An integrated service-based solution addressing the modernised common agriculture policy regulations and environmental perspectives

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Katerina Karagiannopoulou
Institute of Communication and Computer Systems

Georgios Tsimiklis
Institute of Communication and Computer Systems

Athanasia Tsertou
Institute of Communication and Computer Systems

Angelos Amditis
National Technical University of Athens

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An Integrated service-based solution addressing the Modernised Common Agricultural Policy regulations and environmental perspectives

Aikaterini Karagiannopoulou*[a], Chrysovalantis Tsiakos[a], Georgios Tsimiklis[a], Athanasia Tsertou[a], Angelos Amditis[a], Grega Milcinski[b], Nejc Vesel[b], Dragutin Protic[c], Milan Kilibarda[c], Nikolaos Tsakiridis[d], Apostolos Chondronasios[e]

[a]Institute of Communication and Computer Systems. 9, Iroon Politechniou Str. Zografou, Athens Greece, 30-210-772-3865

[b] Sinergise. 29, Cvetkova, Ljubljana, Slovenia, 386-1-320-6150

[c]GiLab. 54 Veljka Dugoševića, Belgrade, Serbia, 381-64-229-7527

[d]Interbalkan Environment Center. 18 Loutron Str., Lagadas, Thessaloniki, Greece, 30-239-402-3485

[e]Core Innovation and Technology. 85 Kallirois Str., Athens, Greece, 30-210-924-6730

ABSTRACT

The EU-funded DIONE project (grant agreement No. 870378) offers an innovative close-to-market (TRL7) solution seeking to improve the traditional methods of agricultural monitoring. The project introduces a cloud-based Software as a Service (SaaS) system architecture, building on a fusion of novel technologies that will support the forthcoming needs of the modernized Common Agriculture Policy (CAP) and the "Greening" perspectives, with an automated area-based monitoring system. In particular, an interoperable and harmonized system is designed, connecting large volumes of Earth Observation data (Satellite, UAV, and in-situ) and user-generated highly precise geolocated data (geo-tagged photos, soil measurements, etc.). DIONE's system architecture encompasses customized and third-party frameworks, where heterogeneous and multi-source data are stored, processed and managed using Artificial Intelligence (AI) algorithms. These harmonized, curated and open accessed data are then provided as Open Geospatial Consortium (OGC)-compliant, web-service layers (WMS, WFS, and WCS). Furthermore, the proposed solution formulates a scalable, flexible, interoperable, and semantically enriched environment, taking advantage of a Spatial Data Infrastructure (SDI) framework capabilities, whilst allowing an interactive connection among different tools and components through RESTful APIs. Our approach establishes a novel, cloud-based, accurate and inexpensive agriculture monitoring solution, enabling the real-time provision of multi-source data to relevant stakeholders such as Paying Agencies, Policy Officers and Control & Certification Bodies, and other domain experts. The system architecture was formulated exploiting a co-design methodology, aiming to ensure a long-term and sustainable solution. Two large scale demonstration will take place in Lithuania and Cyprus, evaluating the system capabilities in real-life and operational conditions.

Keywords: Common Agriculture Policy, Earth Observation, Software as a Service (SaaS) platform, OGC services, RESTful API, Spatial Data Infrastructure

1. INTRODUCTION

1.1 Sustainable agricultural sector under the Common Policy Agriculture (CAP) framework

The agri-food sector has been proven as one of the most promising economic sectors in the global industry, offering more than 181.7 billion on an annual basis in Europe (1.1% European gross domestic product (GCP))[1]. The rationale of the synergetic perspective, where a local business can contribute as a key component in the big food industry, has been proven to be the cornerstone of the local economies and the main source of income for the latter[2].

*katerina.karagiannopoulou@iccs.gr; phone +30-210-772-3865; fax +30-210-772-2291; https://i-sense.iccs.gr

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Therefore, one of the major challenges that the agriculture industry has coped with during the years, is the immediate and continuous increase of the food demand, in terms of global population increase. Towards this need, a growth-oriented agriculture policy has been adopted by local authorities, during the 1960s', promoting the exploitation of non-environmental practices (e.g. conventional heavy inorganic chemical fertilizers, pesticides). This rapid agricultural growth achieves to satisfy the global food demands but as a result it sacrifices food security and produces an under stressed, non-sustainable ecosystem with the critical problems to be deforestation, soil contamination, overgrazing of rangelands, overuse of inorganic fertilizers, and eventually the looming threat of human health[3]. Mainstreaming the sustainable and environmentally resilient agricultural practices requires the development of a common strategic plan, which will prioritize the criticalities over Europe and raise awareness in environmental and societal crisis[4]. This policy will address goals and targets of major international frameworks, such as the Sendai Framework for Disaster Risk Reduction[5], the Paris Agreement on Climate Change, the New Urban agenda[6], or the United Nations Sustainable Development Goals (SDGs)[7] of 1 (poverty alleviation), 2 (food security and sustainable agriculture) and 6 (clean water and sanitation access)[8, 9].

Towards this direction, the European Union in 1962 designed the Common Agricultural Policy (CAP), with a willingness to ensure the provision of affordable and high-quality food on European markets[10, 11], support the farming productivity and thus promote the rural development[12], with respect to the environment resilience. Until now the EU has allocated "the lion's shares" (68.9% of the total CAP budget) of its annual budget to direct green payments. Each member state national or regional authority (Paying Agencies-PA) is given the jurisdiction to monitor the farmer's compliance process[11] and fairly allocate the CAP funds. Every year the EU farmers have to submit their subsidy declaration to the national Paying Agency (PA), revealing information about the precise location of all the declared agriculture fields, the crop types of the cultivated fields, the irrigation activities, and the agricultural area that is under organic farming[13]. In return, the national PAs are obliged to supervise the credibility of farmers' annual declarations. Until now, they only manage to monitor a very limited and randomly selected sample (up to 5%) of the beneficiaries by either a physical inspection, so called on-the-spot-Check (OTSC) compliance or occasionally assisted by the Very High Resolution (VHR) and High Resolution (HR) satellite images[14]. However, it has been proven that this procedure is, very expensive due to large and rugged areas that needed to be inspected, time consuming and prone to erroneous judgements, related to inspector's training maturity.

Contrariwise, in order to address the above limitations, the European Commission (EC) announced on 22 May of 2018 the Modernized architecture of CAP[15]. This revolutionized schema, is set to be applied in 2021-2027, introduces a new era in green direct payments inspection, providing reliable evidence on farmers' compliance (Pillar I of the CAP) and supporting the rural developments (Pillar II of CAP). For the first time, the Checks by Monitoring (CbM) procedure is exploited[16] accompanied with the effectiveness of the Copernicus Sentinel missions, giving a new perspective in the inspections of crops. This new controlling system aims to gradually substitute the OTSC activities, where visits to the field will only be necessary when the CbM procedure provides insufficient results of verifying compliance. Additionally, this procedure will help in reducing the time and the cost of farmers' compliance evaluation and thus, will ensure the equal distribution of CAP funds in all beneficiaries[15].

1.2 Earth Observation contribution in the modernized CAP objectives

Towards the aforementioned needs, a plethora of novel studies have been published, emphasizing in the different aspects of CAP, with the majority of them to be oriented in the crop land use/ land cover change (LULCC). Operational crop monitoring and yield forecasting activities have explored over the years, using Earth Observation (EO), optical[17] or Synthetic Aperture Radar (SAR)[18] data, with an ultimate goal to provide accurate spatio-temporal information on agriculture activities[10, 11 19, 20, 21]. In some cases, the combination of the multisource data into fused datasets, offer new findings and more accurate results[22, 23]. All the aforementioned scientific domains were enabled after the generation of the open-source Copernicus Sentinel data. A keystone example of their contribution is the European Space Agency's (ESA) Sentinel-2 Agriculture project, aiming to enhance the traditional practices in a more efficient crop type management. Furthermore, the Group on Earth Observations, Global Agricultural Monitoring (GEOGLAM) initiative increases the market transparency and improves food security by and disseminating relevant, timely, and actionable information on agricultural conditions and outlooks of production at national, regional, and global scales. According to the above challenges, a set of novelty supervised learning techniques were exploited, with the most known to be the non-parametric k-Nearest Neighbours (k-NN), Artificial Neural Network (ANN), Support Vector Machine (SVM) and the ensemble technique of Random Forest (RF). As a consequence, the examination of the crop type maps and their diachronic change (i.e. phenophase monitoring), in pixel- or object-level becomes feasible[24].

Continuing, a limited number of studies have focused on the Greening perspectives of CAP. The lack of accurate ground-truth measurements and high spatio-temporal EO data prevent the researchers from examining environmental objectives, such us the irrigation activities, the organic farming, the soil properties and the nitrogen balance in terms of land degradation risk, or the assessment of the greenhouse gas (GHG) and ammonia (NH_3) emissions. Exceptions are the studies of Paredes-Gómez et al[16], Xiang et al[25] and Alexandridis et al[26], who tried to provide accurate information about the location and the extent of irrigated areas, leveraging both satellite-based multispectral data (e.g. ASTER, SPOT-4, Landsat 7 ETM+, MODIS, and Sentinel-2A & -2B) and other ancillary data, such as cumulative precipitation measurements, and digital elevation models (DEM). Furthermore, preliminary results have been conducted for the discrimination between the organic and not-organic fields, and thus to provide a less expensive certification process[27]. Their findings were based on the assumption that the different fertilization and pest control activities would have a perceivable difference in bio-chemico-physical characteristics of the plantation growth, and thus could be measured with in-situ and remote sensing indicators. The univariate and multivariate logistic regression models achieve an overall accuracy of 86% that seems efficient for a future expansion into a generalized model. Equivalent constraints revealed also in the examination of climate resilience factors, e.g. the GHG emissions, or land and water degradation. Some preliminary analysis was conducted using Unmanned Aerial Vehicle (UAV) MSI data that estimates the nitrogen rates as an indicator of the fertilizing status, and therefore an indirect consequence in land degradation[28]. Moreover, Visible-Near-Infrared (VNIR) spectroscopic algorithms have been developed to receive improved estimations of soil properties [29, 30, 31].

However, all the reviewed technologies reveal discrepancies in the quality level that is usually established on an operational activity. Uncertainties and trade-offs with a difficulty to provide estimations for smaller parcels (<200-300m^2) increase the need of a new approach to be established. Under this background, the DIONE EU project (grant agreement No. 870378) attempts to take advantage of the already demonstrated state-of-the-art (SotA) methods on Earth Observation and automated CAP compliance, and thus enable the provision of cloud-free high-resolution datasets of crop types and of related agricultural activities (i.e. mowing, grazing, etc.) as well as their agri-environmental status. DIONE will introduce an automated platform, empowering the capabilities of Sentinel satellite data (Sentinel-1, Sentinel-2 & Sentinel-5P Tropomi) with the very high resolution datasets received from the European Commission's Data Warehouse (EC-DWH) mechanism and from drone VNIR sensors. Additionally, soil measurements sourced through Internet of things (IoT) sensors and citizen-generated geo-tagged photos of high positional accuracy and trustworthiness will be exploited to ensure a proper monitoring solution of the observed areas. As a result, even the small-parcel (<100 m^2) dominated regions will become feasible to be continuously monitored, and thus provide a more accurate and less expensive view of the farming activities. The DIONE project will expand the capabilities of the previous CAP related projects and initiatives, e.g. ReCAP, Sen4CAP and Sen2Agri, by overcoming several limitations for upscaling and marketisation, for example alleviating the cloud presence limitation and the insufficient resolution for smallholder parcels (smaller than 1ha)[32] or for more constrained non-productive Ecological Focus Areas (EFA) types.

1.3 Landscape of monitoring platforms and approaches

This project will capitalize on all the aforementioned knowledge and technological innovations in order to address some of the highest challenges of the business market in the domain of green direct payments. Adopting a similar concept, existing information and communication technologies (ICT) operations attempted to develop an end-to-end approach, in order to address the administrative burden or farmers' real needs in a more environmental manner. Our findings from the recent literature revealed a tendency of interest in two specific domains concerning the agricultural sector, with the first to be the Precision Agriculture (PA) monitoring[33, 34] and the second the automated farming management infrastructure (FMI)[35]. Typical paradigms of such operations in the first category comprise wireless sensors[36], smart IoT platforms[37] and mobile applications, seeking to develop a low-cost, low-power, and multi-functional platform, and thus to achieve the maximization of crops' productivity and the evolution of farmers' income. For example, the ModiCrop mobile app developed a cloud-oriented backend to support the accessibility of pesticide information through a three-layered deployment; comprising mobile nodes, a cloud-hosted middleware, and a cloud-hosted database server[38]. Geibel et al.[39] established an interoperable network of embedded sensors, which adapted into the standards of the OGC Sensor Web Enablement (SWE) framework. It permitted users an open access into a harmonized, interoperable, scalable infrastructure, where multitude of sensor systems and services are involved.

On the contrary, the automatic CAP compliance systems revealed fully-featured operations, facilitating a comprehensive approach, closer to the national authorities[41]. They are usually employed under domain-specific requirements, which are elicited from user-scenarios. The most representative example of such approaches is a Business-to-Business (B2B) application, initiated by Kaivosoja et al[35]. It promotes a collaborative Platform as a Service (PaaS) agriculture monitoring system, capable of integrating for multiple personas, of diverse business sectors. The main concept of this web-platform is to support multiple domains and the complete supply chain "farm to fork", with an emphasis on greenhouse management. Continuing, a usage-driven architecture design is presented in[42] in the context of the FI-WARE project, which in fact evaluates users' needs in terms of a sophisticated solution of individual software tools.

The notion of the aforementioned studies was the connection of such novel technologies e.g., the IoT big data[40], cloud computing services, into a data-driven perspective and a interoperate schema, which either address individual aspects of CAP or sometimes the synergetic interaction of them. The utilization of such technologies enabled interconnections among multiple data, and transferring this information into the real world's needs[41]. Therefore, it seems that until now the aforementioned infrastructures lack homogeneity, usability and user friendliness. Additionally, they present a limited functionality, which concludes in a very narrow aspect of the overall business process, isolating the business actors and thus, not being able to maximize the potential capabilities. Even in the most recent cases the absence of a generalized business model, which could operate in different conditions and geographic locations, and will address the needs of different business domains is still missing.

To this end, we attempt to design the system architecture of an integrated area-based direct payment monitoring toolbox, capitalizing all the novel technologies and provide a comprehensive, end-to-end solution, aiming to bridge the diverse gaps between different –but directly associated – domains. The DIONE H2020 project (grant agreement No. 870378) proposes a close-to-market green accountability toolbox, addressing the key challenges of collecting, storing, processing, managing and, visualizing a multitude of varied data in a harmonised and interoperable way, following the Open Geospatial Consortium's (OGC) standards[39, 42]. We adhere to a user-design perspective, which will gradually replace the traditional evaluation methods with the provision of customized products, fitting to different user profiles. For the first time a co-design process is initiated[43], fostering not only the CAP compliance perspective, but more importantly the provision of a continuous support to farmers, whereas ensuring the production of safe and healthy food in a way that works in harmony with the environment and not against it.

The rest of this paper is organized as follows. Section 2 briefly presents an overview of the DIONE project, mainly identifying the designed functionalities of its core components. Furthermore, we analyse the methodology with which the software architecture was developed, including details on its deployments and information flows (Section 3). In the final section (Section 4) we provide some preliminary findings and additional insights of the system usefulness. An additional future outlook illustrating the demonstration of toolbox capabilities in the two selected pilot areas (Lithuania and Cyprus), is also presented.

2. OVERVIEW OF DIONE PROJECT

The main objective of the DIONE project is to address the needs arising from the forthcoming modernized CAP regulations. A close-to-market Software as a Service (SaaS) platform is designed, offering a fusion of individual components that are stemming from the use of EO and its smart integration with novelty technologies. These technologies aim to improve the workflow of agricultural monitoring by the deduction of the related operational and computational costs, arising from the OTSC procedure. The DIONE's overall concept is illustrated in Figure 1.

The EO component addresses one of the main goals of the project, which orients in the development of an automatic chain to retrieve and process the Sentinels constellations, or even expand their capabilities with additional customized EO products. This way, we exploit Data and Information Access Services' (DIAS) storage of Copernicus data, making use of additional services such as Data Catalogue and Sentinel Hub[44]. Currently, the following DIAS platforms are available: ONDA[45], Mundi[46], CreoDIAS[47], Sobloo[48], and WEkEO[49]. These systems provide access to Copernicus Sentinel datasets through standard web services and protocols such as OpenSearch, Web Feature Services (WFS), Web Map Services (WMS), Web Coverage Service (WCS) and Catalogue Services for the Web (CSW)[50]. Through these infrastructures, DIONE has access in Copernicus satellite data which are further enriched with a variety of VHR imageries from ESA Data Warehouse (DWH) or drone flights[40]. This information introduces us to a new big data era, where the agricultural monitoring can be national-scaled and low-cost. The data fusion operation will open a completely new world, making it possible to engage complex data processing workflows in Sentinel Hub platform, which until now were possible only in cloud platforms like Google Earth Engine (GEE)[51]. The downscaled satellite images transform this knowledge into added value services for the agriculture domain, even in problematic cases, considering smallholding parcels or cloud covered areas. Thematic maps of permanent pastures, crop-type maps in terms of crop rotation CAP requirement[15], farming activities (e.g. mowing, ploughing, and grazing) and the so far neglected environmental focus areas (EFA) types (fallow land of all sizes, buffer strips, hedges, trees, etc.)[52], are estimated in high spatial and temporal accuracy.

In cases of discrepancies between the EO-generated thematic maps and farmers declarations, ground-based geo-tagged photos can be captured as a reliable source for validating farmers' crops annotations. The component pertains with the core philosophy of collaborative mapping, creating what Goodchild refers to as "citizens as sensors"[53], and thus enabling the provision of much larger sets of information[54]. As a result, citizen-sourced geo-tagged photos with high quality and trust are collected using a developed mobile application. To ensure the maximum positional and time accuracy, the Network Time Protocol (NTP) and multiple location sources, such as GNSS, Cell-ID, Wi-Fi or the more recent European Geostationary Navigation Overlay Service (EGNOS) services, are utilised. To maximise trust level, a secure light-weight digital signature scheme with the complementary metal–oxide–semiconductor (CMOS) image pattern noise algorithm[55] is exploited. To maximise user-friendly experience and thus minimise the erroneous measurements, we introduce users to Augmented Reality (AR) technology.

Additionally, we attempt to intercept the environmental impact, arising from the intense agriculture productivity with the continuous measuring soil's health related properties (organic carbon, level of erosion). In detail, we invest in low-cost sensors and novel machine learning algorithms, to first collect VNIR spectral profiles and finally transform them in soil properties. Afterwards, this information will be fused with other data streams, such as EO data from Sentinel, LULC maps, soil maps, DEMs, in order to derive regional or national-scale maps of key indicators which will monitor and evaluate the land degradation status of an area[41]. Estimations on additional agri-environmental indicators (e.g. air emissions, irrigated areas, organic farming, etc.) are also performed.

The individual components of EO and farmers' tools encapsulate their findings into two key-components, the Farmers' compliance tool (FCt) and the Environmental Performance Tool (EPt), both constructing the Green Accountability Toolbox (GAT). The first key-point is designed to automatically collect data and transform them into rule-based compliance decisions and transfer their outcomes to a dedicated web interface component. Subsequently, under the same rationale, the environmental performance tool is deployed to facilitate meaningful analysis, stepping away from static and standard environmental impact assessment approaches that have been proven to be of limited value in a fast climate-changing context[56]. To this end, all the aforementioned products and services are provided from GAT as OGC-compliant web services and offered to Global Earth Observation System of Systems (GEOSS) portal, contributing to its principle motives of global data management and sharing among stakeholders from different domains (institutes, Small and medium-sized enterprises-SMEs, etc.) in the EO realm[57]. Additionally, DIONE is formulated with the principles of producing an interoperable, reusable, scalable, multi-user system under the framework of the Spatial Data Infrastructure (SDI)[58, 59]. The integration of them in the aforementioned key-components will be described in detail, in Section 3.2.

DIONE toolbox adopts a user-centred design approach[60], where user's requirements are transformed in information technological (IT) solutions. In this context, two customer groups have been detected. The primary group of stakeholders, including the local farmers and national authorities (e.g. Paying agencies and national Ministries), whose benefits are oriented in the provision of automated digitised solutions to deal with their daily administrative burden of regulations and compliance standards, and subsequently ensure the quantitative environmental impact. The secondary group, include the control and certification bodies (CCB) and the EU citizen communities (e.g. Scientific communities, general public, etc.), who are responsible for the secure provision of quality food (e.g. organic food production). DIONE offers clear value to significantly lower inspection cost and improves overall monitoring of farmers compliancy. From the outset of the project, a generalized approach[61] is considered as a reasonable perspective in order to achieve DIONE's penetration strategy into markets, where at least 1/3 of the European stakeholders' requirements will be accomplished.

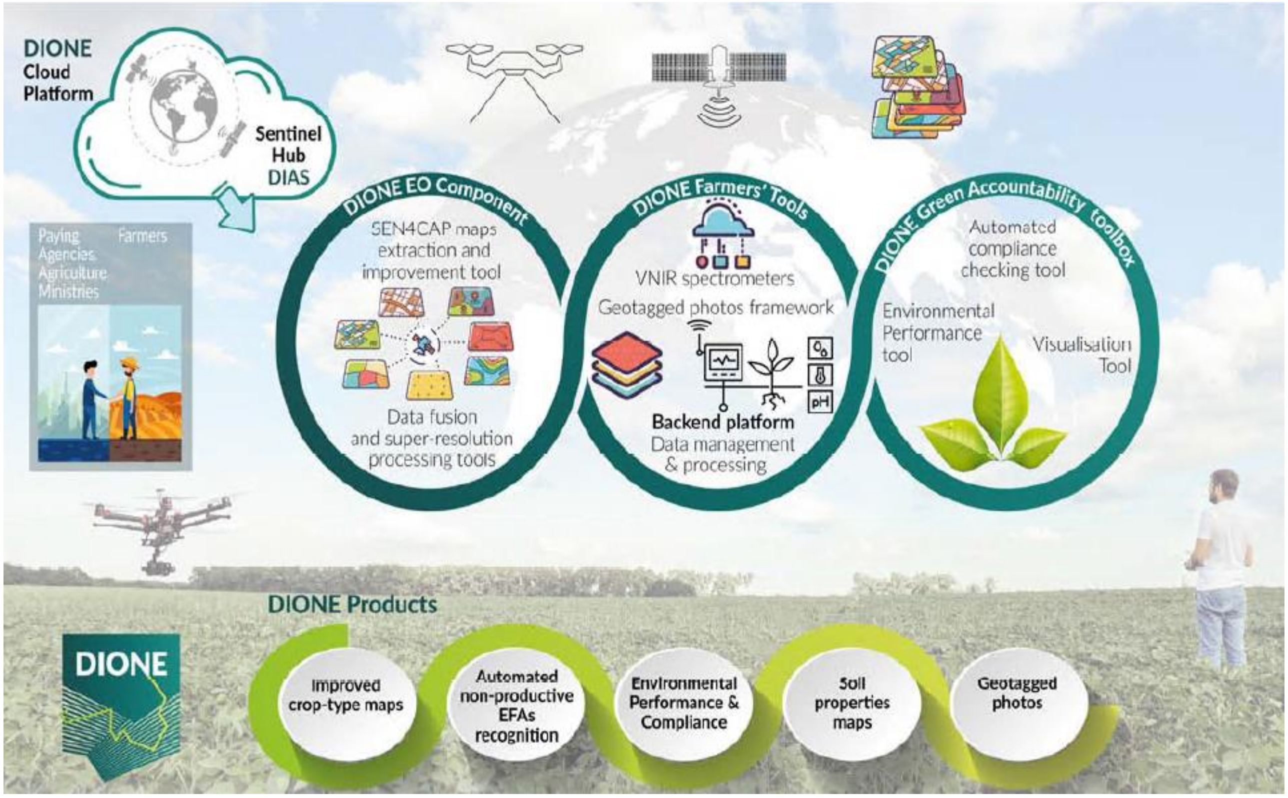

Figure 1: DIONE overall concept

3. TOOLBOX SPECIFICATIONS AND SOFTWARE ARCHITECTURE

3.1 System specifications: A Co-design process

A stakeholder-driven perspective was adopted, where system components and functionalities were designed to meet users' requirements. It follows the principles of co-design, highlighting the collaboration among different personas in terms of system's participatory design (SPD). The notion of co-design is also conceived as a collaborative knowledge of sharing and creating processes that empowers the design of new ideas and solutions[62]. With this rationale, the co-design process was implemented following the activities of an initial questionnaire, a workshop and a very comprehensive online questionnaire, aiming first to collect useful information of the PAs of Lithuania and Cyprus, then evaluate these information and formulate the user requirements and finally stabilise their importance from a broader range of stakeholders. As a result, seven user persona archetypes were identified, i.e. the Inspector of the Paying Agency, the Organic Inspector, the Agronomist-Consultant, the Farmer, the Researcher, the Official at the Ministry and at the PA, (Figure 2), as the potential application users and high-level user and technical scenarios were established. Based on the findings of the co-design process, system's specifications were compiled and analysed from the four following different angles.

- Coverage: All user scenarios and requirements have to be covered, considering the system-level importance as it is proposed in the MoSCoW technique[63]. Based on the MoSCoW mechanism, system requirements specifications (SRS) are categorized in nominal order according to their priority (must, should, could and won't have), which most of the time illustrates the user's needs. This technique provides an easy and time-efficient method of categorizing the system specifications, while it promotes the collaboration between different stakeholders, as it is usually conducted via focus groups or unordered interviews and questionnaires.

- Dependency: Indicate which system specifications are dependent on the earlier implementation of other specifications.

- Conflicts: Specify any specification's existence contradictory upon other system specifications, making the implementation of them less feasible.
- Overlaps: Indicate any functionality that occurs repeatedly in more than one specification.
- The process was concluded with the evaluation of the specifications' importance based on PA's user experience.

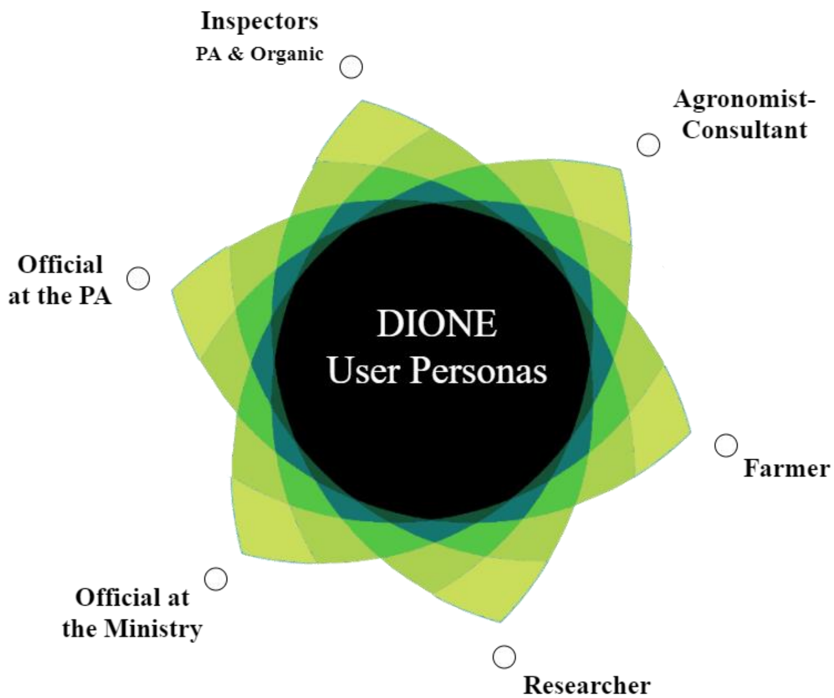

Figure 2: User persona archetypes

3.2 Conceptual Software as a Service (SaaS) Architecture

The conceptual system architecture was designed under the well-established approach of Rozanski and Woods[64], who suggest to decompose the architectural description into views. With this perspective, the system architecture is divided into separate views, making it easier to identify the individual functions and interfaces, the processes of information structure and the proposed technologies for data exchange. The DIONE architecture design was introduced as a simple and intuitive way of ensuring the quality properties of the individual components[65].

The DIONE toolbox leverages the advantages of cloud computing and the notion of transforming "everything as a service"[65]. This viewpoint is lately promoted as the most efficient solution, enabling users to discover, access and visualise numerous pieces of data, whereas on the contrary it subsequently reduces the maintenance effort of the constructor. The National Institute of Standards and Technology (NIST) summarises the functionalities of the cloud computing with the following definition: *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"* [67]. Likewise, the exploitation of open source cloud systems such as Hadoop and Spark or the cloud platforms of Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform change the traditional process of structuring, storing, processing, managing and data exchange[68], and contribute to the evolution of geospatial science and Big data Earth Observation[69]. Cloud computing services are mainly divided into three categories, the Infrastructure as a Service (IaaS), the Platform as a Service (PaaS), and the Software as a Service (SaaS). The first option is used for the development of services and applications, the second for the deployment of mobile applications using PaaS tools and lastly SaaS platform provides a fully functioned service solution, hosted on the cloud[67].

Under this frame, the design a cloud-based SaaS platform was chosen that facilitates a standardise access to EO data through the cloud-based DIAS platforms, aiming to improve the workflow of agricultural monitoring and thus addressing the forthcoming modernized CAP regulation. Figure 3 provides an overview of the high-level toolbox architecture, summarising the basic buildings blocks of the system.

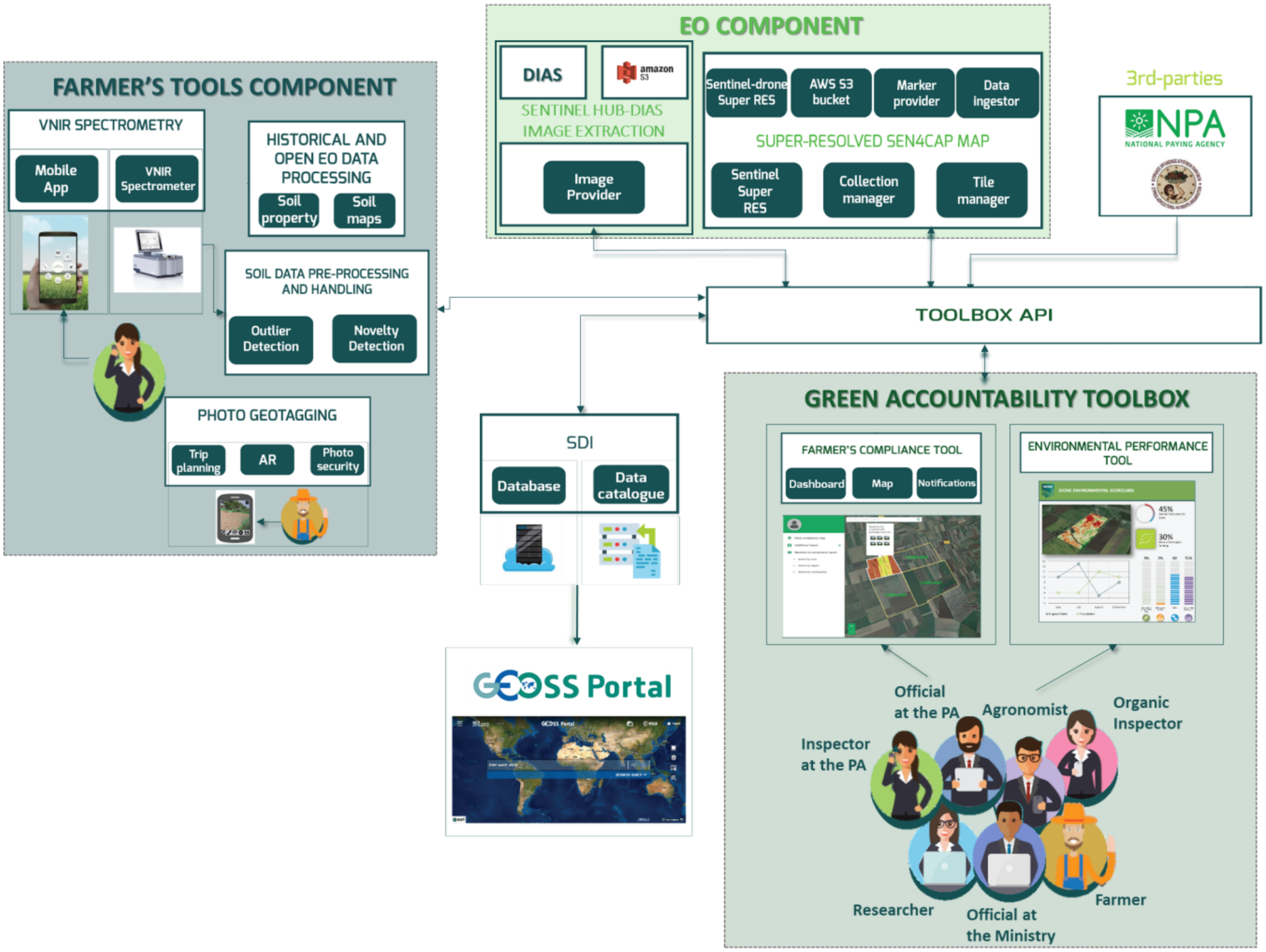

Figure 3: Overall conceptual architecture of the ecosystem of the DIONE toolbox

The DIONE toolbox encapsulates apps and dashboards (i.e. the frontend components of the farmer's compliance monitoring tool and the environmental performance monitoring tool and the mobile applications for in-situ data collection) interfacing with the users (presentation layer). Additionally, a standardized OGC-compliant format data repository (persistence layer) is included, aiming to manage raw and processed data (Spatial Data Infrastructure)[70] as well as to offer them to global repositories such as GEOSS. In the middle of the architecture, an application layer, also called business logic layer, contains all the functions performed on data of DIONE, including artificial intelligence algorithms for imagery processing, models for automated compliance checks and environmental performance assessment.

This Bottom-Up design pattern[71], (Figure 4) is adopted for each of the three main components of the system, where data are stored in the central SDI database and disseminated as Geospatial Web Services. In specific, the components are able to work independently but therefore, communication interfaces are established between the isolated systems, to mitigate dependences and foster isolation. The toolbox RESTful API (service layer) provides the necessary interfaces for the communication between the parts of the presentation and the application layer as well as the communication with external API endpoints and interfaces. Built on the principles of service-oriented systems, this configuration allowed us to create smaller client applications, addressing the different user requirements[61].

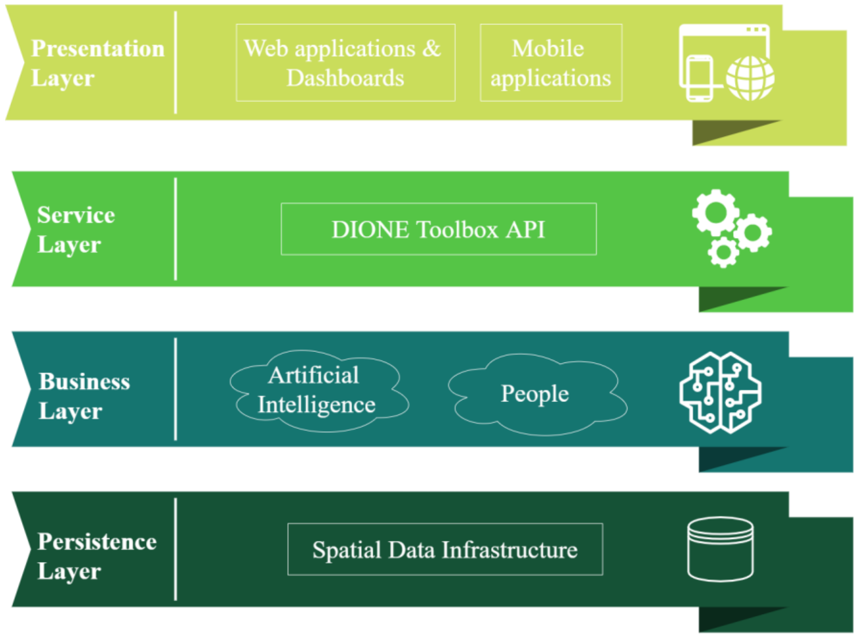

Figure 4: Main architecture layers of the DIONE toolbox following a Bottom-Up design pattern

This platform demonstrates a secure, scalable, flexible, and interoperable semantically enriched system with a set of core features, presented below.

- Secure: The security perspective is handled in two levels. The first (single component level) includes all the measures to ensure Confidentiality, Integrity, and Availability (CIA) at each component level. The second level (global level) includes all the measures and policies to be adopted, ensuring CIA at global scale (e.g. secure communication among the components). A user manager system is deployed using the OAuth 2.0[72] industry standards, where processes such as user registration or access to data, are authorised according to user's authorisation level.
- Scalable/flexible: Technological protocols and equipment, such as APIs, open source tools and cloud services are introduced to manage processes of various of in-situ and EO data and the provision of added value services on CAP compliance and environmental performance assessment.
- Interoperable: A standardized information model is followed, enabling interoperability of data and harmonisation with external systems. APIs and cloud infrastructure permit different subsystem to have their own data, implement specific functionalities and also share information requests to other system components.
- Semantically enriched: Different processes are employed for the harmonisation of different data sources in order to provide homogenised data products with added value information, directly exploited from relevant stakeholders.

In the following section, emphasis is given on the design of the main subsystems of the toolbox, including also details about the deployment of the functional components, and the data flows. Therefore, data models and the developed algorithms are briefly analysed as they do not address the primary scope of this study.

3.3 The main subsystems of DIONE toolbox

Sentinel Hub-DIAS image extraction

The first sub-component of DIONE toolbox represents the processing workflow, which gives access to satellite images from various data sources (e.g. Sentinel-1, Sentinel-2 or custom generated). In this component a RESTful API, named image provider acts as the intermediate connector between the data storage and the client. EO data retrieved from DIAS-es, ingested into the Sentinel Hub (SH) and finally stored into the Amazon Web Services (AWS) Open Data storage in Cloud Optimized GeoTiff (COG) format. SH uses the concepts of Data Source, Instances and Layer to present the available data as OGC-compliant services. These data named Collections are stored in Amazon S3 bucket. The Instance acts as an independent service, providing a set of Layers depending on user requirements. Each Layer is associated with one or more bands and related processing scripts, called EvalScript. EvalScript is responsible for the processing functions and Batch modules. It performs different functions at pixel-level, while with the Batch module the asynchronous interactions are allowed[50]. Given input parameters of the requested imagery such as, area of interest and data source type (e.g. S2L1C, S2L2A, etc.), the SH API provides access to the requested EO data and enables image processing techniques such as image rendering, statistical analysis and data fusion.

Super-resolved EO data and Sen4CAP maps

Sen4CAP [73] tools and EO products are exploited and further improved to meet the requirements of the modernized CAP. Marker maps of crop types, pastures and non-productive EFAs as well as grazing, mowing and ploughing farming activities are estimated and provided in an improved spatial resolution. When the resulting data (super resolution maps, reference maps, machine learning maps, etc.) give satisfactory results, they transform in COG format and are stored in an AWS S3 bucket.

Two RESTful APIs, tile manager and collection provider, provide lists of user's collections of tiled-images. Each tile contains a set of spectral bands, accompanied with the available metadata (acquisition date, file-name, etc.). Tiles with the same spectral bands are combined into image collections regarding their similar geometry and image acquisition dates. Image tiles and collections become visible to the user, depicting information about each new tile inside the collection with the geometry and sensing time parameters. The marker service provides information based on the requested data. According to this, a specific token is made available to the image provider and the requested data are fetched into the system. Afterwards, the markers maps are calculated and provided via either time series plots or in JSON format [74] depicting the aforementioned values.

This component also uses the image provider module to retrieve the satellite data. A dedicated interface the data ingestor is utilised, being responsible for the provision of the requested reference data that will be used by the marker provider. To obtain marker information, first the user must define an area of interest (AOI) for which the marker information will be estimated. Afterwards, the requested satellite data are ingested in the system, containing a unique identity that is related to the AOI feature and any additional properties, such as geometry, image year, land use, and crop type. Continuing, DNN algorithm is applied for the requested data, incorporating the relationship between Sentinel-2 imagery and drone/satellite/aerial imagery. These models sharpen the Sentinel-2 imagery in a two-level Super Resolution scheme. In the first level, the super-resolution is performed in order to pan-sharpen the low-resolution (20m and 60m) bands into 10m, while in the second level, uses the VHR images that are acquired from the drone flights and the DWH. The foreseen processing cycle improved the resolution of the satellite products and subsequently enabled the recognition of permanent pastures' crop-types, non-productive EFA types, and the grassland mowing/ploughing maps.

Both marker system and super-resolved EO products will be built based on a plethora of Python libraries such us NumPy[75], Pandas[76], for data manipulation and statistical analysis, matplotlib[77] for data visualization and scikit-learn[78], TensorFlow[79] for development of machine and Machine and Deep Learning (DL) algorithms. Frameworks of Dask[80] and Zarr[81] will enable the large-scale processing of series of data.

Drone platform

Data related to the VHR drone images can also be uploaded to Sentinel Hub and stored to AWS Simple Storage Service (S3) bucket. These data are used in order to give complimentary information of LULC types, and EFAs with a spatial accuracy of 1m or lower. The drones/multicopters platform is deployed using the open source ArduPilot[82] and ground control software, equipped with the necessary sensors and cameras, including GNSS positioning, and with the capability of covering the visible and the near-infrared parts of the electromagnetic spectrum. The outcome of the drone component is VHR, VNIR orthomosaics, with respect in time and space, while they are implemented using the Agisoft software[83].

VNIR spectrometer and Soil maps extraction

Visible and near infrared (VNIR) range spectrometry measures are collected with low-cost MEMS VNIR spectrometers and a developed mobile application. The mobile devices are deployed to run in Android smartphones ($\geq$ Android OS version 5), equipped also with cameras, built-in GPS, Bluetooth, supporting at the minimum 3G internet connection. Afterwards, soil data pre-processing is conducted to detect outliers and erroneous measurement, or peculiar soil spectra. Then, the processed spectral measurements are stored in a central NoSQL database, hosted in a local server. As a consequence, soil maps are predicted and updated at a regular time interval (e.g. every 3 months soil properties can start to change)[84]. Their estimations are conducted using the aforementioned measures or other ancillary data, such as historical spectral libraries (e.g. GEOCRADLE soil spectral library[85]), and archive EO data.

The mobile connection with the miniaturised VNIR spectrometers is fabricated using Apache Cordova[86] and Ionic framework[87] and other relative plugins. Pre-processing of spectral data (statistical analysis and novelty detection) and soil maps estimation are performed using the most known data analytics and machine learning python libraries of scipy, scikit-learn, as well as the DL frameworks of Keras[88] and TensorFlow. The dB management system will be implemented using MongoDB[89] allowing the easy integration of schema-less JSON documents.

Geo-tagged photos

The geotagging component comprises of the backend and frontend interfaces. The first interface is responsible for providing curated geo-tagged photos, and it consists of three sub-processes. During the primary step, the farmer is guided through the trip planner, in order to reach his parcels. Then, the augmented reality component provides instructions regarding the process of taking a representative photo of the given parcel. Finally, the third component ensures the photo integrity and anonymization process according to GDPR principles. The security framework guarantees the integrity of the taken photos and detects if any digital modifications took place. In particular, stenography-based techniques shall be used to ensure the photos integrity. After the quality certification, photos are stored in the central dB, receiving a unique id, relevant with the Land-parcel identification system (LPIS) id. The same id is subsequently connected with each farmer's single user account. This way, the inspector can easily have access to farmer's photos and evaluate parcels' compliance. The frontend component will be an Android application that is responsible for sending notifications to farmers' when photos are required. The app navigates users in the parcel and gives them directions through the employment of AR features, regarding the photo acquisition in order to provide a representative view of the investigated parcel.

The geotagged photos mobile application will exploit the Unity framework[90], in order to support the AR technologies. The date and time of the photo is calculated according to GNSS messages, while the operator will be identified through the use of Keycloak[91] identity manager. The application utilises the Oauth2 (Authorization Code Grant) and OpenID protocols to verify the security authorisations. The geo-location reliability will leverage on dual frequency devices and Open Service Navigation Message Authentication (OS-NMA) [92]. Furthermore, photos' quality verification will be performed regarding the digital signature scheme and the steganography, using the crypto[93] and stegano[94] python libraries. Pillow[95], cython[96] pywavelets [97] python modules are exploited for the digital camera identification operation. Imago[98] is used for the extraction of the metadata. Additional, pre-trained models will be also developed to estimate any abnormal activities.

Farmer's compliance monitoring tool

FCt integrates two levels of the Bottom-Up design pattern (Figure 4), the presentation layer (frontend), which is responsible for the visualisation of the compliance status for all the farmers and the business logic layer (backend) that includes the rule engine for the deduction of the compliance results. Configurable rules verify the compliance level on each parcel, based on DIONE generated data. Authorised users i.e. Inspectors and the Official at the paying agency, have access to the aforementioned results, as it is necessary to receive information of user's lists/grid of data or the farmers under inspection/pre-review. Middleware APIs are responsible for collecting the necessary data/metadata and reformat them in JSON objects. Through these APIs, server-client connections are performed automatically by the relevant requests (GET, POST, etc.). All this information is visible through the frontend interface, consisting of dashboard, map viewer, data collection, users' authorisation and notification modules. More specifically:

- User's management module carries out user authorization and authentication processes, with which users' information and profiles are visualized according to the relevant stakeholder.
- Data collection interacts with the toolbox API in order to collect all the necessary data and reformatting them into JSON objects, consisting of the relevant WMS URLs and metadata.
- Dashboard controls approximately 90% of farmers' tool, including web map viewer, layer controls, tabular viewing modules, with which authorised users receive information about farmers, specific parcels and identify automatic changes on map preview. Asynchronous and unblocking operations of view/upload/delete information are allowed.

- Interactive map viewer enables users to visualise layers, such as geo-tagged photos related to parcels and also querying information about them. Map viewer is controlled from the dashboard.
- Notification service play the messenger role, subsequently sending POST messages to toolbox API in order to retrieve user requested data.

Environmental Performance tool

The EPt consists of the ML-based inferencing engine that is responsible for the estimation of the environmental impact in the examined regions and the web application which visualises the produced results. The inference service is deployed on Amazon's cloud infrastructure, allowing users to demonstrate large-scale processes using heterogeneous data into a predefined data-format that will be stored in the database. HTTPS protocol and username/password authentication techniques will ensure the secure data transmission from clients to servers. Additionally, trained models will be hosted on the cloud as services, whereas the classification results will be stored in the central database and visualised on the interactive web map (front-end interface).

Both, FCt and EPt components are designed based on User Interface (UI) protocols providing intuitive graphical dashboard interfaces to end-users. Multilingual support (English, Lithuanian, Greek, etc.) will be offered to attract users who often only speak their mother tongue. The front-end interfaces will be built, integrating a plethora of web technologies. In fact, the triple of JavaScript (React)[99] /HTML5/CSS3, in collaboration with customised Semantic UI library, will be exploited. The Web Map viewer will utilise Openlayers[100] as a very good implementation of OGC services. For better maintenance, there will be two environments (production and development) controlled by Webpack [101].

Spatial Data Infrastructure & DIONE toolbox API

The last component consists the ‘heart’ of DIONE, enabling the connection of all tools and components, while also facilitating the integration with existing third-party infrastructures (e.g. PAs modules). The component consists of an internal Spatial Data Infrastructure (SDI) that manages the various datasets that are produced by the DIONE toolbox components. Data is stored in the SDI database and catalogued including metadata information and shared as OGC web services through toolbox API to third-party software infrastructure or to GEOSS portal. Established GEOSS data management principles are followed to ensure the discoverability, accessibility and usability of the data.

The DIONE toolbox API and the SDI will be deployed as Docker containers, hosted on a dedicated server. Django[102] will be used for developing the toolbox API. The SDI Catalogue portal will be implemented using Geonode[103]. Geoserver[104] and PostgreSQL[105] will be utilised to make spatial data publicly available through standard OGC services.

3.4 Information views

Understanding system structures has been proven more essential, if we consider them as an assemblage of multiple views. The 4+1 views model[106] introduces a new description of system’s functionalities, which are expressed in five categories, the logical view, the process view, the physical view, the deployment view and the fifth view, named scenarios or use cases view[107]. Additionally, the aforementioned views are further categorised in two aspects, where the first expresses the functional requirements and the relationships of the developed modules (static), and the second visualises the run-time behaviours of the system (dynamic).

Static Information View

In terms of a static view, the data model of DIONE follows a standardised information model that enables the interoperability of data and harmonisation with external systems. All the objects that participate in the DIONE system are employed with specific information in order to collect and exchange information (data and metadata) between the different components (explained in detail in Section 3.3).

Dynamic information view: End-user scenarios

On the contrary, the dynamic view exemplifies the exploitation of the designed architecture under the frame of specifically demonstrated user scenarios. We identify at least ten use cases that exploit different communication perspectives between the components of the toolbox, including the interactions with the end-users. In the context of this analysis, two connected examples are presented aiming to showcase the applied methodology.

The first scenario presents how the farmer's compliance tool performs the compliance calculations. In the illustrated processing flow, (Figure 5) the CAP compliance is evaluated in an examined parcel using the estimated marker maps (Section 3.3). When the compliance procedure is initiated, the integration component fetches the estimated marker maps from the central database, which is deployed in a Docker container (SDI). Then, the requested marker maps are provided to the compliance component as JSON objects (i.e. complianceParcel). The JSON object reveals information for the examined parcel about the marker maps, along with the metadata, and it is stored in the SDI database. At a regular basis, the compliance dashboard requests to receive notifications about the compliance status of the parcels. When the dashboard gets notified about the compliance status, the compliance object of the examined parcels is fetched from the Toolbox API and finally visualised on the map viewer service (presentation layer).

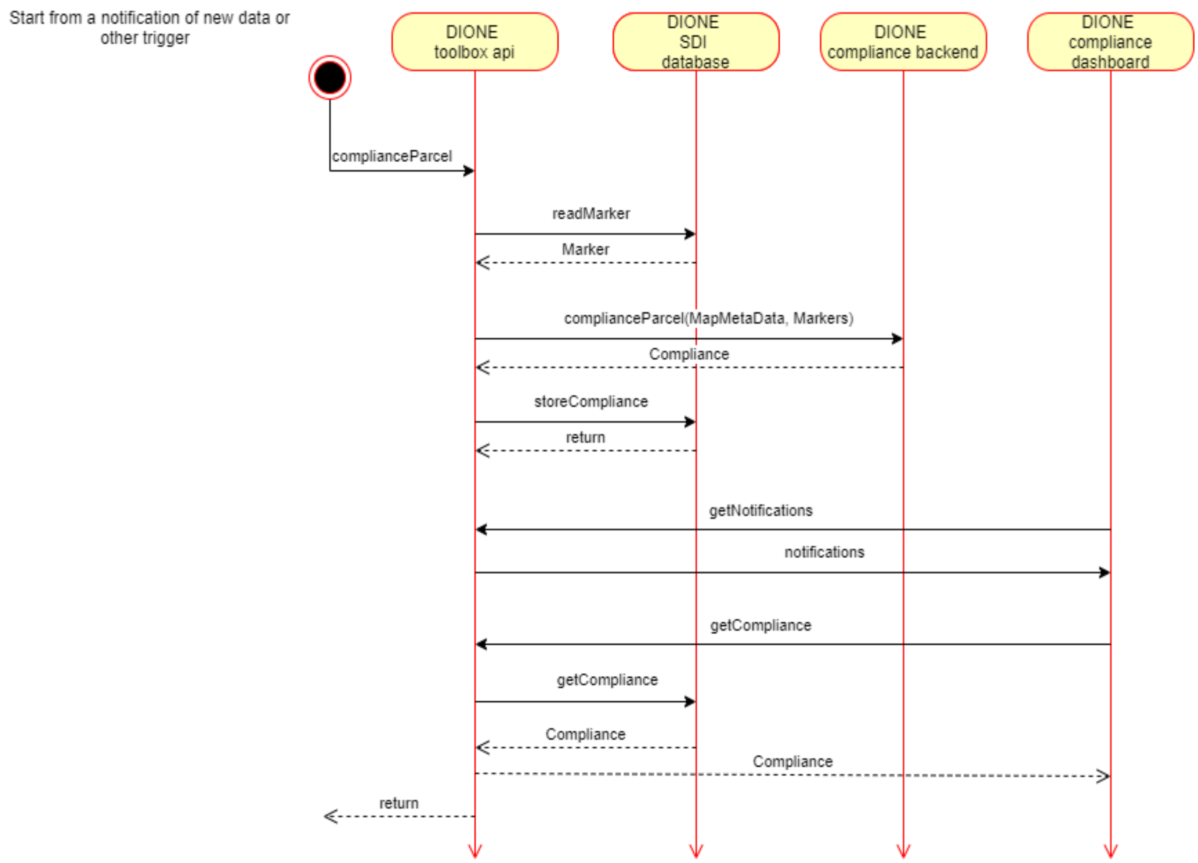

Figure 5: Information flow diagram of the first scenario, depicting the transmission of the information flow with which parcel's compliance in performed.

In case of ambiguities regarding the compliance, the inspector requests for the reviewed farmer to capture trustworthy geo-tagged photos, in order to improve the compliance performance. This procedure assists human operators to perform better decisions regarding the CAP compliance, and reduces field inspections. The process is initiated with a notification alert to farmers, who have been identified with non-compliant parcels. This notification is transmitted by the DIONE toolbox API to the geo-tagged service, and the on-site inspection activities are activated. Through the geo-tagging photo app, farmers receive a guidance moving towards the parcel in order to capture the photo and thus avoid to provide erroneous measurements. When photos are captured, they are uploaded on the toolbox where they are evaluated regarding their integrity and finally stored in the SDI central database. Subsequently, when the data are stored an immediate notification is transmitted to the compliance dashboard. Then, the dashboard component requests the geotagged photo, which is retrieved from the SDI dB as a JSON object and visualized in the frontend interface.

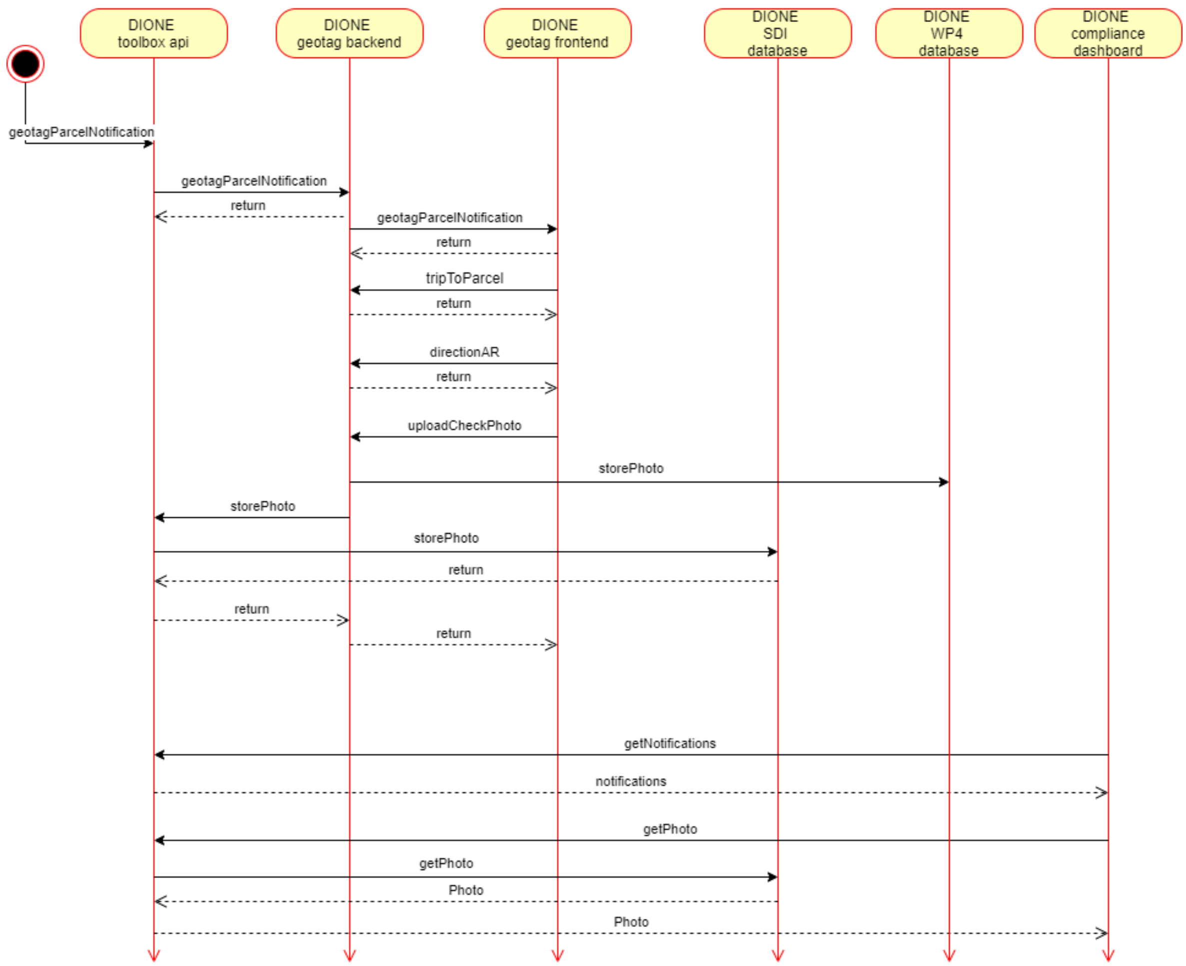

Figure 6: Information flow diagram of the second scenario, illustrated the procedure of evaluating the parcel's compliance with the photo-tagging information.

4. CONCLUSION/DISCUSSION

The focus of the study lies on the establishment of an efficient, low-cost and national-scaled solution, with the aim to support CAP compliance monitoring and relevant stakeholders' decision-making processes. This way and in the context of DIONE EU funded project, a close-to-market (TRL7), cloud-based platform is proposed offering a fusion of individual components that are stemming from the use of EO and its smart integration with novelty technologies. In details, a holistic, scalable, highly accurate and cost-effective agricultural monitoring system is attempted to be developed, aiming to gradually replace the traditional methods of farming compliance evaluation (i.e., on-the-spot-checks, validation using VHR images via photo-interpretation) and promote the environmental resilience.

From the implementation point of view, the system architecture is designed with the notion of decomposing everything in different building blocks and with the ambition to satisfy all the user needs. Suchwise, a co-design perspective was introduced, where seven user personas were identified and contributed to the definition of user needs and the transformation of them in system's specifications. Continuing, a Bottom-Up design pattern was adopted and a cloud-based service-oriented architecture was designed as SaaS system architecture exploiting a plethora of technologies and web standards that allow the provision of harmonized, open accessed, multi-source data as OGC-compliant web services, under the SDI framework.

To this end, the DIONE toolbox will be tested as a country-level CAP monitoring system in the two pilot areas of Cyprus and Lithuania, (Figure 7). They comprise of 38,860 and 199,910 crop parcels and occupy approximately 118,400 km^2

and 2,742,560 km^2, respectively[108, 109]. DIONE will attempt to fulfil, National Paying Agency of Lithuania (NPA) ambition and increase the satisfaction of their ~130 000 farmers, in such a way ensure that the control process will be considerably more transparent, while at the same time significantly reduce the costs of compliance monitoring. In the same content, Cyprus Agricultural Payments Organisation (CAPO) will be able to automatically inspect small-sized parcels size, and thus gradually replace the percentage of on-the-spot checks and reduce the operational costs.

The performance of DIONE platform will be evaluated, considering the time response of any changes, in terms of quality resilience and platform scalability, and the safeguard of preserving data integrity. For the first time, DIONE paves the way of an alternative, and sustainable perspective where stakeholders from different business sectors will collaborate with a common goal to empower the agriculture productivity, and ensure the environmental resilience.

Figure 7: DIONE pilot areas.

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