS)	https://effis.jrc.ec.europa.eu/
Global Drought Observatory (GDO) as a part of the Copernicus Emergency Management Service	https://edo.jrc.ec.europa.eu/gdo
Catalogue of the European Centre for Medium-Range Weather Forecasts (ECMWF) real-time products	https://www.ecmwf.int/en/forecasts/datasets
Copernicus Global Land Service, theme Vegetation	https://land.copernicus.eu/global/
NASA Open Data Portal	https://data.nasa.gov/

TABLE 8. *Inspected supportive data sources. Source: Copernicus Climate Data Store, 2020.*

Risk of Drought Impact on Agriculture (RDrI or RDrI-Agri) is a capital product of the Global Drought Observatory (GDO), further described in above section **¡Error! No se encuentra el origen de la referencia.**. RDrI-Agri is a high-level compound product (index) made of auxiliary datasets, such as FAPAR anomaly, soil moisture anomaly and precipitation anomaly. Along with some basic socio-economic indices, it attempts to comprehensively assess the drought hazard or threat in a given region. RDrI-Agri is expressed in three levels: low, medium and high impact (FIGURE 18).

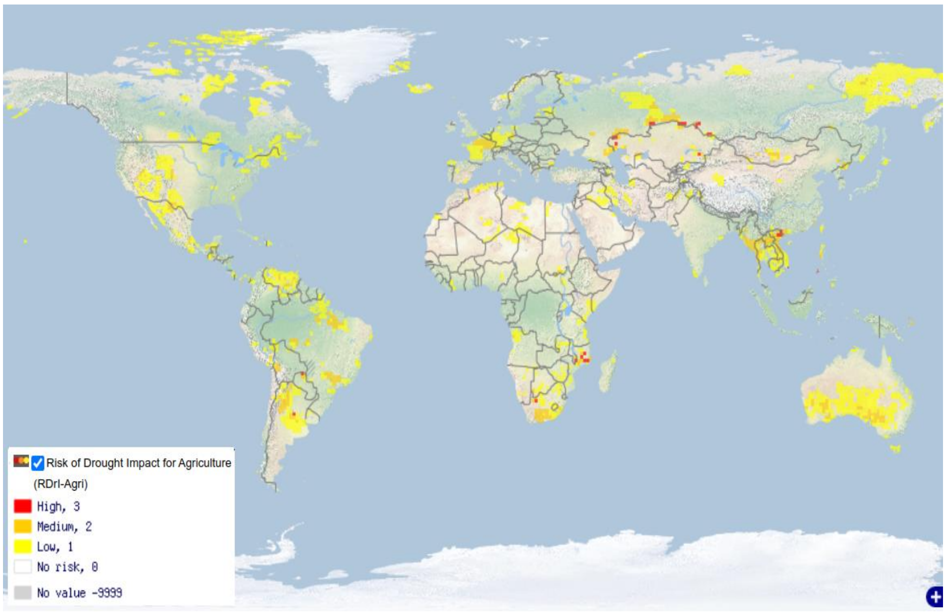


FIGURE 18 *A sample view of the global RDrI-Agri on August 11, 2020 (alternatively the 2nd third of August, 2020).*

RDrI-Agri is primarily a raster dataset that, however, cannot be easily obtained from the GDO website (as of August 2020). Downloadable RDrI-Agri time-series files (JSON or CSV file formats) are geographically associated with lower administrative units (usually but non-exclusively level-1 units) of large countries (e.g. Colombia, Philippines) or with level-0 unit (country as a whole) in case of smaller countries (e.g. Netherlands). Each file contains all dates pointing to an enumeration of recorded drought impact levels where the underlying affected area is stated. A way to download these files in batch or to download aggregated time series of large countries has not been found. This represents a complication for users who may wish to carry out spatially extensive analyses. Given its frequent update (10-day periods, respectively three times each month) but medium spatial resolution, RDrI-Agri is appropriate for large-scale crop production assessments and predictions. Technical information on the RDrI-Agri dataset is summarized in below TABLE 9.

Dataset title	Risk of Drought Impact on Agriculture
Topic	agriculture
Original Provider	Global Drought Observatory
Data language	English
Service type	service, text file dataset (not georeferenced)
Data type	raster/grid, text file
Data format	raster not available, JSON/CSV
Limitations on access and use	none
Spatial coverage	global
Spatial resolution	raster 0.1°
Temporal coverage	2013-present
Temporal resolution	10 days
Usable data/indicators	RDrI-Agri
CRS (EPSG code)	4326 (WMS)
Dataset documentation	Probably yet missing. Introductory information available in the GDO's map viewer legend at https://edo.jrc.ec.europa.eu/gdo/php/index.php?id=2001.

TABLE 9. *Technical information on the GDO RDrI-Agri dataset*

Charts with area-related RDrI-Agri time series were created for each country from the processed data. Each stacked bar represents a 10-day, x-ticks are displayed in two-month intervals for clarity. The charts also show a percentage of each country's affected area on the right y-axis. RDrI data, extracted from GDO, for all countries of interest are delivered as a CSV file.

Drought impact is further described based on the regional affiliation of countries of interest.

- Risk of Drought Impact on Agriculture (RDrI-Agri) in the selected countries of the Latin American region (LAC).
- Risk of Drought Impact on Agriculture (RDrI-Agri) in the selected countries of the Southeast Asian region (SEA).
- Risk of Drought Impact on Agriculture (RDrI-Agri) in the selected countries of the European Economic Area (EEA).
- Risk of Drought Impact on Agriculture (RDrI-Agri) in the remaining selected countries (South Africa, Turkey).

Because the RDrI-Agri information is exclusively based on in-situ anomalies, we should understand that the charts always refer to the drought assessment relative to the displayed country and not to the global situation. It must be noted that the underlying environmental conditions that lead to a given impact risk level may (and often will) differ from region to region. High temperatures and lack of precipitation can signify high risk of impact on agriculture in Germany while the same conditions are within tolerance in Spain. Even when the charts in the previous section always show the percentage of the country's affected area, there is more to comparing particular bars (within or cross-country) as these are cumulative. If we are to quantitatively express the total drought impact, we should assign weights to different RDrI levels before summing the related areas.

This Technical note presented the RDrI time series by territorial units. This is originated from the fact that the only publicly accessible form of data at the time of the creation of the document were the time-series text files. The user is, nevertheless, encouraged to perceive data as a set of continuous mosaics of RDrI-assigned pixels (rasters). The data can be thus associated to an arbitrary areal unit, the corresponding value will, nevertheless, not overcome the resolution of the raster (0.1° latitude/longitude).

In conclusion, the RDrI dataset is an expertly created high-level indicator and with its wide time span, it can be used in a variety of assessments and predictions. The usability is yet limited by lack of available data forms and complicated acquisition and requires an improvement on the side of the provider or a custom agreement. With the raster time series, it will be possible to extend Greenspin's Croptify web application (described in TN1 of this project).

Indonesia and Thailand both lie in Southeast Asia within tropical, tropical monsoon and savanna climatic zones (Af, Am, Aw according to Köppen classification). While Indonesia is extended in the east-west direction around the equator, roughly between 5° northern and 10° southern latitude, Thailand spans almost perpendicularly, north-south, between 20 and 6° northern latitude. Rice is the primary agricultural crop in both countries. In Thailand, it is mainly produced in the Chao Phraya River basin and the Khorat Plateau, in Indonesia mostly on the islands of Java, Bali and Sumatra, however here the percentage of cultivated land is much lower.

The aim of this work package is to showcase an assessment with the data gathered to support qualitative interpretation of outputs of TN1 (resulting from WP1 and WP2) for both countries in the view of rice production. Along with the general assessment of the data from TN1, Risk of Drought Impact on Agriculture (RDrI) and several agro indicators are further put into context of historic natural events.

It is important to note that the data gathered in TN1 with the one gathered in this WP3 are <u>still inconsistent in terms of time spans</u>, which prevent more elaborated assessments within the short duration of this project (6 weeks). In both case studies for Indonesia and Thailand respectively, indices can behave differently and point to various area-specific phenomena, while not being strongly correlated to real rice production and yield. Once the region related crop yield and production data and masks are available in longer time series, the analyses could return much more convincing results. <u>It would be thus worth diving more deeply into both datasets' theoretical bases and practical implications of decision making based on them</u>.

4 DELIVERIES

Outcomes from above two work packages are delivered as technical notes and as separate files with the data. In addition, the web application (https://app.greenspin.de) is available including continuous updates until the end of 31st October 2020.

The folders delivered contain the following files:

a) From WP1 and WP2
   - Technical note 1 containing the explanatory results of WP1 and WP2
   - Files
     - **10day_statistics**: EXCEL-files separated by crop types and parameters. The files contain a description of the content and the values for each administrative unit. A number system was introduced to distinguish between different countries and different administrative levels (id_0 for country specific numbers, id_1 for state specific numbers, id_2 for district specific numbers and id_3 for provinces). Further explanations and examples are given in each of the EXCEL files.
     - **cropClassifications**: all raster maps described in the report are delivered as GeoTIFF in this folder. The naming of the files indicate the country and the year of the classification.
     - **coverages**: per pixel coverage of usable and cloud pixel per country delivered as GeoTIFF files, and summaries of coverages as vector-shape files averaged within the lowest possible administrative unit of a country
       - GEOTIFF: *per pixel coverage of usable and cloud pixel per country and year*, band 1 indicating number of cloudy pixel during a year, band 2 indicating the number of usable pixel. The name of the file -e.g. *5_lev0_2013_coverage_evi .tif*- indicating the country ID, level 0 to show country level was processed and "evi" as used satellite-based indicator.
       - GEOJSON: vector file -e.g. *statistics_yes_no.geojson- averaging the pixel values into administrative boundaries* of the country. In the attribute table, the attribute "avg_yes" show the average number of usable pixel whereas "avg_no" indicate the average number of cloudy pixel in this administrative unit during a year.
       - GEOTIFF: *per pixel coverage of usable and cloud pixel per countryfor all years summarized* (e.g. *statistics_yes_no.tif*). In this file, band 1 indicate the average of usable (cloud-free) pixel during all years and band 2 show the average number of cloudy pixel during all years.
     - **official_area_statistics** : EXCEL files with official statistics gathered from national statistic authorities from each country. Sorted by crop type and IDs

Country	ID-0 in the files	Country	ID-0 in the files	Country	ID-0 in the files
Colombia	35	Philippines	40	Germany	0
Mexico	37	Thailand	41	Netherlands	11
Peru	39	South Africa	42	Italy	13
Indonesia	36	Turkey	30	Spain	4
Malaysia	38	France	2	Poland	2

b) From WP3
   - Technical Note 2 containing the results of WP3
   - CSV file: containing table with Risk of Drought Impact on Agriculture (RDrI-Agri) indicator that was processed for all the project countries
   - The Python source code for processing and work with RDrI-Agri index that was used during the project.

c) From WP4
   - Final Report: this document compiling the objectives and achievements of the Project together with the conclusions and findings. It presents how to support a larger service over other regions, countries and indicators. The potential of the methodology applied during the project is described, but also its limitations, for EFNLT and other stakeholders to be aware of the working flow and it's potential.

5 SUMMARY AND FUTURE ACTIONS

Monitoring global vegetation growth, growing conditions and crop status for the most important crop types and across countries is highly valuable information for the financial sector (including commodity trading) and policy makers of countries and in international institutions. Using up-to-date objective information for crop health will be an enhancement for sovereign environmental, social and governance data.

The World Bank launched the Sovereign ESG Data Portal in October 2019, a free and easy to use online platform that provides users with environmental, social and governance data. In the environment group some agricultural related indicators are already available, like share of agricultural land and share of GDP. The ESG data portal as part of the World Bank's Global Program on Sustainability (GPS) aims to provide policy makers and the financial sector with the necessary metrics. In this context, gaps are identified concerning to agricultural crop health and status information regarding granularity and frequency of data. Consequently, the need for cross-country consistent data, which is available long-term and over large areas is clearly visible.

The European Space Agency, through the EO-Clinic Frame contract launched this small work order, requested by the World Bank Group (WBG) – EFNLT, with the main initial objective to provide crop health indicators for selected countries on crop type maps generated for various crop types. It is intended to demonstrate the great potential use of EO data as an added value to the ESG data portal to improve the situation and provide a source of valuable information.

After the project kick-off, we expect World Bank Group to continuously stay in contact with the project consortium, especially after first deliveries are published in CROPTIFY. This will support further common developments and lead to a higher acceptance of stakeholders after the end of the project. In particular, the support may be needed to receive assistance from World Bank Group in case we have more in-depth questions about the type and intensity of integrating the results into the ESG Portal.

If this RFP is successful, it is very likely that the developed methodology may be of interest to be improved and completed, may be applied to additional countries and to measure crops at larger scale. Such information may be used for general and specifically agricultural consulting purposes at international and national levels. Continuous monitoring of crop health has great impact on an assessment of national and domestic food security issues and therefore addresses stakeholders in the agricultural sector as well as of development agencies. In addition to the already included information in the ESG data portal, crop health and long-term comparison data gives investors a more profound background and quality for their investment decisions.

In addition to international organizations such as the World Bank and the UN, the following table shows only examples of possible stakeholders and their sectors, including several countries in three continents and where many stakeholders operate only locally.

Users and Stakeholders	Sector	Website
Latin American Agribusiness Development Corporation S.A.	Investment funds	https://www.laadsa.com/
GrowAsia	Partnership platform	https://www.growasia.org/
PRO AGRO (Mexico)	Insurance companies	https://www.proagroseguros.com.mx/
SGS (Indonesia)	Traders	https://www.sgs.co.id/en/trade/commodity-trading

Table 6: Example users and stakeholders

To attract stakeholders and to increase the service acceptance and the impact of demonstration, we highly recommend to use the web-application to do a combined effort of both project presentation and visualization. This has the advantage of an immediate response and start of discussion and is clearly a success criteria. Commonly discussed new indicators can be set up and included in the processing chain and into the web-application in the future, giving potential users a greater involvement in the developing process.

APPENDIX A: REFERENCES

The following table shows references of our consortium which apply to the current RFP:

Company		
EVERIS	General cartographic repository of Unnamed Traffic Management Demostrator for SESAR JSU (DOMUS)	Spain, 2019
	Small Infrastructure Study, associated with public transport services and urban and rural terminals	Regional Government of La Araucanía, Chile, 2018
	Technological specialized consultancy about Corporative GIS of the Metropolitan Transport of Barcelona	Barcelona, Spain, 2018
	Madrid Digital, GIS applications maintenance: urban planning, official street name, property and real estate valuation system	Madrid, Spain, 2018
	Framework GIS of Autonomous Community of Madrid	Madrid, Spain, 2018
	Spatial Data Infrastructure (IDE) of the Spanish Directorate General of Cadastre of National Institute of Statistics	Madrid, Spain, 2018
GREENSPIN GmbH	Land cover and agricultural land use mapping	Project: Sustainable management of land and water resources in Uzbekistan (https://www.zef.de/khorezm.html) Project: Regional Research Network 'Central Asian Water' (CAWa; https://www.cawa-project.net/)
	Grassland mapping in northern Germany	Chamber of Agriculture, Schleswig-Holstein, Germany
	Mapping of large-scale agricultural land use	Bavarian State Ministry for Food, Agriculture and Forestry
	Mapping of large-scale agricultural land use and agricultural activities	Chamber of Agriculture, North Rhine-Westphalia, Germany
	Automated crop mapping and monitoring for industrial and institutional customers based on machine learning	Proprietory web application by GREENSPIN: https://app.greenspin.de/app
	Agricultural time-series analysis	Project: Data fusion of Sentinel time-series for agricultural monitoring (Techs4Times; https://bit.ly/2ZiLd6P) Project: German contribution to global agricultural monitoring (GLAM.DE; https://bit.ly/2EVIjga)
	Note: Publications of the key personnel involved in the execution of the work can be found in Appendix B	N/A

WORLD FROM SPACE	DynaCROP - ready-to-use satellite API for agricultural applications & AI	proprietary SaaS product, 2020 https://dynacrop.world-fromspace.cz/
	Crop damage assessment after hail storm for insurance company	2019
	Analysis of urban vegetation dynamics and green areas	different projects in Prague, Brno, SLavkov and Pilsen Czech Republic , 2018, 2019
	Urban heat island methodology	Prague, 2019
	Vegetation detection and classification	Liberty Steel, 2019
	Copernicus data and services consulting	Alpha Consult, 2019-2020

Table 7. References

APPENDIX B: BIBLIOGRAPHY

Publications of the key personnel involved in the execution of the work:

Conrad, C., Dech, S., Dubovyk, O., Fritsch, S., Klein, D., Löw, F., Schorcht, G., u. a. (2014). Derivation of temporal win-dows for accurate crop discrimination in heterogeneous croplands of Uzbekistan using multitemporal RapidEye images. Computers and Electronics in Agriculture, 103, 63 – 74.

Fritsch, S., Machwitz, M., Ehammer, A., Conrad, C., & Dech, S. (2012). Validation of the collection 5 MODIS FPAR product in a heterogeneous agricultural landscape in arid Uzbekistan using multitemporal RapidEye imagery. International Journal of Remote Sensing, 33(21), 6818-6837.

Conrad, C., Fritsch, S., Zeidler, J., Rücker, G., & Dech, S. (2010). Per-Field Irrigated Crop Classification in Arid Central Asia Using SPOT and ASTER Data. Remote Sensing, 2(4), 1035-1056.

Fritsch, S., Conrad, C., & Dürbeck, T. (2015). Mapping marginal land in Khorezm using GIS and remote sensing tech-niques. In J. P. A. Lamers, Khamzina, A., Rudenko, I., & PLG, V. (Hrsg.), Restructuring land allocation, water use and agricultural value chains Technologies, policies and practices for the lower Amudarya region (S. 167-178). Göttingen: Vandenhoeck & Ruprecht. Abgerufen von http://public.eblib.com/choice/PublicFullRecord.aspx?p=1939223

Dahms, T., Lex, S., Zellner, P., Fritsch, S., Schmidt, M., & Conrad, C. (2015). Techs4Times – innovative techniques for the generation and evaluation of Sentinel time series. DLR-SentinelWorkshop – Nutzung der Sentinels und nationalen Erdbeobachtungs-Missionen.

Schorcht, G., Löw, F., Fritsch, S., & Conrad, C. (2012). Crop classification at subfield level using RapidEye time series and graph theory algorithms. In Proceedings of SPIE Remote Sensing 8538, Remote Sensing for Agriculture, Ecosystems, and Hydrology XIV, 85311G (October 19, 2012); doi:10.1117/12.974670.

Conrad, C., Machwitz, M., Schorcht, G., Löw, F., Fritsch, S., & Dech, S. (2011). Potentials of RapidEye time series for improved classification of crop rotations in heterogeneous agricultural landscapes: Experiences from irriga-tion systems in Central Asia. In Proceedings of SPIE Remote Sensing, 19.-22. Sep. 2011. Prague, Czech Re-public: ISBN: 9780819488015.

Fritsch, S., Machwitz, M., Conrad, C., & Dech, S. (2011). Relationships between high resolution RapidEye based fPAR and MODIS vegetation indices in a heterogeneous agricultural region. In Proceedings of ZPIE Remote Sens-ing, 19.-22. Sep. 2011. Prague, Czech Republic: ISBN: 9780819488015.

Ehammer, A., Fritsch, S., Conrad, C., & Dech, S. W. (2010). Statistical derivation of fPAR and LAI for irrigated cotton and rice in arid Uzbekistan by combining multi-temporal RapidEye data and ground measurements. In Re-mote Sensing for Agriculture, Ecosystems, and Hydrology XII (Bd. 7824, S. 1-10). SPIE remote sensing sym-posium 2010, 20. – 23. September, Toulouse.

APPENDIX C: LIST OF ACRONYMS

Acronym	Meaning
BIC	Business Incubation Centre
CD	Chebyshev Distance
CDS	Climate Data Store
CVA	Change-Vector Analysis
DOY	Day Of Year
ED	Euclidian Distance
EEA	European Economic Area
EFNLT	Long-term Finance Team
EO	Earth Observation
ESA	European Space Agency
ESG	sovereign-level Environmental, Social and Governance (ESG) data
EVI	Enhanced Vegetation Index
FAO	Food and Agricultural Organisation
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GDO	Global Drought Observatory
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Program on Sustainability
HTML	HyperText Markup Language
KoM	Kick off meeting
LAC	Latin America and the Caribbean
LAI	Leaf Area Index
OLCI	Ocean and Land Colour Instrument
PDF	Portable Document Format
RDrI	Risk of Drought Impact on Agriculture
RFP	Request for Proposal
SAM	Spectral Angle Mapper
SCM	Spectral Correlation Mapper
SEA	South-East Asia
SID	Spectral Information Divergence
SPAM	Spatial Production Allocation Model
URL	Uniform Resource Locator
WBG	World Bank Group
WFP	World Food Programme
WfS	World From Space
WO	Work Order
WOR	Work Order Report
WP	Work Package

Table 8. List of Acronyms

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