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An Interaction Methodology to Collect and Assess User-Driven Requirements to Define Potential Opportunities of Future Hyperspectral Imaging Sentinel Mission

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Abstract: Evolution in the Copernicus Space Component is foreseen in the mid-2020s to meet priority user needs not addressed by the existing infrastructure, and/or to reinforce existing services. In this context, the European Commission is intending to evaluate the overall potential utility of a complementary Copernicus hyperspectral mission to be added to the Copernicus Sentinels fleet. Hyperspectral imaging is a powerful remote sensing technology that, allowing the characterization and quantification of Earth surface materials, has the potential to deliver significant enhancements in quantitative value-added products. This study aims to illustrate the interaction methodology that was set up to collect and assess user-driven requirements in different thematic areas to demonstrate the potential benefit of a future Copernicus hyperspectral mission. Therefore, an ad hoc interaction matrix was circulated among several user communities to gather preferences about hyperspectral-based products and services. The results show how the involvement of several user communities strengthens the identification of these user requirements. Moreover, the requirement evaluation is used to identify potential opportunities of hyperspectral imaging in addressing operational needs associated with policy obligations at European, national, and local levels. The frequency distribution of spectral range classes and spatial and temporal resolutions are also derived from the preference expressed by the user communities in each thematic area investigated.

Keywords: user-driven requirements; policy-driven requirements; EU Copernicus Programme; hyperspectral; spectral ranges; spatial and temporal resolutions

1. Introduction

Increasing awareness of the influence of climate change and anthropogenic impacts on the environment requires an increasingly in-depth knowledge of environmental matrices, of the changes taking place in these matrices, including the study and understanding of the mechanisms of influence between human activities, and consequent changes in the different environmental sectors [1]. This is particularly true for the agricultural sector, where in-depth information is required to face ongoing challenges concerning better efforts to ensure worldwide the production of safe, high-quality, affordable, nutritious, and diverse food (see, e.g., the UN's Sustainable Development Goals 2030 (SDG 2030)). At the same time, advances in the use of increasingly sophisticated technologies make it possible to have available datasets measured on the ground or acquired remotely. Using these data synergistically makes it possible to characterize the compartments and interactions of the environment with human activities in an extremely more accurate way than in the recent past, whether it be observations of ocean, cryosphere, and land, Global Land Cover (GLC) information, macroecology applications from space on terrestrial ecosystems [2–4]. However, the use of these new technologies and the reliability of the derived information are strongly influenced by quality and availability as well as the ability to know how to use and interpret them [5]. Following the investments of the European Commission (EC) and European Space Agency (ESA) to design, build, and operate Copernicus satellite missions, which are referred to as Sentinels, a fully-fledged European Union (EU) Earth Observation (EO) satellite capacity is now operational with the primary objective of providing appropriate satellite observations [6] supporting, in particular, the implementation of EU policy through the supply of innovation Copernicus downstream services [7].

Thus, among the various technologies and data sources available, the availability of spectral data makes it possible to obtain valuable information in support of, for instance, the observation and characterization of natural resources, environmental processes, cropland phenology and canopy, as well as information on the impacts of many of the main human activities that affect the environment to varying degrees.

For instance, spectral signatures of different surface types and targets can be used to provide information on (*i*) chemical properties of soil and rock [8,9]; (*ii*) hydromorphological features of river systems at multiple scales [10]; (*iii*) pigment composition and chlorophyll fluorescence [11–13]; and (*iv*) land-cover and land-use variability [11]. These information have become crucial to support:

- The management of natural and anthropic risks (e.g., hydrological and geological risk, volcanic risk, effects of climate change, and pollution of water resources);
- The monitoring and management of agricultural, water resources, and forestry resources (e.g., areas covered by fire, desertification, soil pollution, habitat monitoring);
- The control of human activities (e.g., mineral resources, urbanization, and cultural heritage).

The Copernicus Programme—the EU Earth Observation and monitoring programme (http://www.copernicus.eu/)–was designed to provide a European response to the aforementioned needs. Initially, the Copernicus Services were developed mainly on the basis of the space and in situ data available. Nowadays, the challenge is to tailor and develop these services, taking into account the user needs collected through the National Copernicus User Forum established in each EU Member State [6], as well as presented by the European Commission in the commission staff working document "Expression of User Needs for the Copernicus Programme" [14]. The aim is to evaluate the potential opportunity provided by future satellite missions as well as to identify a portfolio of new products to support and consolidate the EU policy and commitments with a wide range of practical applications [15–18].

Presently, the Copernicus Space Component (CSC) does not include hyperspectral imaging capabilities. With the purpose to investigate how this technology could support the user needs, the EC issued in 2016 the tender "Hyperspectral Imaging Mission Concepts" to fund two parallel studies in support of the second generation of the Copernicus Programme.

One of the studies, which was coordinated by Italy and ended in February 2018, achieved a twofold objective: (*i*) identifying the user requirement baseline for operational information data streams not yet covered by either current or planned in orbit satellite capacity that could take benefit from the availability of hyperspectral data; and (*ii*) evaluating the overall utility of a complementary Copernicus hyperspectral mission to be added to the Copernicus Sentinels fleet, avoiding (or at worst minimizing) overlaps with current and planned multispectral and hyperspectral missions.

In order to collect the user needs and, consequently, to define the user requirement baseline, a continuous, effective involvement of different users from public and private communities was required within the study. From one side, the involvement of the users from the public communities (including ministries, environmental agencies, and local administrations) was useful to identify needs mainly derived from policy obligations at European, national, and local levels. From the other side, feedback from the private sector community was used to recognize the strategy necessary to improve and advance the market performance. Given the heterogeneity and complexity of the user needs, a scale approach system, based for instance on an objective model [19], should be adopted. Such an approach allows correctly evaluating the user requirements and correctly addressing the technological innovation answer of the hyperspectral sensor. However, in order to improve and strengthen the strategies implemented in previous experiences [19] and support the operational implementation of EU, national, and local policies, a new, standardized methodology to collect, analyze, and prioritize in this framework the user needs and successively identify the service requirements was defined as follows.

Usually, 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*" [20]. Appling this concept to a service, the requirement is a condition or capability of the service to solve a user's problem or to achieve a user's task [21], because of a need identified by the user itself. The definition of user requirements is a common practice in the field of Information Technology, where a specific role is assigned to the "requirements engineering" [22–24]. Its aim is to connect the user communities that have specific needs with those who are involved in developing algorithms that fulfill these needs [23]. When the user needs are clear, the products will be developed efficiently, effectively, and quickly [25]. To achieve the goal of defining a clear and unambiguous list of realistic requirements and, at the same time, of ensuring the fruitful engagement of users and stakeholders, the requirements engineering should be based on an interaction methodology, as the ones reported, for instance, in [26,27], which is characterized by at least three different phases:

- the identification of the users and stakeholders to be involved in the requirement collection;
- the analysis of the collected requirements in order to identify the priorities for the different user communities and the preferences on spectral, spatial, and temporal resolutions of possible future products and services;
- the identification of those requirements that are already fulfilled by available products and those for which the development of new products is feasible.

Finally, a management phase of the requirements is necessary to assess and verify the compliance of developed products to the user and stakeholder needs and to define a suitable strategy to fulfill the gaps that can be detected during the product development.

Hence, the "requirements engineering" approach can be conveniently adapted to assess user requirements in the current framework. For instance, a similar methodology was already implemented to evaluate potential hyperspectral applications in the domains of water quality monitoring, vegetation analysis and ecology, aerosol retrieval, materials classification, as well as Bidirectional Reflectance Distribution Function (BRDF) [28]. Having in mind these previous experiences, also applied to other topics, an interaction methodology was adopted to study the potential benefits of a future hyperspectral mission within the Copernicus Programme by a direct involvement of several user communities. A wide user involvement is necessary to highlight the interest in diversified potential hyperspectral-based products and services to both the institutional users in supporting the implementation of EU, national, and local policies and the private users in developing, promoting, and marketing downstream products and applications.

The present paper investigates how this interaction methodology was designed and implemented and discusses the user preferences in terms of spectral ranges and spatial and temporal resolutions. These latter results are extremely useful to design the high-level observational requirements for a future Copernicus mission.

The paper is organized as follows. The Copernicus Programme and the state-of-the-art of the hyperspectral technology are described in Section 2. An overview of the framework under investigation, including Copernicus application domains, EU policy, thematic areas, user communities involved, and a description of the interaction methodology used to collect and assess the user requirements are also proposed in this section. The results of the user requirement evaluation are shown in Section 3 and discussed in Section 4. Finally, Section 5 provides conclusions on the usefulness of a users' consultation procedure.

2. Materials and Methods

2.1. The Copernicus Programme

The Copernicus Programme is designed and operates to make available to several public and private user communities trusted and quality multi-source products and services. These products and services are also based on EO data from the Sentinel missions observing land, atmospheric, and oceanographic parameters and in situ monitoring and simulations. They are relevant to facilitate and sustain the implementation of environmental legislation and policies (i.e., policy-driven), to take critical decisions in the event of an emergency, such as a natural disaster or a humanitarian crisis, and to realize societal benefits through improving environmental resource and risk management. Being part of the Copernicus Programme, Sentinel data and derived products are regulated by a free and open access policy that has entailed a significant shift in the current way of thinking about the geo-information market and facilitated the realization of new commercial downstream applications [16]. In addition, the Copernicus Programme is structured to be user-driven (Figure 1). This implies a strong engagement of the institutional, scientific, and industrial communities in a unique and virtuous system. This system should be intrinsically devoted to innovation while aiming at the provision of multifaceted operational Copernicus Services: user-centered design benefits can include "increased productivity, enhanced quality of work, reductions in support and training costs and improved user satisfaction" [26].

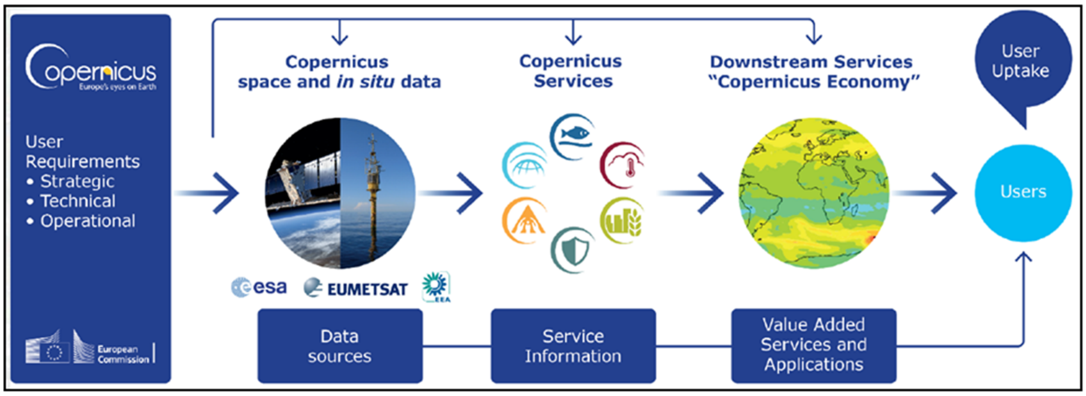


Figure 1. Copernicus user-oriented strategy (after the European Copernicus website).

The Copernicus Programme is built upon two main pillars:

- the upstream component that includes in situ measurements (from ground-based stations and airborne sensors) and observation from satellites (Sentinels and Contributing Missions from other space agencies); and
- the services, processing raw data into exploitable information for end users.

To cope with additional and advanced user needs, ensuring the improvement of geo-information data and services for environmental monitoring, emergency response, and crisis management and security, a new generation of Sentinel missions, including a hyperspectral Sentinel, is foreseen and under investigation.

Since space and EO are strategic fields for EU, the new Space Programme for period 2021–2027, which is currently under discussion [29], aims to strengthen investments in space activities, adapting to new needs and technologies.

2.2. The Hyperspectral Remote Sensing State of the Art

In recent decades, the need for improved detection technologies and an increased quantity of information on the Earth's surface has boosted initiatives and fora where hyperspectral imaging spectroscopy and its mission legacy have been discussed [30,31]. The history of hyperspectral imaging spectroscopy is connected both to technological development and to the improvement of absolute and relative radiometric calibration [32,33].

Hyperspectral imaging sensors acquire images characterized by hundreds of contiguous bands with high spectral resolution. The main principles of the hyperspectral imaging rely on the exploitation of light dispersion technologies to split the light beam by using prism optical systems and innovative solutions based on diffraction gratings devices before the detector arrays sensing [33–36].

The light dispersion principle exploited in hyperspectral imaging is the main feature that makes this technology radically different from the multispectral (MS) and super-spectral (SS) technologies that are widely used for remote sensing imaging. In fact, in place of dispersion optical systems, multispectral and super-spectral imaging are achieved by using optical spectral filters applied to the detectors. This different imaging mechanism and the capability of acquiring image with several bands make the design of hyperspectral satellite missions highly demanding [35,36].

Since the early 1980s, airborne observations have been used to demonstrate the capabilities that hyperspectral remote sensing brings to understanding environment, atmosphere components, and terrestrial and aquatic ecosystems, and to providing information in the field of ecology, agriculture, forest status, oceanography, and geology analyses [33,36–40], as summarized in Table 1.

Table 1. Main features of some typical airborne hyperspectral imaging systems, including spectral range, spectral sampling interval (SSI), number of channels, field of view (FOV) and instantaneous field of view (IFOV).

Sensor (Country)	Spectral Range (nm)	SSI (nm)	Number of Channels	FOV (deg)	IFOV (mrad)	Application
AVIRIS NG (USA) [41–64]	380–2500	9.7–12.0	224	30	1	Ecology, agricultural and forest status, oceanography, geology, atmosphere, ice, snow, clouds
MIVIS (Italy) [65–78]	433–833 1150–1550 2000–2500 8200–12700	20 50 8 400–500	20 8 64 10	70	2	Geological and environmental study
Hymap (Australia) [79]	400–2500	10–20	128	61.3	2×2.5	Mineral exploration and environmental, agricultural and forest monitoring
APEX (Europe) [80]	380–970 940–2500	0.5–8.0 10.0–6.0	114 199	28	0.48	Pigments and chlorophyll fluorescence in agriculture
Hyplant-DUAL (Germany-Finland) [81–88]	380–970 970–2500 670–780	4.0 13.3 0.25	350 272 1024	32.3 32.3	0.0832 0.0832	Agricultural and forest status, vegetation fluorescence
CASI (Canada) [89–98]	400–2500	2.4/7.5	96/200	40	0.49/0.698	Ecosystem, terrestrial features observation

With reference to the spaceborne configuration, the first satellite-based hyperspectral sensor was Hyperion, which was aboard the NASA EO-1 platform [99]. Despite its limitations, Hyperion has demonstrated the potential for hyperspectral data compared to multispectral systems [100–113] and provided the basis for algorithms applicable to next-generation sensors such as hyperspectral Precursor of the Application Mission (PRISMA), Environmental Mapping and Analysis Program (EnMAP), and Surface Biology and Geology (SBG, previously Hyperspectral InfraRed Imager – HyspIRI), e.g., [102,114]. The Hyperspectral Imager for the Coastal Ocean (HICO), a sensor that was aboard the International Space Station, was another pioneering example of how a hyperspectral sensor can provide more detailed information about the environmental conditions compared to multispectral systems [115–120]. Table 2 highlights 20 years of past and future hyperspectral satellite missions and applications. The new initiatives under development will lead to missions with increased data acquisition capacity and quality [121].

Table 2. Main features of some current and planned spaceborne hyperspectral imaging systems. BRDF: Bidirectional Reflectance Distribution Function.

Mission/ Sensor (Country)	Launch Date	Spectral Range (nm)	Spectral Resolution (nm)	Number of Channels	Spatial Resolution (m)	Swath (km)	Features
Hyperion (USA) [99,122,123]	Nov. 2000 Now closed	400–2500	10	220	30	7.5	Technology validation/demonstration mission
CHRIS (Europe) [124,125]	Oct. 2001 Now closed	400–1050	1.25@400 nm 11@1050 nm	62 Mode 1 18 Mode 2–5	36 Mode 1 18 Mode 2–5	14	Technological demonstrator to collect BRDF data for the better understanding of spectral reflectances
HICO (USA) [115–120]	Sep. 2009 Now closed	380–960	5.7	102	90	42–192	Observing coastal ocean
PRISMA (Italy) [126–128]	Mar. 2019	400–1010 920–2500 400–700	10	66 173 1	30 30 5	30	Europe and the Mediterranean region observation
EnMAP (Germany) [129–132]	Exp. 2020	420–1000 900–2450	6.5 10	98 130	30	30	Scientific path finder mission for later operational services, for environmental monitoring, process understanding
HISUI (Japan) [133,134]	Dec. 2019	440–970 900–2500	10 12.5	185	20 (cross track) 30 (along track)	20	Oil/gas/mineral resource exploration and other fields such as agriculture, forestry, and coastal issues
FLORIS/ FLEX (Europe) [135]	Exp. 2022	500–780	0.3–3		300	105–150	Quantitative global mapping of actual photosynthetic activity of terrestrial ecosystems, as a function of variable vegetation health status and environmental stress conditions
SHALOM (Italy-Israel) [28,136]	Exp. 2022	400–1010 920–2500 400–700	~10		10 10	10	Environmental quality, crisis monitoring, search for mineral and natural resources, monitoring water bodies, assisting precision agriculture activity
HYPXIM-P (France) [137]	Exp. 2020	400–2500 8000–12000	10 100–150	210 40	< 8 100	16	Vegetation, coastal and inland water ecosystems, geosciences, urban environment, atmospheric studies, security and defense
HyspIRI/SBG (USA) [54,138–143]	Exp. 2022	380–2510	10		30(60)	145–600	World ecosystems, natural disasters (volcanoes, wildfires, and drought)

The processing of hyperspectral data (wavelengths from 400 to 2500 nanometers, with a spectral resolution of 10 nanometers), using physical models and specific algorithms, allows exploiting the spectral signature of the imaged targets. Then, this processing could support the identification of chemical components present in the observed scene and their relative abundance. Innovative applications should optimize cultivation practices (e.g., precision farming) by generating improved and accurate land-use maps and analyzing the state of forests and crops. Moreover, these applications should support the identification of chemicals and pollutants on the ground and in building materials (e.g., asbestos) and the diagnosis on the state of cultural goods [144]. It will provide an opportunity to assess ecosystem changes and functions, natural hazards such as volcanic eruptions and wildfires, and snow properties [145]. To this aim, global observations at high spatial and spectral resolution are needed [139,146].

2.3. Methodology: The Interaction Legal Framework

One of the first aspects considered for the definition of an appropriate methodology for collecting and analyzing the user-driven requirements was to investigate and to identify the linkage between the Copernicus Application Domains and the EU policy. This aspect was extremely relevant and pivotal in the methodology definition considering that the underlying strategy of the Copernicus Programme is to provide data, tools, and services that facilitate and sustain the implementation of the European environmental legislation. The result of this investigation is the matrix reported in Table 3 that described how each of the Copernicus Application Domains are related to each of the directives, regulations, agreements, and communications that regulates the EU environmental policy framework. In addition, the EU legislations were also aggregated with respect to several thematic areas to facilitate the interaction with the different user communities. The thematic areas considered cover the following fields: Agriculture/Food security (hereinafter referred to as "AF"), Ecosystem structure/composition ("EC"), Inland/coastal water and environment ("IC"), Air quality ("AQ"), Cultural Heritage ("CH"), Raw materials ("RM"), Natural and man-made hazards ("NH"), Ice and snow ("IS"), and Urban Area Management ("UM").

The public and scientific user communities and the private sector that were involved in the study are reported in Table 4. In addition, Table 4 reports for each user community information on territorial reference level, the main field of activity, and thematic areas of interest. Considering that the study was a pilot action aiming at evaluating potential opportunities provided by hyperspectral imaging, it was decided to apply the interaction methodology to all the user communities of the Italian National Copernicus User Forum. As stated in the EU Copernicus Regulation *"Copernicus is user-driven; it requires the continuous, effective involvement of users, particularly regarding the definition and validation of service requirements. In order to increase the value of users, their input should be actively sought through regular consultation with end-users from the public and private sectors"*. For that purpose, a working group at the national level in Italy, a "User Forum", was set up to assist the Copernicus Committee Delegation with the identification of user requirements, the verification of service compliance, and the coordination of public sector users. The Italian National Copernicus User Forum that was indeed constituted in 2014 in the framework of the Italian Presidency of the Council of Ministers with the aim of (*i*) sharing information about the ongoing and foreseen EU Copernicus activities, (*ii*) contributing to the definition of EU and national space policies, and (*iii*) stimulating qualified, authoritative and coordinated national requirements to support the implementation of user-oriented services offered by the Copernicus Programme. The implementation is based on the task of monitoring the application of the regulation (EC) based on the national statistical approach of harmonized concepts and methods and to disseminate comparable national and European statistics as EUROSTAT (Eurostat (CE) n. 577/98). This choice guaranteed covering all the thematic areas under investigation and, at the same time, prevented results from being biased by different national environmental laws, considering that the national survey met the requirements of European regulations implementation at each national level that is tuned with the application for each single member state.

Table 3. Copernicus Application Domains versus European Union legal acts and communications.

	Copernicus Application Domains							
Thematic Areas / European Policy	**Agriculture, Forestry & Fisheries**	**Biodiversity & Environ. Protection**	**Climate & Energy**	**Civil Protection & Humanitarian Aid**	**Public Health**	**Tourism**	**Transport & Safety**	**Urban & Regional Planning**
Agriculture/Food security								
Nitrates European Directive (91/676/EEC)								
Common Agricultural Policy								
Habitats Directive (92/43/EEC)								
Birds Directive (2009/147/EC)								
Enhancing Europe's Natural Capital COM/2013/0249 final								
Animal By-Products Regulation (1069/2009/EU)								
Ecosystem structure/Composition								
Habitats Directive (92/43/EEC)								
Birds Directive (2009/147/EC)								
Animal By-Products Regulation (1069/2009/EU)								
Inland/Coastal water and environment								
Marine Strategy Framework Directive (2008/56/EC)								
Water Framework Directive (2000/60/EC)								
Bathing Water Directive (2006/7/EC)								
Maritime Spatial Planning Directive (2014/89/EU)								
Strategic Environmental Assessment Directive (2001/42/EC)								
Floods Directive (2007/60/EC)								
Habitats Directive (92/43/EEC)								
Directive Urban Wastewater Treatment (91/271/EEC)								
Air quality								
Ambient Air Quality and Cleaner Air Directives (2004/107/EC and 2008/50/EC)								
Cultural heritage								

Table 3. *Cont.*

	Copernicus Application Domains							
Thematic Areas European Policy	Agriculture, Forestry & Fisheries	Biodiversity & Environ. Protection	Climate & Energy	Civil Protection & Humanitarian Aid	Public Health	Tourism	Transport & Safety	Urban & Regional Planning
General Conference of the United Nations Educational, Scientific and Cultural Organization meeting, Paris, 17 Oct. – 21 Nov. 1972								
Raw materials								
Raw Materials Initiative (COM/2008/699)								
Natural and man-made hazards								
Restrictions on the marketing and use of certain dangerous substances and preparations (asbestos) [1999/77/CE]								
Thematic strategy for soil protection (COM/2006/231)								
Water Framework Directive (2000/60/EC)								
Floods Directive (2007/60/EC)								
Ice and snow								
No specific reference								
Urban area management								
Decision n. 1386/2013/EU								
EU biodiversity strategy (COM/2011/0244 final)								
Enhancing Europe's Natural Capital (COM/2013/0249 final)								

Table 4. List of public and private user communities involved in the study, with indication of the territorial reference level (national, in light blue vs. regional, in orange), the main field of activity, and the thematic areas of interest.

USER COMMUNITIES [Public/Private]	USERS	USER MAIN FIELD OF ACTIVITY [Thematic Area of Interest]
Italian National System for Environmental Protection (SNPA) [Public] *https://www.snpambiente.it*	ARPA Liguria	Management/Services [IC - AQ - RM - NH - UM]
	ARPA Veneto	Management/Services [AF - EC - IC - AQ - RM - NH - IS - UM]
	ARPA Valle d'Aosta	Management/Services [AF - EC - AQ - IS]
	ARPA Puglia	Management/Services [AF - EC - IC - AQ - CH - RM - NH - UM]
	ARPA Piemonte	Management/Services [AF - EC - IC - AQ - RM - NH - IS - UM]
	ARPA Calabria	Management/Services [IC - UM]
	ARPA Lombardia	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
	APPA Bolzano and Provincia Autonoma di Bolzano	Management/Services [AF - EC - IC - AQ - RM - NH - UM]
	ARPA Toscana	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
	ARPAE Emilia Romagna	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
	ARPA Friuli Venezia Giulia	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
Italian National Committee for Operational Hydrology Services [Public] *http://www.isprambiente.gov.it/pre_meteo/idro/Tavolo_IdrologiaOper.html*	Regione Basilicata	Management/Services [IC - IS]
	ARPA Lombardia	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
	Regione Puglia	Management/Services [IC - NH]
	ARPA Veneto	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
Italian Ministry of Agricultural, Food and Forestry Policies (Mipaaf) [Public] *https://www.politicheagricole.it*	CREA – Council for Agricultural Research and Analysis of the Agricultural Economy	Research [AF]
Italian Civil Protection Department (DPC) [Public] *http://www.protezionecivile.gov.it*	DPC	Management/Services [AF - IC - AQ -NH - IS - UM]
Italian National Research Council (CNR) [Public] *https://www.cnr.it*	CNR	Research [AF - EC - CH - RM]
Association of Italian Space Enterprises (AIPAS) [Private] *https://www.aipas.it*	INDUSTRY 1 INDUSTRY 2	Management/Services [AF - EC - IC - AQ - CH - RM - NH - IS - UM]
Italian Ministry of Infrastructures and Transport (MIT) [Public] *http://www.mit.gov.it*	MIT ENAC RFI	Policy/Management/Services [IC - AQ - CH - NH - UM]
Italian Air Force Meteorological Service of Ministry of Defense (MID-AM) [Public] *http://www.meteoam.it*	MID-AM	Management/Services [AQ - NH]
Italian National Institute of Geophysics and Volcanology (INGV) [Public] *http://terremoti.ingv.it*	Remote Sensing Activities	Research/Services [NH]

The Interaction Methodology with the User Communities

The interaction methodology aimed to identify the user-driven and policy-driven services potentially generated using hyperspectral satellite data. The methodology can be summarized as follows (Figure 2):

- A pre-processing phase that consisted of the involvement of the user communities and in the collection of their feedbacks on EU policy, thematic areas of interest, requirements, and parameters by means of an interaction matrix;

- A processing phase where the feedback from user communities was analyzed in order to prioritize the user interests, identifying a "priority value" for each requirement as a function of an "importance value" that users provided to each parameter (Figure 3a–c);
- A post-processing phase in which the assessment of results was used to match the spatial and temporal resolutions required by the user communities with hyperspectral-based products and services (hyperspectral-derived algorithms, hereinafter referred to as "hyperspectral layers"), which were available and already developed at the time of the study. An extensive review of the scientific literature about hyperspectral-derived algorithms was hence conducted to detect suitable layers for the identified user requirements. Moreover this match highlighted the number of times a particular spectral range was present in those products and services achieving user needs.

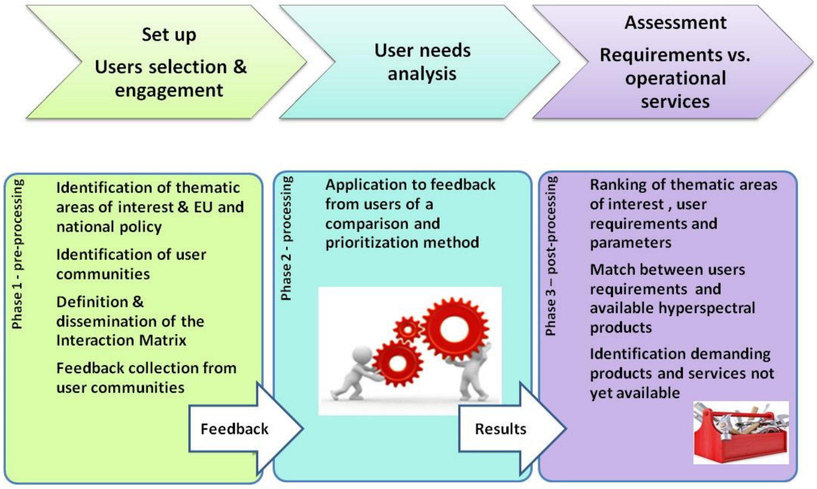


Figure 2. Interaction methodology developed for the study to collect and analyze user needs and to assess user requirements for hyperspectral products.

The interaction matrix used in the pre-processing phase consists of three sections:

- Section 1 includes information on thematic areas and policy framework (i.e.; the specific objects of the EU policy for each linked thematic area);
- Section 2 includes requirements necessary to cope with the specific EU policy reported in Section 1 and the associated parameters for the specific environmental compartment (air, water, soil/sediments, etc.) that are necessary to achieve the identified requirements;
- Section 3 is used to inquire user communities about the score in terms of "importance value" for each parameter reported in Section 2 (Figure 3a) and the expected technical attributes of the services, namely the spatial resolutions (Figure 3b) and temporal resolutions (Figure 3c).

This matrix was disseminated among the selected user communities (see Table 4), and the collected feedback was analyzed during the processing phase. First, the feedback analysis was conducted per single user community. This was done in order to assess which of the requirements were more relevant with respect to their institutional or commercial activities. Then, the results associated with all the involved communities were evaluated together. This was useful to provide a unique picture within the Italian context of the potential opportunities given by EO products based on data from hyperspectral sensors.

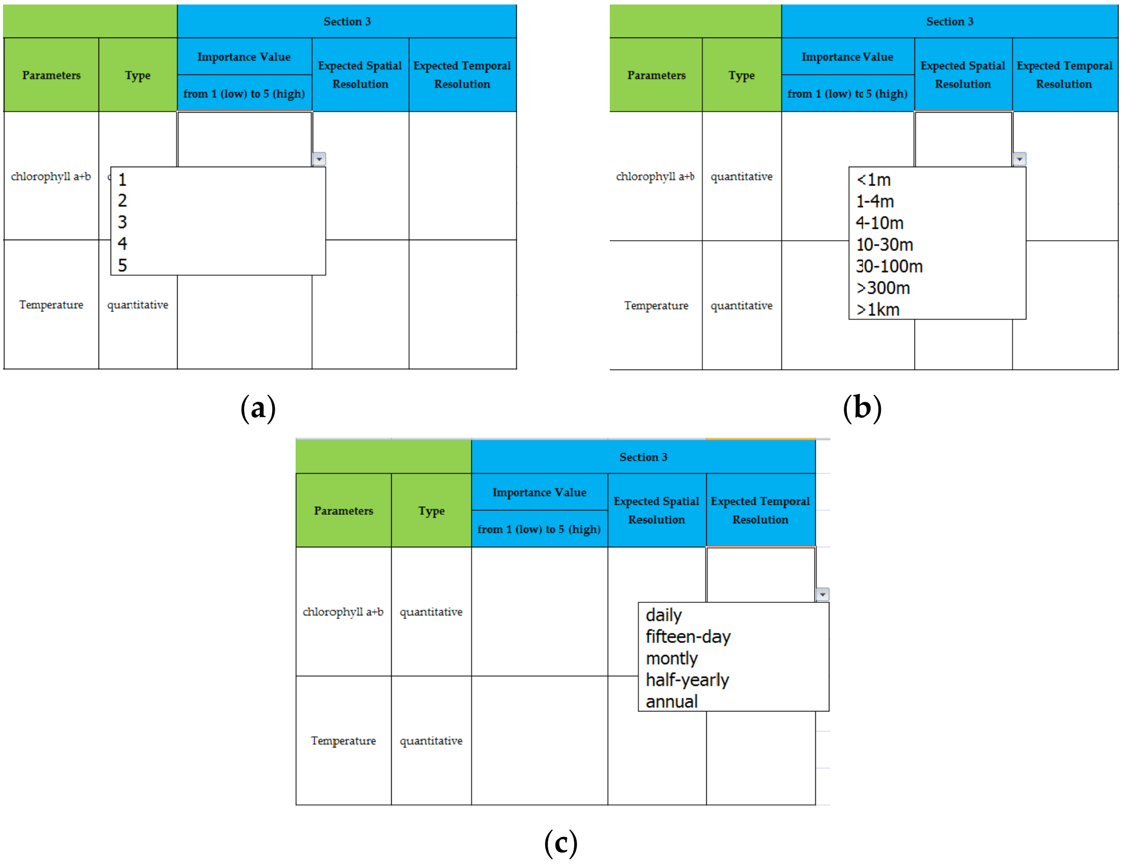


Figure 3. Example of how user communities were questioned about the priority value (**a**) and expected spatial resolution (**b**) and temporal resolution (**c**).

In the processing phase, the priority value (in percentage) for each parameter was calculated as the average of the users' importance values normalized between 0 and 100 by using the following equation:

$$Priority\ value = \frac{100}{max\ Importance\ value} \frac{1}{N_{users}} \sum_{j=1}^{N_{users}} Importance\ value_j \quad (1)$$

where N_{users} is the number of users that provided feedback on the considered parameter and *Importance value$_j$*, for $j = 1, \ldots, N_{\text{users}}$ is the value assigned to the parameter by each user in a 1–5 scale, where 1 represents the minimum and 5 represents the maximum. Then, a priority value is assigned to each identified requirement by averaging the priority values obtained by all the parameters necessary to achieve that particular requirement.

Figure 4 shows the flow chart of the user requirement assessment. The assessment was conducted per user community by evaluating the priority value of each thematic area (referred to as PV TA, from 1 to i, in Figure 4) by means of the averaged priority values assigned to the related requirements (e.g., $\overline{\text{PV}}_{\text{R1}}, \ldots, \overline{\text{PV}}_{\text{Rm}}$ for TA_i in Figure 4). These averaged priority values were also used to produce a ranking of the requirements within each thematic area. The assessment at the user community level had a twofold goal: to compare and contrast the needs for each thematic area, and to identify those parameters that are more helpful to solve the user problem or to achieve the user task. In addition, this analysis allowed pointing out similarities among user communities in terms of requirements and parameters, even if evaluated with different priority values. The graphical method chosen to represent here the results of feedback analysis is the Sankey diagram, which is a flow diagram that relates entities through lines whose thickness expresses the quantitative relationship between them. This diagram is particularly suited to highlight and assess the priorities given by user communities to requirements and parameters, as in the case of the analysis of remote sensing indices suitable at monitoring green infrastructures for natural water retention measures [17].

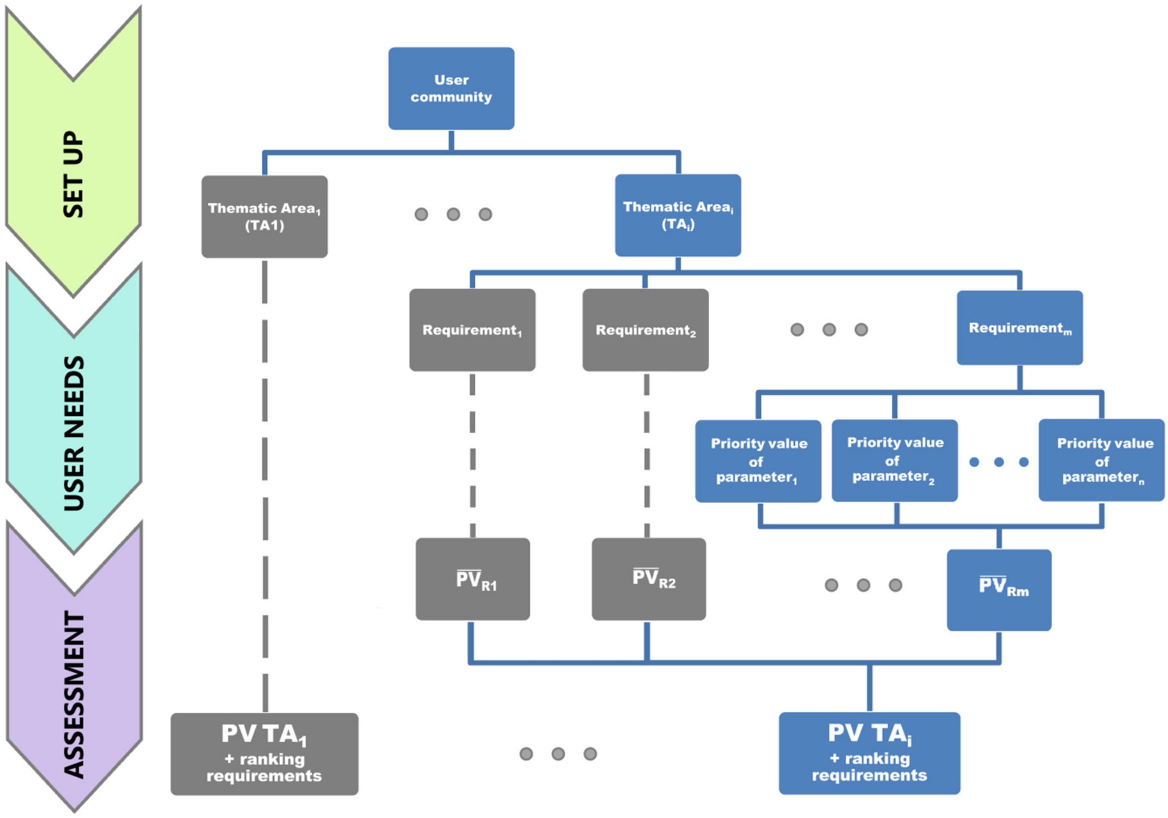


Figure 4. Flow chart of the user requirement assessment.

3. Results

The study received feedback from all of the user communities involved. Not all of them expressed interest in all thematic areas. The user communities made explicit the priority value for each parameter in the thematic areas on the basis of their institutional mandates connected to EU policy and their commercial needs (if any).

Particularly relevant contributions were provided by the "Environmental control system community" constituted by the Italian National System for Environmental Protection (SNPA) and the Italian National Committee for Operational Hydrology Services. These two communities were indeed chosen as a reference point for the implementation of the interaction methodology, since they could cover almost all of the thematic areas considered (Table 4) and are involved in the implementation of most of the investigated EU policies (Table 3). The contributions of these communities are representative of the entire national territory, from the North (e.g., Friuli Venezia Giulia Region) to the South (e.g., Basilicata Region). The feedback received also accounted for the specificities related to different territorial morphology, namely the predominantly landlocked mountainous territories, plain areas (including the Po valley), lakes and river basins, and coastal areas (including wetlands and lagoons).

The other communities involved have instead interest only in specific Copernicus application domains. Hence, their feedback covered only some of the thematic areas investigated, as for instance in the case of the Italian Ministry of Infrastructures and Transport (MIT), which expressed its interest only for "IC", "AQ", "CH", "NH", and "UM" areas. However, the interest provided by MIT took into account also feedback from the Italian Civil Aviation Authority (ENAC), concerning technical regulation, certification, surveillance, and oversight in the civil aviation field, and from Rete Ferroviaria Italiana (RFI), the company of the Ferrovie dello Stato Italiane Group, concerning the rail traffic on the national network, track, stations, and installations (Table 4). In other cases, the feedback highlighted interest only in just one thematic area. This is the case of CREA, the Italian research organization with competence within the fields of agriculture, agro-industry, food, fishery, and forestry, which provided requirements only for "AF". This happens also for the Italian Air Force Meteorological Service (AM), which gave feedback only for "AQ" given its role in providing meteorological services for military tasks as well as for civil protection, including daily weather forecasts.

The feedback analysis was first conducted by considering together the results from all the users, without distinguishing between communities, in order to assess the priority of the identified needs at a national level. Therefore, a ranking of the thematic areas was gathered. Figure 5 shows by means of a Sankey diagram the averaged priority values assigned by each user community to the user requirements identified within each thematic area.

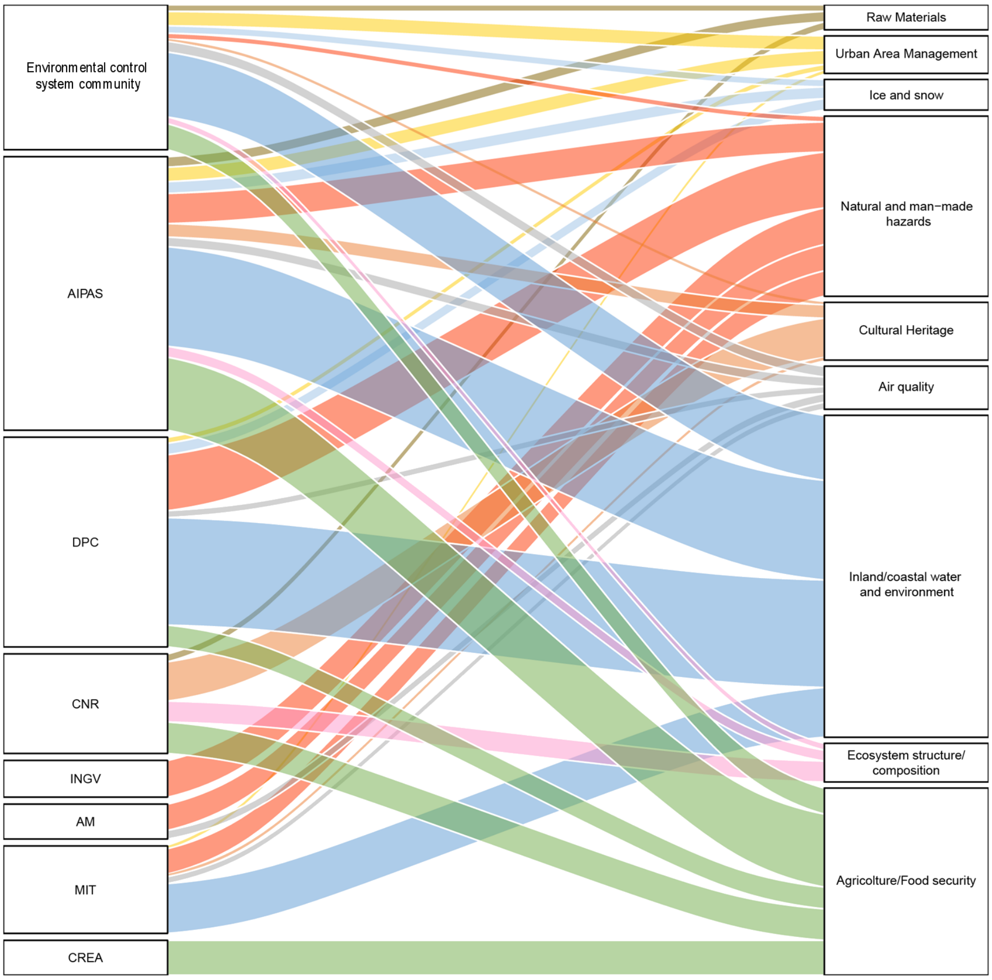
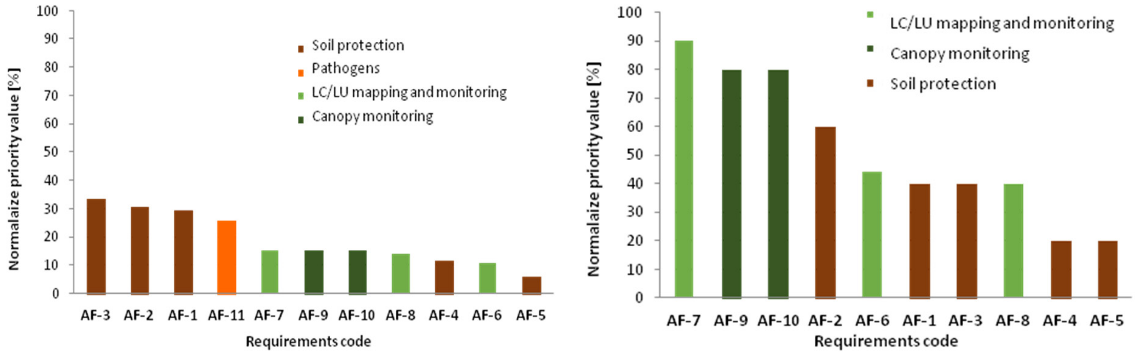


Figure 5. Sankey diagram representing the preference of each user community (left side entities) for the considered thematic areas (right side entities). The thickness of each connecting line is determined as a function of the (averaged) priority values assigned by each user community to the requirements identified for each thematic area (represented by a different color).

As one of the most involving results, we have highlighted the interest provided by the Environmental control system community and CREA to the "AF" thematic areas (see Table A1 in Appendix A for a detailed description of the "AF" requirements and parameters). This thematic area is exemplary to illustrate how two communities with different institutional mandates have similar needs related to "AF" but with different priorities (Figure 6). Both user communities provided feedback on (almost) all the identified requirements. However, the Environmental control system community expressed a quite uniform interest for all the requirements, with a slight preference (ca. 30%) for those requirements linked with soil protection (from AF-1 to AF-3) and pathogens (AF-11), whereas CREA showed a greater preference (80%–90%) for the requirements associated with land-use and land-cover mapping and monitoring (AF-7) and canopy monitoring (from AF-9 to AF-10).



(a) (b)

Figure 6. Ranking of the Agriculture/Food security ("AF") requirements based on the priority values assigned by the Environmental control system community, constituted by the Italian National System for Environmental Protection (SNPA) and the Italian National Committee for Operational Hydrology Services (**a**) and CREA, the Council for Agricultural Research and Analysis of the Agricultural Economy (**b**).

The next step carried out for the "assessment" activity, as reported in Figure 2, consisted of matching the parameters associated with the requirements for a specific thematic area with the available (if any) hyperspectral layers. The matching analysis discriminates between those parameters for which a hyperspectral layer is already available and those ones for which a layer is not yet available, and therefore, it is necessary and desirable to identify a further development path (not shown).

Among the thematic areas investigated, it is worth mentioning the explicit request of the involved users for hyperspectral layers for the "AF" thematic area to fulfill the geospatial information needs for sustainable agricultural management, with particular attention to soil properties and agricultural services, including food security and biodiversity [147]. As a matter of fact, this request has also been an outcome of several user requirement workshops organized by the EC to support and consolidate the Copernicus services and to meet the priority user needs not already addressed by the existing programme.

Figure 7 reports the Sankey diagram of the match between the required parameters and the hyperspectral layers for the "AF" thematic area. By considering feedback from the Environmental control system community and CREA, for each required parameter, it was evaluated whether an available layer from the hyperspectral sensor data was present in the aforementioned list. In this way, it also identified those parameters for which no layer was available at the time of matching (reported with the class "NONE" in Figure 7). The layers are reported in the figure only by means of the code used within the study, without any additional details. The description and discussion of these layers are out of the scope of the present paper.

Another thematic area presented here is "RM", for which significant economic and environmental challenges for private and public users (mining industry, research entities and environmental management community) have been recognized [147,148]. Figure 8 reports the Sankey diagram of the match between the required parameters and the hyperspectral layers for the "RM" thematic area. The user requirements concern the identification of the soil surface composition and the presence and/or the abundance of specific minerals. The required parameters, namely the mineral content and the acid pH, could be solved by layers already available which have the following spectrally diagnostic features: iron oxides; clay minerals; carbonates; sulfates and phosphates; pyrite oxidation products;

and red mud pollution (ferrous, aluminum, and silicon oxides) to distinguish raw materials from other bare soils and materials.

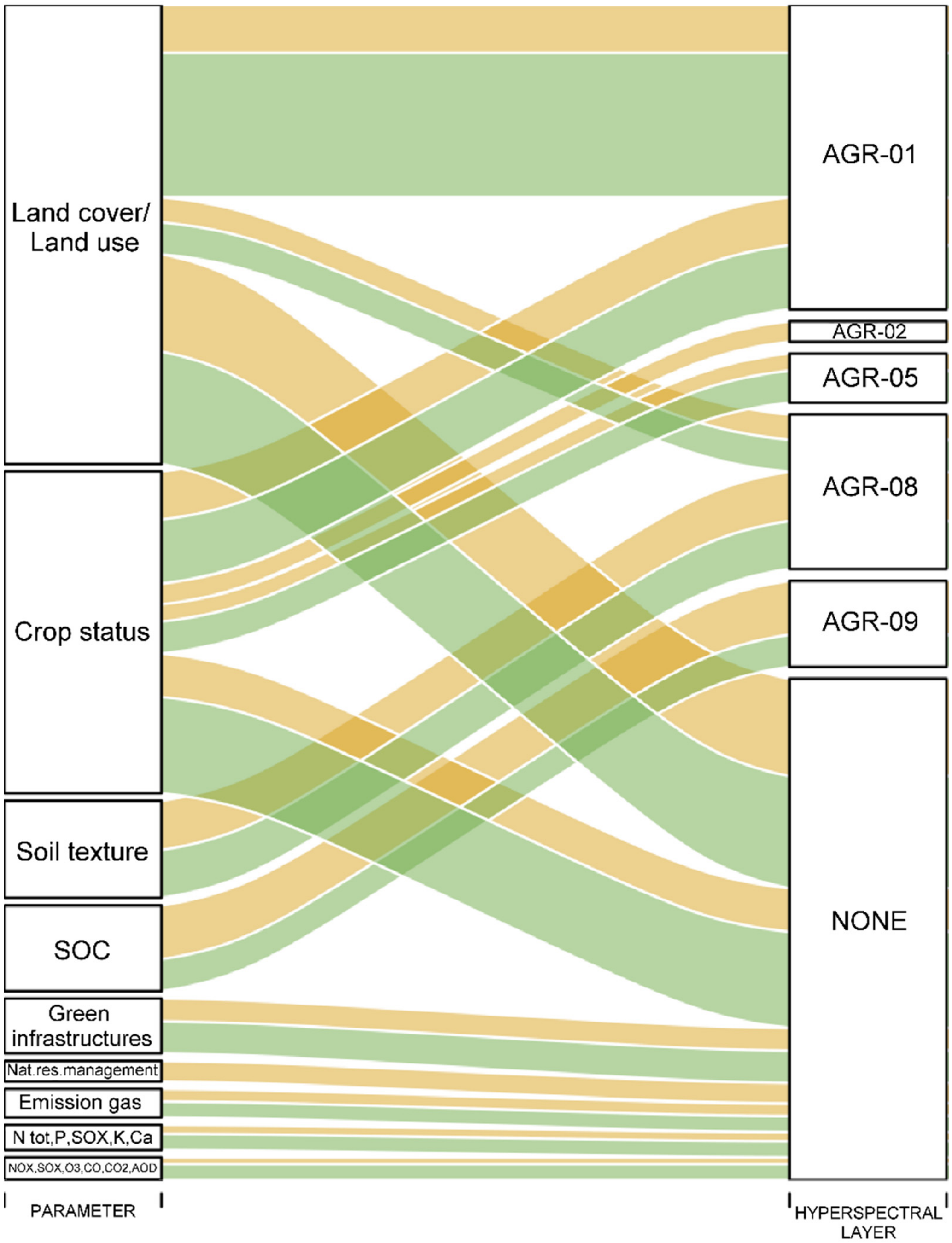


Figure 7. Sankey diagram representing the link between required parameters (left hand side column) and available layers from hyperspectral sensor data related to the "AF" thematic area (AGR-xx), as requested by the Environmental control system community (reported in spicy mustard) and CREA (reported in green). The thickness of each connecting line represents the number of times the parameter is requested by the considered community to satisfy the user requirement. Layer coding was defined within the study as an alphanumeric and unambiguous code for each product. The code "NONE" indicates an unavailable hyperspectral layer.

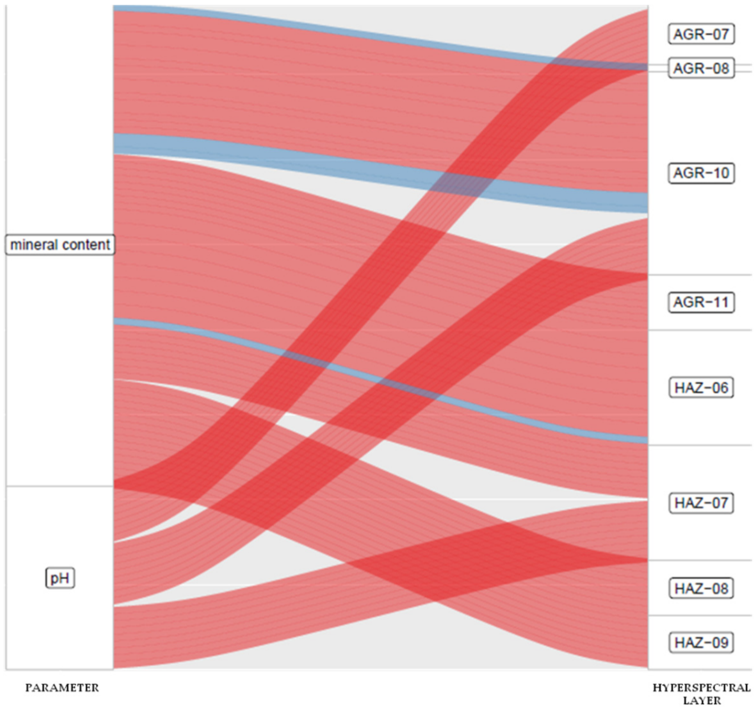


Figure 8. As in Figure 7, but for the Raw materials ("RM") thematic area.

Based on the analysis of the existing and consolidated hyperspectral layers that satisfy the user requirements, the associated spectral requirements were identified. Figure 9 reports the spectral ranges covered by the identified layers, namely VIS (Visible), NIR (Near Infrared), SWIR (Shortwave Infrared), and TIR (Thermal Infrared). As can be seen, all the four spectral ranges (including TIR) are useful to some extent to achieve the user requirements. Nevertheless, it is quite evident how the NIR and SWIR spectral ranges are necessary (and in some case fundamental) to satisfy the requirements of most of the thematic areas.

The frequency distribution of these spectral range classes as a result of user requirement evaluation is reported in Figure 10 (for a more detailed description of how the figures are disaggregated at thematic area and EU policy levels, readers may refer to Figure A1 in Appendix A).

The number of times each combination of the required spectral range classes is necessary to achieve the user requirements, aggregated at thematic area level, is useful to give an overview of the expected spectral requirements of future sensors. All the thematic areas (except IS) expressed higher preferences on the VIS–NIR–SWIR configurations reaching 34.0% of the whole preferences. The NIR spectral range alone contributes only to the "IS" thematic area. On the contrary, when NIR is combined with the other portion of infrared (SWIR and TIR), more user requirements can be satisfied. The frequency distribution led to an overview of what is expected from the hyperspectral data also in terms of synergies among sensors considering that TIR wavelengths could be provided by complimentary satellite sensors, leading to a higher quality of both the products, the NIR–SWIR and TIR.

The user communities also specified for each parameter the expected spatial and temporal resolutions. Figure 11 shows an overview of these analyses and highlights that most of the users are expecting a resolution comprised between 1–4 m and 10–30 m with a monthly revisit time.

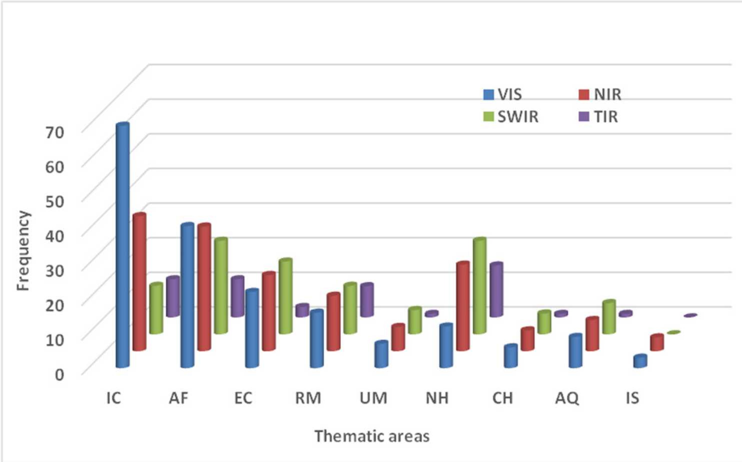


Figure 9. Spectral ranges, namely Visible (VIS), Near Infrared (NIR), Shortwave Infrared (SWIR), and Thermal Infrared (TIR), covered by the available layers (hyperspectral-based products and services), distinguished by thematic area, as a result of the interaction with the user communities. The frequency reported refers to the number of times a particular spectral range is present in a layer that achieves a user need.

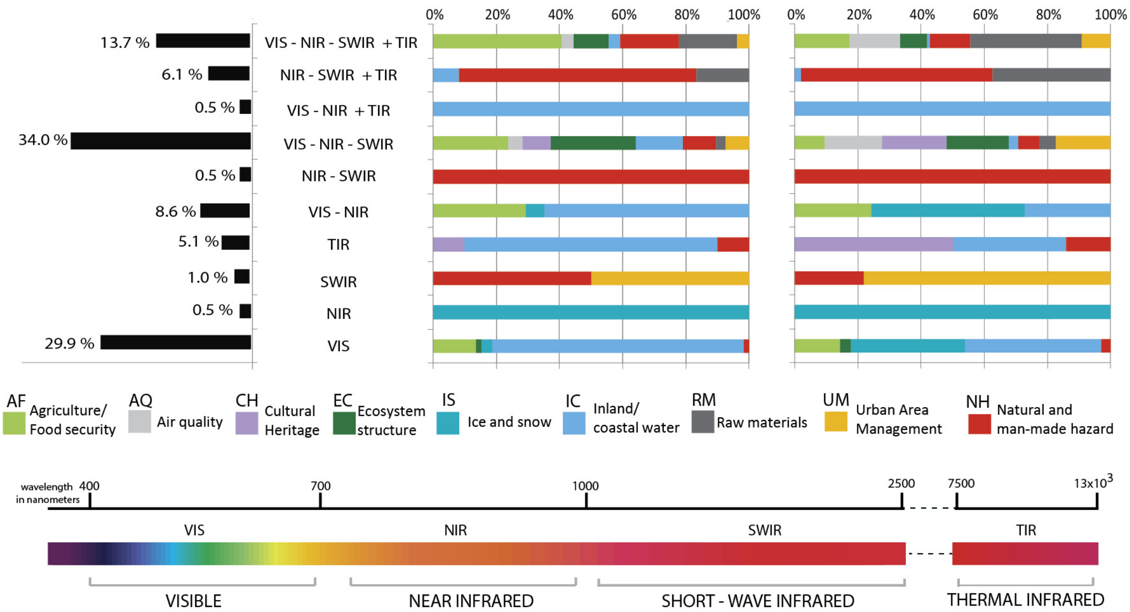


Figure 10. Frequency distribution of spectral range classes. From left to right: frequency distribution of spectral range classes as sum of the preference expressed by all the thematic areas on each class; frequency of the preferences expressed by each thematic area in each class; frequency of preferences expressed by all the thematic areas on each class. The legend of colors and acronyms is located below the frequency distributions.

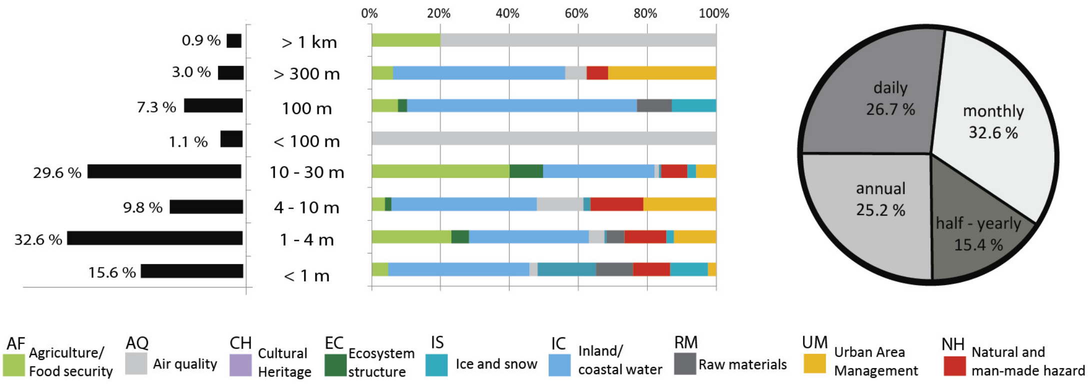


Figure 11. Frequency distribution of spatial and temporal resolutions. From left to right: frequency distribution of spatial resolution classes as sum of the preference expressed by all the thematic areas on each class and the frequency of the preferences expressed by each thematic area in each class; the circular graph summarizes the preferences on the temporal resolution.

4. Discussion

The assessment of the user requirements has been performed with the twofold purpose of a future Copernicus hyperspectral mission in mind: providing new satellite-based operational tools and services to support the activities of the institutional user communities and a new opportunity for enhancing the satellite-based EO market. The received feedback reflects the interest in each specific thematic area due to both the user institutional roles in supporting the implementation of EU and local policies and the private users' experiences in developing, promoting, and marketing downstream products and applications. All these aspects combined are suitable to provide a clear overview for a hyperspectral sensor in terms of spectral, temporal, and spatial resolutions as expected by all the user communities.

The capability to provide hundreds of contiguous bands with high spectral resolution offers a unique contribution in term of the completeness of the information that can be extracted through the combination of different analyses that hyperspectral sensing effectively enables.

This paper shows an approach to build up a traceability matrix, as Figures 9 and 10 highlight, which emphasizes the contribution of each spectral range and of a combination of several spectral range classes in those hyperspectral layers that satisfy the specific user parameters.

All the available layers necessary to satisfy the user needs require bands spreading on the full 400–2500 nm spectrum. For instance, in the "IC" thematic area, a sensor with multiple contiguous spectral bands in VIS–NIR wavelengths and, for very turbid waters, also into the SWIR, allows switching between the different wavelengths and wavelength combinations. This is fundamental for discriminating phytoplankton types and assessing the concentration of associated pigments. Overall, the availability of a contiguous spectrum (with narrow bands) makes algorithms more effective in a wide variety of waters with varying water column depths and bottom reflectance. Therefore, hyperspectral imaging improves the estimation accuracy of variables currently observed by multispectral sensors (e.g., Chl-a, TSM), as well as discerns new variables of interest (type and size of suspended particles, types of pigments, organic matter composition, cyanobacteria, inorganic pollutants, etc.). In the field of raw material, the VIS–SWIR spectral ranges are useful to detect chemical compounds resulting from the oxidation of pyrite and other iron sulfide minerals or the dissolution of mineral efflorescent salts [148]. Whereas, in the field of agricultural and food security, the VIS–NIR–SWIR spectral ranges can be used to identify the change in the structure of the canopy, due to the continuous sampling within the bands of this range.

For each parameter, the preferences specified by the user communities for the expected spatial and temporal resolutions could be suitable to satisfy their needs in terms of the operational requirements for potential operational services. Then, the occurrence (frequency) of each combination of these expected resolutions were counted in order to orient the observational requirements for the Copernicus hyperspectral satellite mission (see Figure 11).

In more detail, the "IC" thematic area is expecting daily products with a spatial resolution less than 1 m; these resolutions combined with the finer spectral resolution provides opportunities for coupling the large-scale monitoring and mapping offered by satellites with the already consolidated protocols for calibration and validation with proximal remote sensing detections. This should be done in order to achieve a high-level accuracy in the product retrieval. Thus, having information from hyperspectral sensor spreading on the full spectrum, the Copernicus hyperspectral Sentinel evolution shall provide detailed observations of key properties of terrestrial surface and specifically related to topsoil (0–30 cm) properties, such as texture (clay, silt, and sand) and soil organic content (SOC), and vegetation biophysical variables (canopy water content, leaf and canopy pigment content, leaf mass/area). The "AF" thematic area needs an improved management of natural resources at the local to regional scale specifically on soil properties, indirectly using vegetation indices [8] and directly through the imaging of bare soils [9] or temporal variability in phenology and canopy variations [11–13].

The application of the interaction methodology had a positive outcome by all the user communities, which were excited about their direct involvement and about the ease of interaction. This was possible with the aid of a task force of experts for each of the thematic areas investigated, which supported the set-up phase of the interaction methodology. Moreover, all the involved user communities took part in a one-day workshop dedicated to the presentation of the usability requirements and prioritization for the users on the different thematic areas.

One of the most difficult issues addressed during the study when applying the interaction methodology was the treatment of a huge quantity of information related to the user community preferences in each thematic area investigated. Then, this application was fruitful to develop a proper way to treat all these heterogeneous data. However, it is important to highlight that user requirements are not static elements but they are, by their nature, in continuous evolution [126,129,133,149] depending on changes in user needs and progress in the technological capabilities adopted to develop the satellite-based EO products. At the same time, this aspect represents both a complexity and a richness. It allows the system under development, or already developed, to evolve in the direction of improvement and/or updating at the same pace with the evolution of the communities to which it is addressed and the corresponding existing technical, social, and institutional contexts. The results of the aforementioned requirement assessment are currently associated with the information collected in the Mission Requirement Document of the Copernicus Hyperspectral Imaging Mission of the Environment (CHIME) [148]. This future planned Copernicus hyperspectral mission aims to satisfy a huge community of users and address many users need in two fields: sustainable agriculture and food security, including biodiversity protection, forestry, and the related environmental degradation and hazards; and raw materials, including mine environment management. Based on the proposed approach, two distinct sets of expectations have emerged from the user consultation process: while increasing the quantity and quality of new products and services, the EU Commission can summarize the results to two sets of requirements. They can be particularly addressed in the considerations for the Next Generation (NG) of the current Sentinels 1 to 6 series providing an enhanced technological improvement of initial observations. Emerging and urgent needs for new types of observations constitute a second distinct set of requirements. They are mainly addressed in the considerations for the timely expansion of the Copernicus Sentinel fleet by so-called High-Priority Candidate Missions (HPCM). Both sets of expectations have been systematically reflected and integrated to the ESA as the Entrusted Entities System Evolution Architect in response to the Commission's expectation [148].

5. Conclusions

The study has ensured the collection and analysis of user requirements provided by several user communities of the EU Copernicus Programme framework, both at institutional and private levels. The development and application of an ad hoc interaction methodology allowed the identification of those operational products and services that can be potentially supported by means of a future Copernicus hyperspectral mission, enhancing the degree of interest of the user communities for the related layers. This goal was achieved through an interaction matrix, which was circulated among members of the selected user communities, which linked together thematic areas, user communities, EU policy, and economic and societal benefits. Moreover, the application of this interaction represents a useful and valuable example of how to explore and understand the potential opportunities provided by the Italian National Strategic Plan for the EU Space Economy (Mirror Copernicus) in terms of EO products and services that are both user-oriented and oriented by users. At a national level, this has been already begun and has been tested in the framework of two technical–scientific agreements between the Italian Space Agency (ASI) and the Italian National Institute for Environmental Protection and Research (ISPRA) on "Habitat Mapping" and "Air Quality".

The correct management of the requirements and the results of their analysis is fundamental in order to facilitate the consultation and the re-elaboration of the requisites collected at later times. One of the main processes that follows the collection and definition of user requirements is the verification phase of the compliance between requirements and developments designed to fill any gaps that exist or can be created in subsequent phases. As already underlined, the users' requirements do not represent a static element but evolve with technological advances, with the changed needs to which every interested community will have to answer. Moreover, it is worth highlighting the wide contribution given by the user communities in terms of needs and technical requirements potential opportunities to support the definition of a future hyperspectral imaging Sentinel mission. For this purpose, it has been useful to define, implement, and organize a database that collects and keeps track of all the interactions that take place with the various communities, starting from the one analyzed in the present manuscript. Therefore, many synergies are foreseen in the next future within the existing and upcoming hyperspectral missions (e.g., GF5, PRISMA, EnMap, ECOSTRESS, and Venus) and the already existing missions such as Sentinel-1 and Sentinel-2 in order to achieve the needs of the user communities. These synergies should target not only spectral improvements but also the spatial and temporal improvements of the data fluxes.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Link between the requirements and the associated parameters that were identified for the "AF" thematic area by the interaction with the user communities. Each requirement is labeled with a unique code, not representing any ranking or order in any way.

Code	Requirement	Associated Parameters (EU Policy)
AF-1	Mapping of the soil physical degradation, including the soil condition and erosional	land cover/land use (acc. Dir. 91/676/EEC) land cover/land use (acc. Reg. 1306/2013/EU)
AF-2	Estimation of soil texture in agricultural fields (when without cultivation), i.e. the particle-size distribution of mineral soil fraction expressed as the relative proportions of clay, sand, and silt	soil texture (acc. Dir. 91/676/EEC) soil texture (acc. Reg. 1306/2013/EU)
AF-3	Estimation and mapping of soil organic carbon (SOC) in agricultural fields as input for simulation models of crops, hydrological and hydrogeological models	SOC (acc. Dir. 91/676/EEC) SOC (acc. Reg. 1306/2013/EU)
AF-4	Support to identify chemical compounds presence (e.g., N tot, P SOX, K, Ca) in agriculture fertilizer	N tot, P SOX, K, Ca
AF-5	Support to identify specific gases presence (e.g., ammonia) emitted by manure through absorption bands detection on parcels	NOX, SOX, O3, CO, AOD emission gas
AF-6	Agriculture practices risk mapping to study the diverse extents, shapes, and connectivity levels of heterogeneous pattern systems in agriculture, in relationship to human impacts	land cover/land use (acc. Dir. 91/676/EEC) crop status (acc. Dir. 91/676/EEC) land cover/land use (acc. Reg. 1306/2013/EU) crop status (acc. Reg. 1306/2013/EU)
AF-7	Mapping and monitoring of land-use/land-cover types and changes	land cover/land use (acc. Reg. 1306/2013/EU) land cover/land use – vegetation (acc. Reg. 1306/2013/EU) land cover/land use – soil/sediment (acc. Reg. 1306/2013/EU)
AF-8	Estimation and mapping on soil and vegetation depletion from agro-ecosystem structure and composition	green infrastructures (acc. Reg. 1306/2013/EU) land cover/land use (acc. Reg. 1306/2013/EU)
AF-9	Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and chlorophyll a+b (Cab) indexes extraction, which is useful to characterize crop status and phenology	crop status (acc. Dir. 92/43/EEC & Dir. 2009/147/EC) crop status (acc. Reg. 1306/2013/EU)
AF-10	Estimation of cropland biophysical variables, such as Leaf Area Index (LAI)	crop status (acc. Dir. 92/43/EEC & Dir. 2009/147/EC) crop status (acc. Reg. 1306/2013/EU)
AF-11	Natural resource exploitation planning and crop biotic stress (pathogens)	natural resource management

Thematic areas	**Spectral ranges**									
EU policy	**VIS**	**NIR**	**SWIR**	**TIR**	**VIS-NIR**	**NIR-SWIR**	**VIS-NIR-SWIR**	**VIS-NIR + TIR**	**NIR-SWIR + TIR**	**VIS-NIR-SWIR + TIR**
Agriculture/Food security	**8**				**5**		**16**			**11**
Animal By-products Regulation (1069/2009/EU)	*1*				*1*		*1*			*4*
Common Agricultural Policy	*2*				*3*		*8*			*1*
Habitats Directive (92/43/EEC); Birds Directive (2009/147/EC)	*5*				*1*					
Habitats Directive (92/43/EEC); Birds Directive (2009/147/EC); Common Agricultural Policy							*1*			
Eu biodiversity strategy (COM/2011/0244 final); Enhancing Europe's Natural Capital (COM/2013/0249 final)							1			
Nitrates European Directive (91/676/EEC)							5			4
Nitrates European Directive (91/676/EEC); Animal By-products Regulation (1069/2009/EU)										2
Air quality							**3**			**1**
Ambient air quality and cleaner air Directives (2004/107/EC and 2008/50/EC)							3			1
Cultural Heritage				**1**			**6**			
UNESCO Convention concerning the protection of the world cultural and natural heritage, adopted in 1972				1			5			
(Other specific item)							*1*			
Ecosystem structure/composition	**1**						**18**			**3**
Habitats Directive (92/43/EEC)	*1*						*15*			*3*
Birds Directive (2009/147/EC)							3			
Ice and snow	**2**	**1**			**1**					
(No specific reference)	*2*	*1*			*1*					
Inland/coastal water and environment	**47**			**8**	**11**		**10**	**1**	**1**	**1**
Floods Directive (2007/60/EC)	*2*						*1*			
Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC); Bathing Water Directive (2006/7/EC)	*17*			*4*	*7*		*4*		*1*	
Water Framework Directive (2000/60/EC); Floods Directive (2007/60/EC)	*3*						*2*			
Water Framework Directive (2000/60/EC); Bathing Water Directive (2006/7/EC)	*12*			*1*	*2*					
Water Framework Directive (2000/60/EC); Habitats Directive (92/43/EEC)	*2*						*3*			
Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC)	*1*									
Water Framework Directive (2000/60/EC); Urban Waste Water Treatment Directive (91/271/EEC)				2						
Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC); Bathing Water Directive (2006/7/EC); Maritime Spatial Planning Directive (2014/89/EC)	10			1	2			1		1
Natural and man-made hazards	**1**		**1**	**1**		**1**	**7**		**9**	**5**
Water Framework Directive (2000/60/EC); Floods Directive (2007/60/EC)							*4*		*3*	*2*
Thematic strategy for soil protection (COM/2006/ 231)							*1*		*1*	*1*
(Combinations of Directives)	*1*		*1*	*1*		*1*	*2*		*5*	*2*
Raw materials							**2**		**2**	**5**
Raw Materials Initiative (COM/2008/699)							2		2	5
Urban Area Management			**1**				**5**			**1**
Living well, within the limits of our planet (Decision n. 1386/2013/EU)							*1*			
Eu biodiversity strategy (COM/2011/0244 final); Enhancing Europe's Natural Capital (COM/2013/0249 final)							*3*			
Enhancing Europe's Natural Capital (COM/2013/0249 final)							*1*			
(Combinations of Directives)			*1*							*1*
Total	**59**	**1**	**2**	**10**	**17**	**1**	**67**	**1**	**12**	**27**

Figure A1. Frequency of spectral range classes covered by the hyperspectral layers that match for each thematic area the parameters requested by the user communities (figures reported in bold). For each thematic area, frequencies are also aggregated at the EU policy level (figures reported in italic).

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