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Monitoring environmental and climate goals for European agriculture: User perspectives on the optimization of the Copernicus evolution offer

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ABSTRACT

A vicious cycle exists between agricultural production and climate change, where agriculture is both a driver and a victim of the changing climate. While new and ambitious environmental and climate change-oriented goals are being introduced in Europe, the monitoring of these objectives is often jeopardized by a lack of technological means and a reliance on heavy administrative procedures. In particular, remote sensing technologies have the potential to significantly improve the monitoring of such goals but the characteristics of such missions should take into consideration the needs of users to guarantee return on investments and effective policy implementation. This study aims at identifying gaps in the current offer of Copernicus products for the monitoring of the agricultural sector through the elicitation of stakeholder requirements. The methodology is applied to the case study of Italy while the approach is scalable at European level. The elicitation process associates user needs to the European and national legislative framework to create a policy-oriented demand of Copernicus Earth Observation services. Results show the limitations faced by environmental managers in relation to the use of Remote Sensing technologies and the shortcomings associated with a purely technology driven approach to the development of satellite missions. Through the introduction of this flexible and user centred approach instead, this paper provides a clear overview of agro-environmental user requirements and represents the basis for the definition of an integrated agricultural service.

1. Introduction

1.1. The importance of Earth observation data for monitoring agricultural activities

Farming and nature greatly influence each other, and the links between the richness of the natural environment and farming practices are complex (Arora, 2019; Bennett, 2017; Webb et al., 2017). Despite the agricultural sector being one of the most vulnerable to climate change, it is also one of its most important contributors (Agovino et al., 2019). Nevertheless, agriculture can improve mitigation efforts by limiting greenhouse gas production but also through the sustainable management of ecosystems and green infrastructures (Webb et al., 2017). Agriculture maintains valuable habitats over Europe, but some intensive farming activities and inappropriate practices can deplete natural resources, have adverse impacts on ecosystem services and aggravate climate change impacts (Bosco and Simeoni, 2018). In this context the EU has shown strong commitment to the COP21 Paris Agreement, and the priorities indicated by the Chilean presidency of CoP25. In particular, the 2030 energy and climate targets set the ambitious level of 40% reduction in emissions by 2030 for all economic sectors (Horowitz, 2016) which will require changes also in agricultural practices. Climate action is also at the core of the European Green Deal which includes the EU Strategy on Climate Adaptation to make Europe a climate-resilient society by 2050 (European Commission, 2019a). The European Commission is also aligned with the UN's Sustainable Development Goals (SDGs) on Climate action and Life on land, through the implementation of regional efforts to improve climate change mitigation and foster sustainable agricultural practices (Kastrinos and Weber, 2020). Given the increasingly difficult climatic conditions that the farming community is faced with, the loss of biodiversity of European soils and the threat of prices volatility that the sector can occasionally face (de Graaff

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et al., 2019), the European Commission is placing great interest in consolidating climate change adaptation and mitigation policies and to the protection and improvement of the environment. These objectives have recently been strengthen by the European Green Deal (European Commission, 2019a) and by the Common Agricultural Policy (CAP) post-2020 reform, aiming to increase the environmental ambition and climate action and contributing to the achievement of environmental and climate objectives of the Union (Jongeneel et al., 2019). The proposed Regulation makes specific reference to the management of climate related risks, defined in terms of direct agricultural losses attributed to disasters. Also, the Commission recommendations for Italy's CAP strategic plan (European Commission, 2020a) highlights the need to: increase the sustainability of production while mitigating climate change and reducing GHG and air pollutant emissions; foster climate change adaptation and resilience by incentivizing sustainable management of agricultural and forestry land; halt and reverse the loss of biodiversity.

While the implementation of agricultural policy support schemes, like green infrastructures and eco-schemes can make a significant contribution to mitigation efforts (Calliari et al., 2019; Panagopoulos and Dimitriou, 2020), limitations in the way environmental and climate related policies are monitored can limit the assessment of agricultural practices and consequently their progress and effectiveness, holding back the potential for European agriculture to fight climate change. As a matter of fact, only recently the European Union has validated the use of Copernicus satellite data and information as an official mean to monitor the implementation of the CAP and to issue payments to farmers (European Commission, 2018a). Furthermore, future CAP regulations will envisage the introduction of an area monitoring system: a procedure of regular and systematic observation, tracking and assessment of agricultural activities, practices and status by Copernicus Sentinels satellite data or other data with at least equivalent value.

In fact, many studies have highlighted the positive opportunities provided by the use of Earth Observation (EO) data to monitor drought events (Arun Kumar et al., 2021; Crocetti et al., 2020); to classify different types of crops (Bargiel, 2017; Hao et al., 2015; Piedelobo et al., 2019a; Rousi et al., 2021); for irrigation management (Brocca et al., 2018; Foster et al., 2020; Vanino et al., 2015); for the identification of different soil tillage practices (Azzari et al., 2019; Hively et al., 2018) and for ecosystem services and biodiversity conservation (Braun et al., 2018; Cord et al., 2017; Dantas de Paula et al., 2020; Hill et al., 2019). Among the many source of data available, Europe has been delivering a series of free and open satellite derived data through the Copernicus program and has progressively linked the implementation of the policies of the Union to the use of such resources (Campos-Taberner et al., 2019; Sarvia et al., 2021). According to the rules set in the new CAP monitoring approach, the eligibility for the aid requested can not only be verified through *on-the-spot checks* but using Sentinels' data, Copernicus EO missions, to continuously, regularly and systematically monitor the whole country (European Commission, 2018a).

Nevertheless, the use of EO data for the monitoring of agro-environmental goals has been lagging behind (European Environment Agency, 2019a) and the use of heavy administrative procedure for farmers has been prioritized to ensure legal compliance and distribution of agricultural payments (Mack et al., 2021; Pe'er et al., 2020). While the uptake of remote sensing data is limited by financial and budgetary constraints, statutory limitations, experience, skills, and training (National Research Council, 2003), part of the issue lays in the way satellite technical specifications and agro-environmental services are developed. As a matter of fact, the EO sector has been dominated by technology determinants, rather than the demand of users, when both are essential to drive innovation efforts (De Concini and Toth, 2019). In this study it is argued that a so-called "market pull" approach, where mission details are driven by user needs, would not only optimize the use of EO derived services but also improve the monitoring of agro-environmental goals for the long-term sustainable growth of European agriculture. This assumption is demonstrated through the use of an interactive approach adapted from Taramelli et al., (2020) and concentrating in particular on the potential of the free and open market of Copernicus, the European Union's EO programme. A solid analysis of technical and operational user requirements would benefit the expansion of the European space component and of its services, however only limited studies have analyzed user needs in this domain (Geraldini et al., 2021; Gomarasca et al., 2019; Taramelli et al., 2020).

1.2. Copernicus user needs and requirement

Copernicus data and information benefit intermediate users who use them as inputs to build value-added products or services (PricewaterhouseCoopers, 2019). Intermediate users often access also high and very high resolution EO data and additional sources of non-space data to create advanced value-added products for end-users. End-users in general don't have deep technical knowledge of EO data but have specific operational needs (Ibid.). Although the mid-term evaluation of the Copernicus programme published in June 2017 (European Commission, 2017) has highlighted very positive results, awareness and user uptake activities should be further enhanced and "expanded beyond specialist communities" (Ibid.). Indeed, despite their value, the adoption of EO data and information, especially from non-technical local and regional governmental authorities, remains low (PricewaterhouseCoopers, 2019). As pointed out already in 2016 by the Directorate General for Internal Policies of the Union (2016), this potential market failure is due to a general asymmetry of information between offer and demand especially among public administrations, while Geraldini et al., (2021) points to some additional factors such as:

1. Users demand is not clearly identified because of the lack of a systematic method and approach
2. The demand at national and European level is highly fragmented: while this foster competitiveness, channeling different needs into investment plans can be challenging and small users can be disregarded
3. The users demand is dynamic, given the evolution of national and European legislation, market needs for the farming sector and technological developments
4. Additionally, there is currently no pooling mechanism to aggregate the demand of specific end users like institutional buyers

Thus, the need to include users' requirements and perspectives in the development of EO services has also been identified as a priority at the institutional level. In fact, the European Commission has advocated for the development of Copernicus services on the basis of user needs of institutional communities and private entities operating in various national and international contexts (European Commission, 2019b). If the coordination is successful, users' need will also help in guiding the Italian National Space Economy (Ministero dello Sviluppo Economico, 2016) redirecting future efforts towards the new challenges that the agricultural sector is faced with. The Copernicus program is structured to be user driven with engagement from the institutional, private, and scientific community (European Commission, 2016). For several years, users' and observational requirements have been systematically identified, structured and prioritized in a continuous process led by the Commission (European Commission, 2019b) but a resolute approach is required to achieve time-critical objectives for climate change adaptation, the Sustainable Development Goals and the commercialization of European EO Data and information. This progress is particularly relevant for the agricultural domain, which is the largest area of investment for the European Union (European Commission, 2020b) but also a crucial sector to implement the environmental and climate goals of the Union. To fill this gap between offer and demand, a technology transfer strategy would allow mutual communication between users and data providers.

In this context, understanding user requirements is critical to orient future policies and to build agricultural resilience to climate change and environmental degradation. In fact, a user-centric design can increase productivity, enhance quality of work, reduce training costs and improve user satisfaction (Maguire and Bevan, 2002a). The elicitation of technical judgement from experts can be a valuable support to public policy decision making. Stakeholders are normally individuals, groups or organizations with stakes in a system such as customers, end users, analysts, developers and testers (Minocha et al., 2008). Given the importance of this process, there is a need for a systematic approach to requirement elicitation to capture stakeholder perspectives (Durugbo and Riedel, 2013). Loucopoulos and Champion (1989) define requirements engineering as "*the systematic process of developing requirements through an iterative process of analysing a problem, documenting the resulting observations, and checking the accuracy of the understanding gained*". The identification and understanding of user requirements was first introduced in the field of Information Technologies (IT) as an integral part of information systems design (Maguire and Bevan, 2002b). A requirement is a "*function or characteristic of a system that is necessary. The quantifiable and verifiable behaviors that a system must possess and constraints that a system must work within to satisfy an organization's objectives and solve a set of problems*" (Software Test & Evaluation Panel - STEP, 1991). Before requirements can be analyzed, modeled, or specified they must be gathered through an elicitation process. Requirement's elicitation is a part of the requirements engineering process, usually followed by documentation and analysis of the requirements. Authors identify different techniques for the assessment of user needs such as the "The inquiry cycle" developed by Alexander at all (2009). In this procedure authors identified four fundamental steps: Discovering, Documenting, Validation and Development of use requirements. This validates the principle that requirements elicitation is a dynamic and iterative process, as requirements tend to generate further requirements from the definition processes.

Given the opportunities provided by requirement elicitation techniques and the poor use of EO technologies (PricewaterhouseCoopers, 2019), an analysis of stakeholder needs is performed to assess the alignment of legal requirements with current technological performance with the purpose to highlight current limitations in EO services and support the optimization of the European upstream component which includes research space manufacturing and ground systems, while the downstream segment includes space operations for terrestrial use, products and services which rely on satellite technology (Reillon, 2017).

The elicitation of stakeholders' needs performed in this study contributes to providing coherence for the development of future EO service for agriculture. In this study institutional users are asked to indicate the most important environmental and climate related requirements in terms of current agro-environmental legislation and the potential of current European EO technology to fulfill their monitoring needs is assessed. To understand their ability to report their compliance to the above-mentioned requirements, users also indicate their satisfaction in relation to current available monitoring techniques and services. The analysis is focusing not only on the prioritization of an area or policy intervention but also on the alignment of legal requirements with current technological performance, with the services provided by European open and free sets of data. This assessment provides direction and reference for policy evaluation and gathers evidence for investment in the sector, also taking into consideration the investments that the European Union is planning for new satellite missions – the so called Copernicus High Priority Candidate Missions (CHPCM). It uncovers emerging political and technological needs in the context of climate change mitigation and adaptation and environmental protection in the agricultural sector and policy.

2. Methodology

2.1. Critical reflection on the methodology of choice

The exercise of requirement collection and analysis has mainly been applied in the sector of information technology and scholars have proposed a number of approaches in past years to document user requirements (Jiang et al., 2008). Choosing one technique for requirements engineering among the great variety proposed, is often a challenge and the decision is frequently based on ad-hoc criteria. Researcher moreover must choose one technique for the different phases of requirements engineering, in particular *requirement elicitation* and *requirements documentation and analysis* (Ibid.).

Requirements' elicitation is the process with which requirements are collected; the most traditional include interviews, questionnaires, social analysis, prototyping, workshops, brainstorming, Joint Application Development (JAD), Rapid Application Development (RAD) and discourse Analysis (Pacheco et al., 2018; Sharma and Pandey, 2013).

In this study user requirements have been obtained through a combination of questionnaires and brainstorming activities. The advantage of using questionnaires is that they adapt to different type of audiences and are very cost efficient (Sharma and Pandey, 2013). Given the heterogeneity and complexity of user needs, the use of surveys is also often preferred because it avoids the collection of redundant and irrelevant data (Ibid.). In order to assist users in understanding the questionnaire and the rules for compiling it, a series brainstorming activities were organized: in this context users were able to agree on an initial list of requirements that should be included in the analysis. Because of the number of requirements that were expected in this interaction, replies where provided with a matrix format which favors a structured and systematic collection of user needs and which will be explained in the next section. On the other hand, *requirement documentation*, or the process in which requirements are reported and coded, features a wider series of models and techniques that have been developed during the years by different scholars (Gerald Kotonya, 1998; Maiden and Rugg, 1996; Sharma and Pandey, 2020). Dos Santos in particular (Dos Santos Soares and Cioquetta, 2012) has proposed a list of 21 criteria for the choice of the most appropriate model among the most common ones applied in the phase of requirement documentation. This study does not aim to develop specific and targeted products and is less attentive to system requirements and more to user requirements. In other words, a fully bottom-up approach is herein adopted without assuming any knowledge of satellite specifications and technical information from users. For this purpose *Structured Natural Language* is employed since it is a precise, unambiguous, and amenable notation (Cooper and Ito, 2002). The methodology adopted in this study is also widely based on the methodology adopted and developed by Taramelli et al. (2020). The main difference between the two methodologies is that this study elaborates on the gap between current demand and offer of EO products like in Taramelli et al. (2019), not focusing only on analyzing user requirements for a specific EO technology.

In order to provide stakeholders with valid products and services in line with the CAP reform, relevant paying agencies were consulted with the aim to identify common monitoring practices and conventional indicator taxonomies for the generation of institutional operational services and to support the design of the next generation of space components in support of climate change action. The methodology, has been developed to find the gap in the upstream sector on the basis of the requirement of key downstream services. Fig. 1 identifies three crucial methodological phases: i) Requirements' elicitation, ii) Requirements' documentation, iii) Assessment of requirements and Gap analysis.

2.2. Requirements' elicitation

In the first phase of the methodology, user communities are involved, and their requirements are collected. These specific institutions were

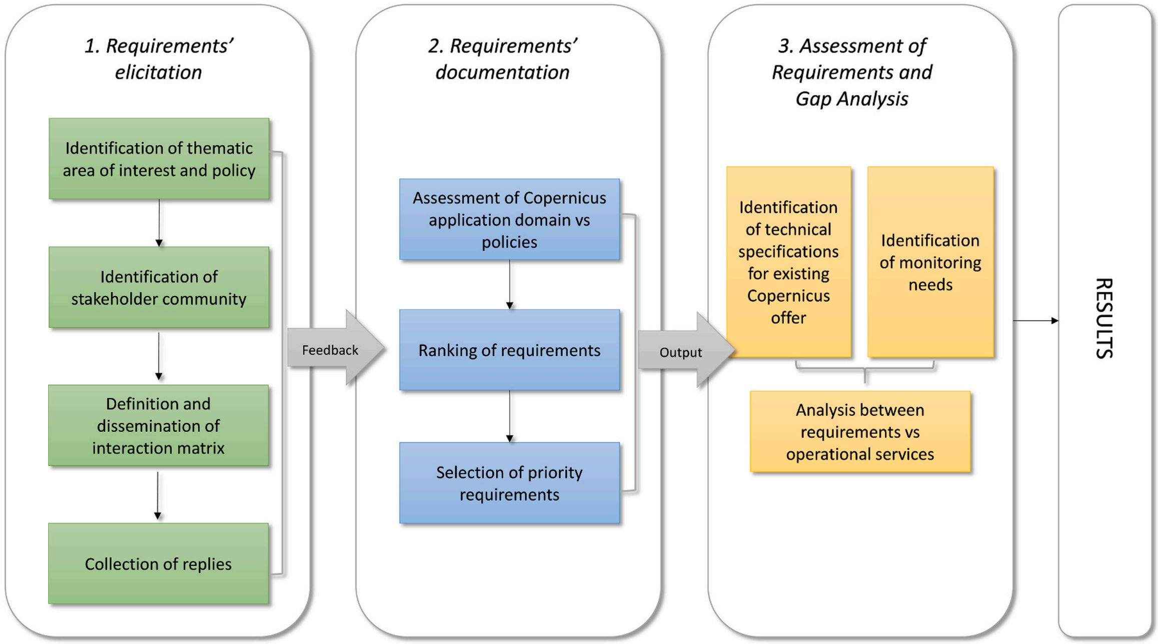

Fig. 1. Interaction methodology developed for the study to collect and analyze user needs.

selected because all respondents are involved, to different degrees in the monitoring of the CAP in Italy, in the verification of compliance to agro-environmental rules and implementation of agricultural policies related to the protection of the environment and disaster management before EU authorities. The criteria for the selection of users was their institutional and public nature. Therefore, the user pool was composed of the following four organization which comprise all the public institutions dealing with agro-environmental laws in Italy, and for each one of them a representative provided the requested answers:

1. The Italian Ministry of Agricultural, Food and Forestry (MIPAAF)
2. The Agency for Agricultural Payments (AGEA), coordination body of 11 Payment Agencies
3. The Council for Agricultural Research and Economy (CREA) with 12 research centers
4. The Institute of Services for the Agricultural Food Market (ISMEA)

User requirements were collected by presenting to user an interaction matrix including questions on both operational and technical specifications. In a first section users are asked to point out to the main national and European legislation they abide by and to list them in the matrix. For each of these legislations' users were then asked to identify specific requirements or activities that each user carries out, for which the use of remote sensing technologies is needed. Thirdly, users indicated the most appropriate and useful EO outputs to monitor each specific activity: this information included types of indicators (such as NDVI, LAI, FAPAR), spectral bands or more refined products. Stakeholders are also asked to provide an importance value from 1 to 5 to this relation, 1 being not important and 5 very important. It is valuable to note that the importance value does not represent the significance of the requirement at stake but the value of the association between policies, requirements and users. In fact, one requirement can pertain to different policies just like one requirement can have a different value for distinct users.

Further, users were asked to provide indications on the technical specifications for this information, namely on the expected spatial resolution and revisit time of the required products and indicators. In this process, users are compelled to choose between a range of technical specification to ensure the viability of users' request. An example of this interaction is provided in Table 1, but the full collection of user requirements is featured in the supplementary material 1 supporting of this paper.

Thereafter, researchers associate policies with the relevant Copernicus application domains divided as follows: Agriculture, Blue economy, Climate Change, Development and Cooperation, Energy and Natural Resources, Forestry, Health, Insurance and Disaster Management, Security and Defense, Tourism, Transport, Urban planning. To direct the research towards specific policies and goals, the associations that exist between European policies and the architecture of the Copernicus EO system is identified. The Copernicus application domains fall in a wide variety of policy areas. The association between the policies of the European Union and the Copernicus architecture is evident and service development follows this classification. The results are linked to the optimization of the current offer of Copernicus EO products and to the development of the six Copernicus High Priority Candidate Missions (HPCM)

2.3. Requirement documentation

In the requirement documentation phase, users' replies are coded to obtain meaningful results. The frequency with which different policies occur in the dataset is first determined and the relationship between the policies and the domains of the Copernicus program is examined; prioritization of users' needs is then performed. The formula applied in this phase reflects the fact that a requirement is important not only because it is valued in the work done by a specific user but also because it fulfills more than one policy, and it is implemented by more than one user. This aspect should be captured in the analysis as to provide a truthful and complete representation of user needs. Hence, requirements are ranked according to:

i. The number of directives or regulations they fulfill
ii. The number of users that select them
iii. The importance value attributed to each of them

The ranking of requirement is thus performed according to Eq. (1):

Table 1
Example of interaction matrix compiled by users. The first column includes information on the Copernicus application domain; the second column specifies a particular policy associated to the Domain in Section 1; the third column includes requirements necessary to fulfil the specific EU policy reported in column 2; the fourth column indicates the most useful spectral band that is necessary to monitor the identified requirements; column five shows the relative importance give to the above-mentioned combination. In columns 6 and 7 users specify their preferred spatial resolution and revisit time for the products in column 4.

Application domains	Legislation	Requirement	Indicator/Product/ Spectral band	Importance value	Spatial resolution	Temporal frequency
Agriculture	Reg. (EU) n. 1306/ 2013	Identification of violations of the ban on stubble burning	NDVI	4	3–10 m	15 days

$$\frac{\forall\, req\left[\left(100^{*}\ \frac{n_l}{NLaws}\right)+\left(100^{*}\ \frac{n_i}{NImp.val}\right)+\left(100^{*}\ \frac{n_u}{Nusers}\right)\right]}{3} \tag{1}$$

where:

i n_u is the number of users who selected a particular requirement and *Nusers* is the total number of involved users,
ii n_l is the number of Directives, Regulations or Communications that regulate a particular requirement, *NLaws* is the total number of Directives, Regulations or Communications identified by users;
iii n_i is the sum of importance values selected for a particular requirement, *NImp.val* is the highest importance value that can be assigned by the total number of users;
iv *req* are the requirements identified in the dataset.

2.4. Assessment of requirements' and gap analysis

When users were asked to provide the most appropriate tools to monitor the requirements, most of them have contributed with a combination of different information including spectral bands (e.g. *Near Infrared*), indicators (e.g. *NDVI*), and products (e.g. *Land cover*). To return a valuable information for the gap filling of the upstream sector and to provide structure to users replies, the products identified by users are all converted into spectral bands. The analysis differentiates between the use of multispectral and hyperspectral data because of the different number of wavebands acquired. This conversion is based on literature and on the way the Copernicus services defines these products (European Commission, 2018a). A conversion table detailing this process and relevant references is available in the supplementary material 2.

Secondly the results obtained from Eq. (1) are aggregated and normalized over the total, to be able to compare and rank different requirements. Subsequently, the policies associated to the requirements are ranked given the frequency with which they appear in users' replies. In the requirements' analysis phase, the association between policies and Copernicus application domains that users have identified to measure the distribution of European legislation across different domains is also studied. Requirements are then divided into quartiles based on their importance value. The requirements above the third quartile of the data, for which the importance value is higher, are selected for further analysis. Furthermore, different spectral bands are associated to the required spatial resolution and revisit times: for each spectral band the distribution of different spatial resolutions and revisit times are calculated for all the specific agricultural areas of interest. Once the demand is identified and characterized, the current Copernicus offer is analyzed by examining relevant EO missions. If a gap exists between demand and offer it means that some requirements are not monitored efficiently and therefore the goals of related policies are weakened. Thus, this gap analysis allows to finally identify areas of investment that are a priority for users.

3. Results

3.1. User legal requirements and association with Copernicus application domains

During the elicitation process, users identify a total of 37 requirements presented in Table 2. Each requirement is associate with a code to simplify data processing.

The regulatory framework identified by users includes different type of European policies and legislations but also some national laws mainly concerning agro-environmental issues. A description of these laws and regulations is provided in the supplementary material 3 of this paper.

From the analysis of the policies identified by users and reported in Fig. 2, most laws are considered to support the development of an agricultural EO service. This is partially justified by the fact that the CAP is one of the oldest policies of the European Union, with reforms gradually moving from being solely focused on productivity, to being more holistic in their view, pushing for increased competitiveness and sustainability (Kiryluk-Dryjska and Baer-Nawrocka, 2019). Secondly, users' replies indicate the need to consolidate the development of targeted agricultural EO products. In fact, EO technology is vital to develop agricultural mapping and monitoring application given the need for recurrent and frequent data to produce seasonal and annual information on crop production and regular, in-season indicators on crop development, crop status, nutrient and irrigation requirements (Transon et al., 2018; Whitcraft et al., 2015). Nevertheless, according to a report by the Joint Research Center (2016a) the integration of high-resolution EO imagery into operational agricultural activities have largely failed due to inadequate technical parameters, high costs of data acquisition and uncertain long-term perspective on data continuity. The results obtained in Fig. 2 thus, point to the need to move from the present vision to fully specified products and to a coherent agricultural service for Europe.

On the other hand, the domain of Climate Change is poorly populated by the laws identified by users. In fact, while a range of hard governance elements have been added to the EU's climate policy in recent years, including explicit legal provisions, external publicity, and concrete links to other policy processes (Schoenefeld and Jordan, 2020), national climate legislation and strategies have somewhat stagnated (Iacobuta et al., 2018). Nevertheless, it is possible to observe that European and national laws are distributed across different domains suggesting their relevance across sectors.

Given this preliminary evaluation, the requirements are ranked according to Eq. (1). This ranking provides a measure of their overall importance in the current legislation and represents the baseline on which the Commission will build its future efforts. As shown in Table 3 the importance values range from a minimum of 0,180 to 0,544 for requirement R27: "Physical characteristics of the vegetation cover".

The results are expressed as a percentage of the total possible value that each user need can take. Further analysis will concentrate on the requirements with the highest calculated value. After dividing the data into quartiles, the values equal and above the 3rd quartile (Q3) are taken into consideration, in other words users' needs with an importance value equal or higher to 0,364 as reported in Table 4.

This operation will allow prioritizing requirements and understanding which actions to adopt to improve their implementation.

Table 2
List of requirements identified by users and related requirement ID.

Requirement ID	Requirement description
R1	Multitemporal analysis of radiometries and vegetation indices for single crops or groups of crops: semi-automatic classification of crops
R2	Maintenance of the land in a state suitable for grazing or cultivation (annual activity) by analyzing agricultural activities throughout the year
R3	Graphic and thematic support for the correct declaration of crop limits in the agricultural parcel by the farmer
R4	Verification of compliance with crop diversification requirements based on eligible hectares declared by the farmer through multi-temporal analysis and indices
R5	Conservation of the permanent lawn area; prohibition of conversion to other use in particular on permanent grassland designated in sensitive areas
R6	Identification of production areas of ecological interest: land withdrawn from production and nitrogen fixing crops through CAPI or semi-automatic classification within specific time intervals
R7	Identification and monitoring of the characteristic elements of the landscape: hedges, tree-lined bands, trees in rows, isolated trees, groves, ponds, ditches, dry stone walls
R8	Continuous monitoring of annual LPIS variations (arable land and temporary and permanent meadows)
R9	Continuous monitoring of LPIS annual variations (permanent crops and artifacts)
R10	Classification of permanent lawn areas counted through a pro-rata system for estimating the ineligible area (rocks, shrubs, trees 0–5%; 5–20%; 20–50%; > 50%)
R11	More or less diffused streams and incisions, up to affect areas and geographical areas with respect to the correct application of temporal and permanent channels and vegetated bands
R12	Identification of vegetated buffer strips (arboreal or herbaceous) and their monitoring
R13	Diffusion/effect of chemical fertilizers on vegetated buffer strips along watercourses: risk analysis
R14	Prohibition of illegal distribution on the ground of manure with straw bedding (outside the impermeable fertilizers) and investigation of the high risk of pollution through the TYR analysis
R15	Burning of the stubble after harvesting through multispectral analysis
R16	Physical elements for the control of the homogeneous vegetation cover. Coverage for at least 90 days
R17	Characteristic features of the landscape, including hedges, ditches, trees in rows, in groups or isolated, fields of fields and terraces
R18	Physical elements; periods of submersion and duration
R19	Physical elements to establish the persistence of the vegetation cover
R20	Physical characteristics of forest types through remote sensing multitemporal analyzes and indices
R21	Physical characteristics of the soil: fraction of mineral soil and clay, portions of sand and silt
R22	Chemical characteristics of the soil through the analysis of absorption bands
R23	Chemical characteristics of organic matter in the soil
R24	Chemical characteristics of the soil
R25	Spatialization of biophysical parameters
R26	Space-time analysis of biophysical parameters
R27	Physical characteristics of the vegetation cover
R28	Spectral indexes time series
R29	Estimation of agricultural production at the local level
R30	Indicators for identifying damage and loss of production
R31	Physical characteristics of forest types by means of spectral signatures
R32	Identification and mapping of areas covered by fire and characteristics of forest types affected by multispectral analysis
R33	Physical characteristics of vegetation cover by comparison with official estimates
R34	Physical characteristics of vegetation cover in urban and rural areas
R35	Biophysical parameters
R36	Physical characteristics of the vegetation cover due to environmental conditions, plant diseases, etc.
R37	Comparison of physical characteristics

Further analysis concentrates only on these 11 requirements and the spectral bands needed to monitor them as reported in Table 5. The indicators provided by users, which are mainly vegetation indexes and land cover/land use products, are converted into spectral bands both in the visible and radar domain according to the relevant literature, a detailed conversion of the indicators into the different spectral bands is provided in the subsidiary material B to this publication. From Table 5 shows that most requirements benefit from the availability of multispectral data while few of them would need to use hyperspectral or radar data. Moreover, these 11 requirements fulfill the prescription of 5 European laws and 2 national ones.

It is important at this point to understand what characterizes these specific requirements and why they appear more important than other to the user pool. Fig. 3 represents the breakdown of the ranking value in its three components: average number of users expressing interest for the requirements, average number of laws fulfilled by each requirement and average importance value assigned by users to requirements in each quartile. This analysis shows that, while the number of users and number of laws or regulation are similar across the dataset, users assign a distinctive higher importance value to the requirements indicated in Table 5, in fact the average importance value for the requirements above the 3rd quartile is close to 5.

By looking at these requirements more closely through Fig. 4, it is evident that the majority of the requirements with the highest importance value (0,364 and above) support Regulation 1307/13 based on the implementation of direct payments under the first pillar of the CAP (about 3.7 billion per year in Italy). The vast majority of CAP legislation is in fact defined under four consecutive Regulations covering Rural Development (Reg.1305/13), horizontal issues such as funding and controls (1306/13), Direct Payments for farmers (1307/13), and market measures (1308/13). Regulation 1307/13 is a prerogative of the institutional users that are involved in the survey since it governs the procedures for requesting and paying direct aid, a procedure that is supported by the formal use of Sentinel data to substitute the area-related on-the-spot checks by the introduction of Regulation 2018/746. The relevance of EO data is especially relevant for these requirements since it is officially sanctioned by the European Commission and because of its simplification potential: the use of EO data for the requirements related to the emission of direct payments would in fact be a consistent improvement in terms of cost-efficiency (Sitokonstantinou et al., 2020; Varras et al., 2020).

3.2. Copernicus earth observation offer

The Copernicus program currently features 7 satellites missions: the so called "Sentinels". Sentinel-1 is a radar mission and it comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging which is particularly useful in agriculture because of its ability to penetrate the vegetation canopy (Ndikumana et al., 2018; Torbick et al., 2017; Veloso et al., 2017). Sentinel-2 on the other hand, provides high resolution optical images for land monitoring services. Its data has been extensively used for a wide range of applications in agriculture such as crop classification (Vuolo et al., 2018), precision agriculture (Segarra et al., 2020), vegetation health assessment and estimation of vegetation indexes (Guerini Filho et al., 2020; Kamenova and Dimitrov, 2021; Shukla et al., 2019). Sentinel-3 provides high-precision optical, radar and elevation data for marine and land services. It features four different instruments: OLCI - Ocean and Land Colour Instrument, SLSTR: Sea and Land Surface Temperature Instrument, SRAL: SAR Radar Altimeter, MWR: Microwave Radiometer. Sentinel 3 is particularly useful for the monitoring of vegetation for evapotranspiration estimation (Guzinski and Nieto, 2019) and land surface temperature (Hu et al., 2019).

Sentinels 4, 5 and 5 P are mainly used to monitor the atmosphere composition and air quality, therefore are not taken into consideration in this analysis (Lutz et al, 2018, 2020). Similarly, because of its scarce

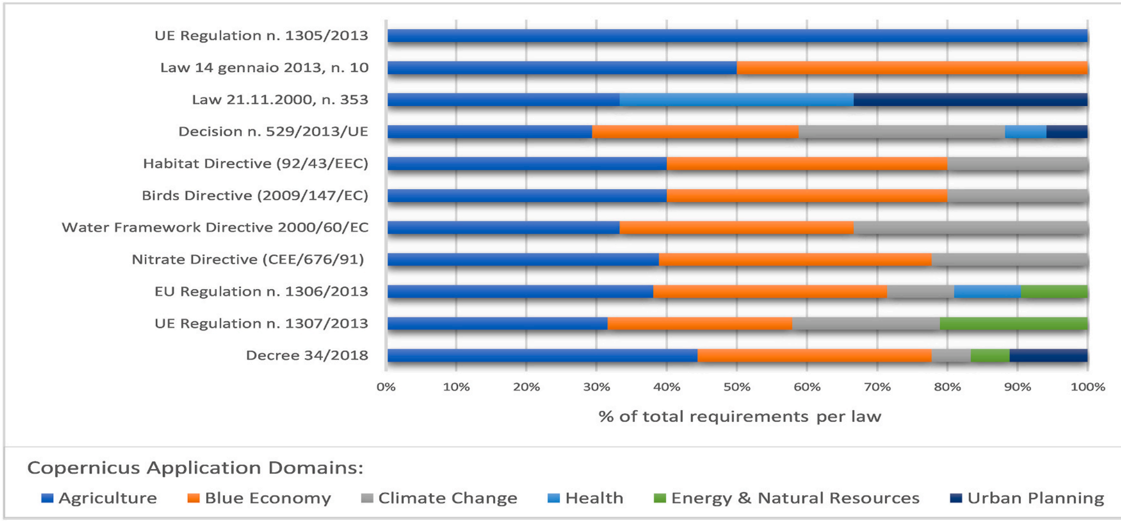

Fig. 2. Distribution of different Directive, Regulations and national laws identified by users over the Copernicus application domains.

Table 3
User requirements ID and their importance value.

Requirement ID	Importance value	Requirement ID	Importance value
R27	0,544	R24	0,324
R8	0,480	R25	0,311
R21	0,374	R26	0,311
R1	0,364	R13	0,297
R2	0,364	R14	0,297
R31	0,364	R35	0,297
R32	0,364	R19	0,294
R33	0,364	R37	0,280
R4	0,364	R23	0,274
R6	0,364	R16	0,264
R7	0,364	R36	0,264
R17	0,361	R18	0,230
R10	0,330	R22	0,224
R11	0,330	R29	0,197
R12	0,330	R30	0,197
R15	0,330	R34	0,197
R3	0,330	R20	0,180
R5	0,330	R28	0,180
R9	0,330		

Table 4
Division of importance data by quartiles.

Quartiles	Q0	Q1	Q2	Q3	Q4
Importance value	0,180	0274	0,330	0364	0,544

application for vegetation and agricultural monitoring, also Sentinel 6 is not considered in this study given its use for the collection of altimetric data for the global measurement of the height of the sea surface, mainly for operational oceanography and for climate studies (Donlon et al., 2021; Scharroo et al., 2016). In addition, satellite missions such as Metop ASCAT is also considered, which is a C band real aperture radar operated by EUMESAT providing data, products and support services to the Land Copernicus service and particularly useful for the development of vegetation indexes and soil wetness (Matgen et al., 2012; Steele-Dunne et al., 2019; Vreugdenhil et al., 2017). As part of contributing missions to Copernicus, the study also takes into consideration PROBA V and SPOT VGT ESA missions. The first collects light in the blue, red, near-infrared and mid-infrared wavebands, ideal for monitoring plant and forest growth (Roumenina et al., 2015) while the latter provides accurate measurements of the basic characteristics of vegetation canopies on an operational basis (Deronde et al., 2014; Lu et al., 2014). Finally, the HyperSpectral Precursor of the Application Mission (PRISMA) is also taken into consideration as an Italian Space Agency contributing mission in its preoperational stage and because of the potential of hyperspectral data for agricultural applications (Loizzo et al., 2018; Stefano et al., 2013). Besides improving the current use of Copernicus data and products, the Commission has been studying six high-priority candidate missions to expand the current capabilities of the Copernicus space component which will address EU policy requirements and user needs. The six new missions include: CHIME: a Copernicus Hyperspectral Imaging Mission (ESTEC, 2021); CIMR: Copernicus Imaging Microwave Radiometer (ESTEC, 2020a); CO2M: Copernicus Anthropogenic Carbon Dioxide Monitoring (ESTEC, 2020b); CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter (ESTEC, 2020c); LSTM: Copernicus Land Surface Temperature Monitoring (ESTEC, 2019); ROSE-L: L-band Synthetic Aperture Radar (ESTEC, 2018). The user requirements elicited in this study will integrate the set of needs already analyzed in this context. Accordingly, in Table 6 key Copernicus satellite missions and their technical specifications are identified. The selection among different missions has considered their relevance for the agricultural sector.

The orbit of Sentinel 1 has a 12-day repeat cycle and completes 175 orbits per cycle. Sentinel 1 has three different acquisition modes: Strip Map (SM), Interferometric Wide Swath (IW), Extra Wide Swath (EW), Wave (WV). However, according to the Product definition (Bourbigot et al., 2016), SM, IW and EW are the most suitable modes for application such as “Water Management and Soil Protection”, Forest Fire and Flood Management, Food Security and Crop Monitoring. Table 6 shows that for the three acquisition modes the highest spatial resolution is of 5 m, but this only allows a swath with of 80 km. The satellite has a global 12-day revisit cycle, however some products, such as the Surface Soil Moisture can be produced daily but only for continental Europe also thanks to the Metop ASCAT, Real Aperture Radar. Copernicus also produces multispectral data through Sentinel 2 which features a wide swath width (290 km) and high revisit time: 10 days at the equator with one satellite, and 5 days with 2 satellites which results in 2–3 days at mid-latitudes. Although Copernicus and the European Environmental Agency does not have a hyperspectral mission in place, the Italian Space Agency has launched in March 2019 PRISMA (Hyperspectral PRecursor of the Application Mission), focused on the development and delivery of hyperspectral products. As reported in Table 6, PRISMA has the ability to provide a spatial resolution of 30 m on a swath of 30 km and a 7-day revisit time.

Table 5
The table shows the requirements above the third quartile of the data, the most useful spectral bands to monitor them and the law that each requirement fulfils.

Requirement ID	Spectral Bands	Requirement description	Legislation
R27	VIS NIR RED SWIR	Physical characteristics of the vegetation cover	Reg. (UE) n. 1305/2013 Decree. 34/ 2018
R8	VIS NIR SWIR	Continuous monitoring of annual LPIS variations (arable land and temporary and permanent meadows)	Reg. (UE) n. 1306/2013
R21	Hyperspectral	Physical characteristics of the soil: fraction of mineral soil and clay, portions of sand and silt	Nitrates Directive Water Directive Decision n. 529/2013/E
R1	VIS RED NIR SWIR Hyperspectral	Multitemporal analysis of radiometries and vegetation indices for single crops or groups of crops: semi-automatic classification of crops	Reg. (UE) n. 1307/2013
R2	VIS RED NIR SWIR	Maintenance of the land in a state suitable for grazing or cultivation (annual activity) by analyzing agricultural activities throughout the year	Reg. (UE) n. 1307/2013
R31	VIS NIR SWIR	Physical characteristics of forest types by means of spectral signatures	D. Lgs. 34/ 2018
R32	VIS NIR SWIR	Identification and mapping of areas covered by fire and characteristics of forest types affected by multispectral analysis	Law 21.11.2000 353
R33	VIS NIR SWIR	Physical characteristics of vegetation cover by comparison with official estimates	D. Lgs. 34/ 2018
R4	VIS RED NIR Hyperspectral	Verification of compliance with crop diversification requirements based on eligible hectares declared by the farmer through multi-temporal analysis and indices	Reg. (UE) n. 1307/2013
R6	VIS NIR RED	Identification of production areas of ecological interest: land withdrawn from production and nitrogen fixing crops through CAPI or semi-automatic classification within specific time intervals	Reg. (UE) n. 1307/2013
R7	VIS SWIR NIR RED Radar	Identification and monitoring of the characteristic elements of the landscape: hedges, tree-lined bands, trees in rows, isolated trees, groves, ponds, ditches, dry stone walls	Reg. (UE) n. 1307/2013

3.3. Users' demand and gap analysis

Concerning the spatial resolution needs for these spectral bands, Fig. 5 shows that user preferences go from a minimum of <1 to a maximum value of 30 m. While for radar sensors users favor the use of data with a spatial resolution below 1 m, for most of the other spectral bands it is sufficient to fall within the limit of 3–10 m resolution. The preferences concerning temporal resolutions, are more heterogeneous, spanning from one week to yearly revisit times.

Specifically, the most prevalent demand per each spectral domain is the following:

1. Hyperspectral: 3–10 m spatial resolution and 15 days revisit time
2. Near Infrared: 3–10 m spatial resolution and 15 days revisit time
3. Short Wave Infrared: 3–10 m spatial resolution and 15 days, 1 month and annual revisit time
4. Red: 3–10 m spatial resolution and 15 days revisit time
5. Visible: 3–10 m spatial resolution and 15 days revisit time
6. Synthetic Aperture Radar: less than 1 m spatial resolution and annual revisit time

The goal of the gap analysis is to facilitate and provide guidance to investment policies suited to realize the potential of the downstream market created by Copernicus in the agricultural sector. The new investment policy will have to consider: (i) the future potential link to Copernicus services, (ii) structuring the internal system based on the new Copernicus evolution. By comparing the needs of users with the available offer, it is determined that, while revisit times are widely coherent with user needs, there is opportunity to further invest in the current spatial resolution offer (Table 7). In particular, Table 7 shows the gap between the most prevalent specifications from users and the highest spatial resolution and revisit time offered by the above mentioned missions.

4. Discussion

Given the preferences expressed by users in this paper, it appears that bridging the gap between user needs and currently available services will need consistent investments to bring the public sector closer to the private one. Despite the relevant effort of the European Commission in gathering user needs in support of the design of the Copernicus system, there is still a limited understanding of high-level non-technical user needs in the design of products and services. The distribution of European legislation into the different Copernicus domains, indicates that current agricultural policies are still concentrated on production and market competitiveness and that the regulation concerning climate change adaptation and disaster management is still marginal in the current CAP architecture (Heyl et al., 2020). This has an impact on the evolution of the Copernicus upstream and downstream sectors for agricultural activities even if the current offer in terms of revisit time appears to be congruent with users' demands. On the other hand, results provide insights into the capacity of Copernicus missions to fulfill the legal framework highlighted by users.

The process was dictated by two distinct sets of expectations. First to guarantee the stability and continuity of the current offer, while increasing the quantity and quality of Copernicus space component products and services for the CAP. These requirements are particularly important for the next generation of Copernicus Sentinels, providing enhanced continuity of the current observational capacity. Secondly, to identify emerging and urgent needs for new types of observations beyond current capacities. Spatial resolutions and revisit times can affect the performance of the application, however, datasets with high spatial resolution and revisit time can be costly and time demanding to be produced and it is important to assess tradeoffs between the accuracy of results and the cost they require. Despite most of the Copernicus products mentioned by users are available at coarser resolutions, relevant progresses for agricultural monitoring can be derived from the use of Sentinel 1 and 2 data. The evolution and expansion of the Sentinel fleet will generate long term time series boosting several applications, including change detection of agricultural land, yield forecast and definition and calibration of agricultural models. A combined use of Sentinel 1 and 2 data has for example been successfully applied for dynamic crop mapping and biophysical parameters estimation (Ferrant et al., 2017; Hasan et al., 2019; Mandal et al, 2018, 2020; Veloso et al., 2017; Wang et al., 2019). Thus the development of new products that follow user requirements would also support the shift from a compliance based to a performance-based CAP scheme (Herzon et al., 2018; Vainio et al., 2021), as foreseen in article 65 (7) of the proposed Regulation establishing rules on support for strategic plans to be drawn up by

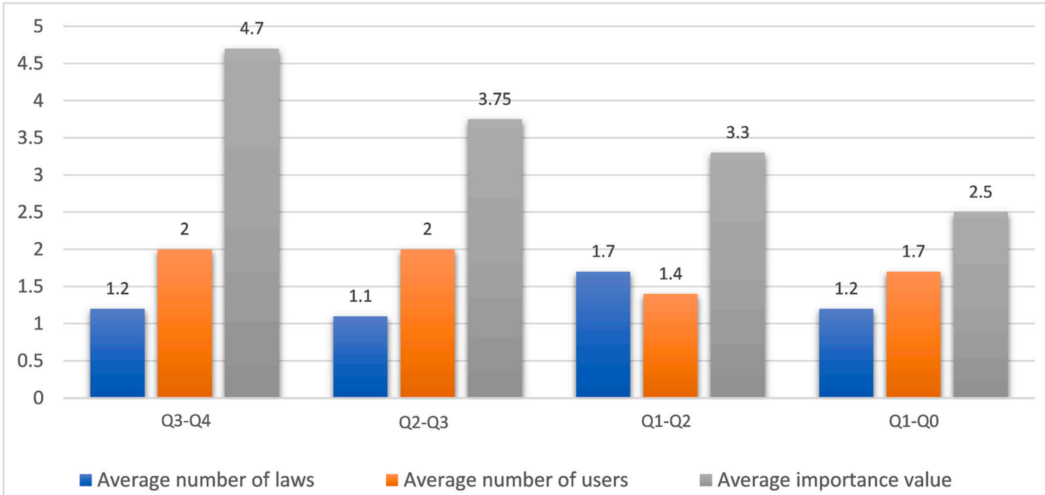

Fig. 3. The figure explains why requirements beyond the 3rd quartile of the data (Q3-Q4) have the highest ranking. The breakdown of the ranking value in its three components is represented: average number of users expressing interest for the requirements, average number of laws fulfilled by each requirement and average importance value assigned by users to requirements in each quartile subdivision.

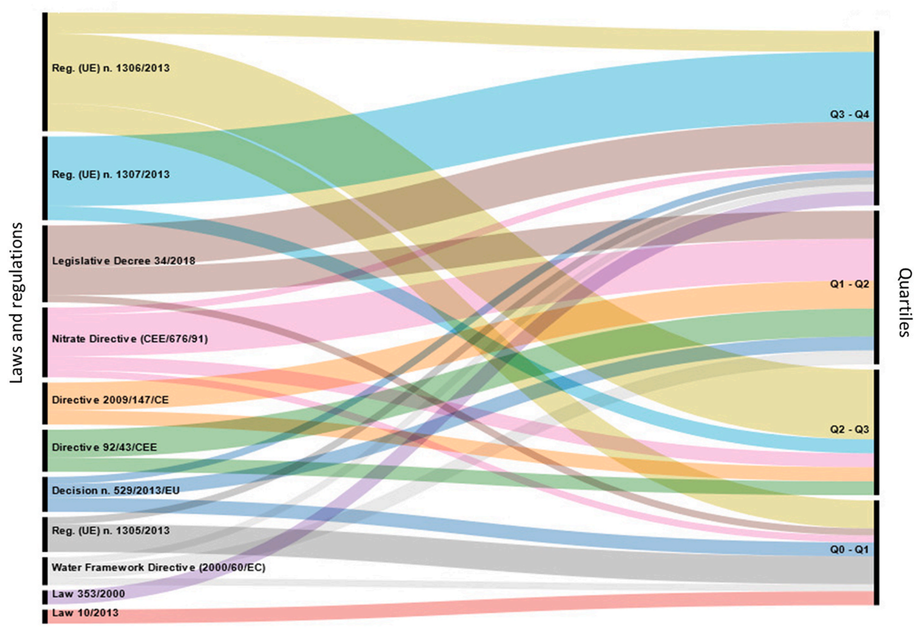

Fig. 4. Alluvial diagram indicating the relevance of each law and policy for each quartile.

Member States under the Common agricultural policy (European Commission, 2018b). As pointed out by Saba (2017) indeed, this new scheme would bring both ecological, economical and socio/cultural benefits to farmers. The results and the methods used in this study provide a contribution in this direction and can be of use to improve the quality and variety of monitoring data for the CAP and to develop measurable and identifiable indicators. This is especially true considering the technological limitations that have been highlighted and concerning the requirements with the highest importance value for users that affect the policies that the users indicated. In particular, the optimization of the shortcomings on spatial resolution identified from the gap analysis and reported in Table 7 can improve the monitoring and management of direct payments and other area-based support schemes under rural development as well as the simplification and digitalization of control procedures (Gomarasca et al., 2019).

These requirements should be addressed under the expansion of the Copernicus Sentinel fleet by the so-called High Priority Candidate Missions (HPCM). Both sets of expectations have been systematically reflected and integrated by the European Space Agency as the Copernicus Space Component System Evolution Architect in response to the Commission requirements (ESA, 2018; ESTEC, 2021, 2020a, 2020b, 2020c, 2019, 2018). Through this study is it also possible to prioritize future investment given the extent of the gap between the user demand and offer of EO products. The results show that the greatest gap occurs in the domain Short Wave Infrared bands, Hyperspectral and Radar data. As reported in Table 7 indeed, the spatial resolution offer for these three types of bands is limited and investment in these areas should be prioritized. In this context and despite their availability, the use of high resolution satellite imagery is largely limited to the development of generic crop land use classes released on a multi-year basis, typically through methods that use medium and low resolution (Joint Research Centre, 2016b). These limitations call for the development of a roadmap

Table 6
This table includes the technical specifications for the Copernicus current offer of optical and radar sensors.

Sensor	Mission	Spectral bands	Spatial resolution	Revisit time
Radar	Sentinel 1, Synthetic Aperture Radar, C band	5.405 GHz	5 m 5 × 20 m 20 × 40 m	12 days
	Sentinel 3, Synthetic Aperture Radar Altimeter	K_u and C band	300 m	4 days
	Metop ASCAT, Real Aperture Radar, C band	5.255 GHz	25 km	1 day
Multispectral	Sentinel 2	VIS, NIR SWIR	4 × 10 m 6 × 20 m	10 days (single satellite) or 5 days (combined)
	Sentinel 3, Sea and Land Surface Temperature Radiometer	VIS, NIR, SWIR	0.5 km	4 days
		Thermal IR	1 km	4 days
		Thermal IR Fire	1 km	4 days
	Sentinel 3, Ocean and Land Colour Instrument	VIS, NIR	300 m	4 days
	PROBA V	VIS, NIR, SWIR	300 m 600 m	10 days
	SPOT VGT	VIS, NIR, SWIR	1 km	10days
Hypespectral	PRISMA, HyperSpectral Precursor of the Application Mission, preoperational	VIS, NIR, SWIR	30 m	7 days

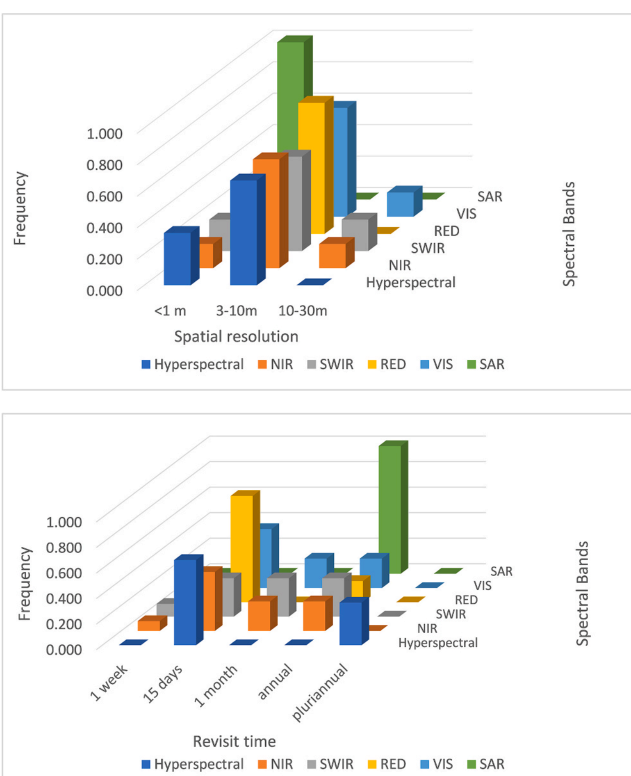

Fig. 5. Distribution of different spatial resolution and revisit time categories for each spectral range. The figures show the need of the user community to effectively monitor the requirements with the highest priority value.

Table 7
This table shows the gap existing between the demand and offer in terms of spatial resolution and revisit times for different spectral bands in Europe.

Spectral bands	Spatial resolution		Revisit time	
	Demand	Offer	Demand	Offer
Hyperspectral	3–10 m	30 m	15 days	7 days
NIR	3–10 m	4 × 10 m	15 days	5–10 days
SWIR	3–10 m	6 × 20 m	15 days, 1 month, annual	10 days
RED	3–10 m	4 × 10 m	15 days	5–10 days
VIS	3–10 m		15 days	
Radar	<1	5 m	Annual	12 days

for the definition of new agricultural products that will exploit the next Sentinel generation for the monitoring of the CAP (Gomarasca et al., 2019; Segarra et al., 2020; Torbick et al., 2017). To this end the European Space Agency has already invested in the Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) which is part of the HPCM and will be operational by the mid-2020s. However its technical specifications will not be very different from the current Italian precursor PRISMA, with a planned spatial resolution of 20–30 m and a revisit time between 10 and 12 days (Rast et al., 2019). But as mentioned in Taramelli et al. (2019), and confirmed by our study, a coarse spatial resolution represents a handicap also for the monitoring of climate change adaptation options such as green infrastructures (Piedelobo et al., 2019b) and nature-based solutions for agriculture. Even if specific legislation for climate change and adaptation should still be improved (Rayner and Jordan, 2016), several policies are associated to the domain of Green Economy, and indeed, the CAP has evolved to integrate environmental concerns and to better serve sustainability purposes. In fact, the CAP has recently introduced changes to improve coherence with environment and climate objectives (Herold et al., 2019). To this end, the European Space Agency has been investing in a L-band Synthetic Aperture Radar (ROSE-L). The ROSE-L mission will complement the data gained from the Sentinel-1 mission with especially useful applications for the agricultural sector and climate change. However, also in this case the planned spatial resolution of around 10 m (Pierdicca et al., 2019) suggest that overall, for the radar sector in forestry and agricultural domain the users analysis point to investments for the development of synergies between missions, such as existing missions supported by lower orbit mini constellations. This is mainly related to the fact that the Climate Change domain comprises a relatively low number of Directives and laws despite the increasing importance of this issue in Europe (European Environment Agency, 2019b; Grillakis, 2019; Harrison et al., 2019), especially in the agricultural sector. Partially this can result from the fact that the food sector in Europe has only recently been concerned with climate related legislation and data and information that can be gathered from radar sentinel. Nevertheless, the distribution of different laws among several Copernicus application domains shows that their effects can be inter-sectoral, and their benefits occur across various domains. Nevertheless, these results could have a different impact if the interaction is carried out in other contexts and other states. As a matter of fact, many European countries have adopted more advanced national adaptation programs aimed at reducing emissions (Biesbroek et al., 2010; Reckien et al., 2014). Differently from the limitations present in Italy, a higher interest in climate change adaptation and mitigation can be expected in countries that have implemented both National Adaptation Policies and Strategies. Although the requirement pertaining to the EU legal framework would not change, national legislations could vary according to the different agro-environmental challenges of the various geographical regions. For example, Europe will see a progressive increase in overall climate hazard affecting in particular south-western regions; key hotspots will emerge along coastlines and in floodplains in Southern and Western Europe, which are often highly populated and economically pivotal (Forzieri et al., 2016). The predicted effect of climate change in these areas could direct the interest of users both in terms of relevant policies and laws but also concerning the type of data required to monitor them.

5. Final remarks

While Copernicus services are structured to be user driven and represent a valuable mean to support the move towards better integration of climate change adaptation and ecosystem management, these user needs are not clearly identified and defined, which restrain the development of specific products and services tailored to non-technical end users like local, regional and national authorities. On the other hand, non–technical users remain generally not aware of the opportunity offered by geospatial solutions to respond to their needs.

Stakeholders have also highlighted some shortcomings to be addressed in the near future. Users have pointed to the improvement in the current offer of European EO products, particularly it appears important to optimize the offer of open and free products delivered by Copernicus to complement existing national missions. The availability of products and data with higher spatial resolution appears to be the main request from the community of users.

The dynamic approach proposed in this article and its focus on operational needs, has the goal to support the sustainable uptake of Space Data-based information for agro-environmental policy and Europe's' ambitious goals for the future. In fact, the gap between actual and potential performance of EO data, could lead in time to inefficiencies.

Actions promoting these objectives, such as the evaluation of users' needs, are preconditions for the efficient use of space data for the public. The limitations of this study can be attributed to the fact that the methodology relies mainly on expert opinion. Despite this information is crucial to grasp the complexity of the interaction between legislations and the availability of technical instruments, users have also different perspectives. Another limitation is represented by the complexity of the interaction matrix submitted to users: as to ensure full understanding of the relation between components, significant time should be spent with respondents. Moreover, the study is limited to only one country, while it would be interesting to explore the differences between different states, also given the diversity in environmental challenges due to geographic and/or climatic differences.

Credit author statement

Emma Schiavon: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing; Andrea Taramelli: Conceptualization, Validation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition; Antonella Tornato: Methodology, Validation, Writing – original draft, Writing – review & editing, Visualization; Fabio Pierangeli: Methodology, Validation, Writing – original draft, Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113121.

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