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EGDI Data Hub Feeding FAIR EGDI Data Into Surrounding EU Information Infrastructures v1

Version: 1

Project	101075609 — GSEU — HORIZON-CL5-2021-D3-02
Deliverable Data	
Deliverable number:	**D7.4**
Dissemination level:	**Public**
Deliverable type:	**Other**
Work package:	**WP7, European Geological Data Infrastructure (EGDI)**
Lead WP/Deliverable beneficiary:	**BRGM**
Deliverable status	
Verified (WP leader):	**Jørgen Tulstrup (GEUS)**
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Funded by the European Union

The Geological Surveys of Europe

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Revision History		
Author(s):	**Description:**	**Date:**
M. Harrison (BRGM)	Draft deliverable	24/11/2023
M. Urvois (BRGM)	Revision 1	08/12/2023
M. Harrison (BRGM)	Revision 2 submitted to WP7 Leader	26/01/2024
J. Tulstrup (GEUS)	2nd Draft	04/02/2024
M. Urvois (BRGM)	Revision 3 with corrections after review by WP7 Leader	08/02/2024
F. Pizzocolo (TNO)	Final version	15/02/2024

Executive Summary

This report forms the output of the “Connecting to Other Infrastructures” Working Group of WP7 (European Geological Data Infrastructure) in the GSEU Project. This is the first of two deliverables relating to the necessity of connecting with other groups. The tenet of this first report is to address the “why” questions and the “who”. Laying the groundwork for a prioritisation and implementation process that will ensure the necessary engagement and the final deliverable.

The report details the FAIR reasons that the European Geological Data Infrastructure (EGDI) must interface with external communities. These relate to ensuring best practice, meeting legal obligations, and representing the European Geological Survey Community on the world stage, in relation to standards and semantics. The whole landscape identified in section 3 was contributed to by the Working Group. Then section 4 does a deep dive into 3 initiatives for which the maturity of connection is at very different levels. The report concludes by suggesting some prioritisation, including the initiatives listed in the deliverable description and identifying the next steps.

Abbreviations	
AI	Artificial Intelligence
DCAT / DCAT-AP	Data Catalogue Vocabulary-Application profile
DOI	Digital Object identifier
EGDI	European Geological Data Infrastructure
EPOS	European Plate Observing System
EOSC	European Open Science Cloud
ERIC	European Research Infrastructure Consortium
FAIR	Findable, Accessible, Interoperable, Re-usable
GSE	Geological Service for Europe
ICS-C	Integrated Core Services-Central hub
PID	Persistent Identifier
TCS	Thematic Core Service
URI	Uniform Resource Identifier

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1. Introduction

This report is the first in a series of two reports about connecting the EGDI to other infrastructures at a national, European and Global level. This first report will analyse the landscape and identify the stages to prioritising these connections. It will also begin an analysis about the purpose of EGDI connecting to other infrastructures and initiatives. Most of the work undertaken to produce this first report was completed by the “Connecting to Other Infrastructures” Working Group of representatives from Workpackage 7 in the period December 2022 to June 2023 and form the responsibility of Task 7.3 in the GSEU project.

Some of these connections are obvious, and indeed were stated in the Commission call text to which the GSEU project responded. At the time, these were identified as being; INSPIRE Geoportal, RMIS, OneGeology Portal and EPOS Research Infrastructure as well as adhering to the FAIR (Findable, Accessible, Interoperable and Reusable) principles. The GSEU project proposal text also added the European Open Science Cloud (EOSC) into this list of key initiatives.
The purpose of this report is to place the explicitly stated links to existing initiatives within a context of the breadth of connections that could be possible. The full extent of the landscape of relevant initiatives is explored in Chapter 3 with a live table to provide continuity and a live link to real and changing information.

Much of the discussion in the Working Group was also about the reasons for connecting to other initiatives and the mechanism through which to connect. This will be explored in Chapter 5.

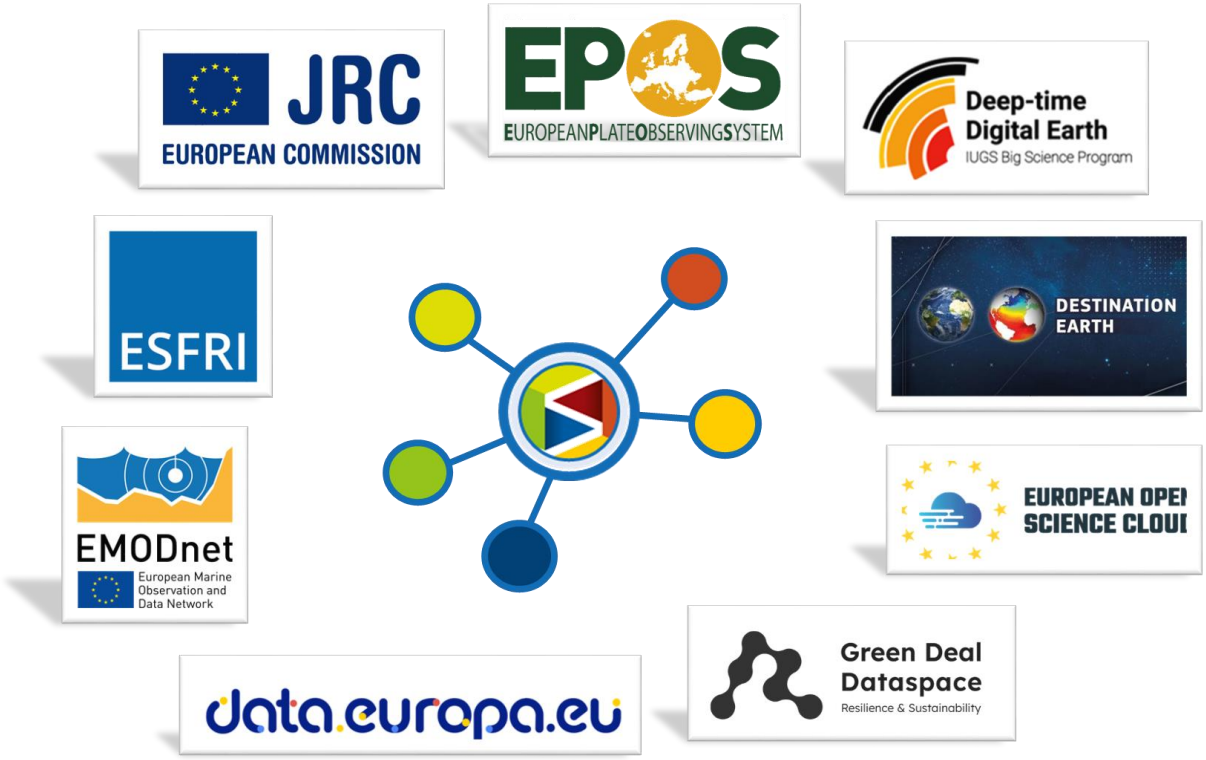

Figure 1. Some of the key connections identified

2. Context

As well as creating a platform to enable access to European-level data created together by members of the EuroGeoSurveys through the GSEU project and in support of the EGDI, there is also an opportunity and duty upon the members of the EuroGeoSurveys to contribute to the overall governance surrounding geoscience data and information at a global scale. This is through both ensuring geoscience data is discoverable and available in recognised formats for onward analysis, validation, and research, and also so that a European geoscience voice and perspective is recognised and listened to in the development of geoscience standards beyond only the boundaries of the European Continent.

2.1. FAIR

As the guiding principle about everything we do in GSEU, adopting FAIR (Findable, Accessible, Interoperable and Reusable) principles for the projects' data and information services is key for the usability of these services. The FAIR principles provide guidelines for creating and sharing data, but does not detail any particular technology/IT approach for publishing and managing such data.

The FAIR Principles from GoFAIR (https://www.go-fair.org/fair-principles /)

Findable
The first step in (re)using data is to find them. Metadata and data should be easy to find for both humans and computers. Machine-readable metadata are essential for automatic discovery of datasets and services, so this is an essential component of the FAIR-ification process.

F1. (Meta)data are assigned a globally unique and persistent identifier
F2. Data are described with rich metadata (defined by R1 below)
F3. Metadata clearly and explicitly include the identifier of the data they describe
F4. (Meta)data are registered or indexed in a searchable resource

Accessible
Once the user finds the required data, she/he/they need to know how they can be accessed, possibly including authentication and authorisation.
A1. (Meta)data are retrievable by their identifier using a standardised communication protocol
A1.1 The protocol is open, free, and universally implementable
A1.2 The protocol allows for an authentication and authorisation procedure, where necessary
A2. Metadata are accessible, even when the data are no longer available

Interoperable
The data usually need to be integrated with other data. In addition, the data need to interoperate with applications or workflows for analysis, storage, and processing.
I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (Meta)data use vocabularies that follow FAIR principles
I3. (Meta)data include qualified references to other (meta)data

Reusable

The ultimate goal of FAIR is to optimise the reuse of data. To achieve this, metadata and data should be well-described so that they can be replicated and/or combined in different settings.

R1. (Meta)data are richly described with a plurality of accurate and relevant attributes
R1.1. (Meta)data are released with a clear and accessible data usage license
R1.2. (Meta)data are associated with detailed provenance
R1.3. (Meta)data meet domain-relevant community standards

The principles refer to three entities: data, metadata, and infrastructure. For example, principle F4 identifies that both metadata and data are registered or indexed in a searchable resource (the infrastructure component).

To achieve this, a specific task is defined within WP7 (Task 7.3) and report D7.3 is produced regarding assessing and enhancing FAIRness. These will assess and discuss the detailed issues faced by GSEU. In this report, we are assessing the external initiatives that GSEU must connect to to both engage in this more detailed FAIR landscape but also fundamentally how to do the connecting.
In part this is also about making the connections to not re-invent the wheel on delivering any of this FAIRness and for that there is a lot of pre-existing work from our own and other communities.

There are some core principles around FAIR that will be needed:

- A mechanism to deliver Persistent and unique identifiers (PIDs, e.g. URI and DOI) are essential to ensure the fact that our research outputs are easily findable by other people
- Metadata (or the underlying data) is the information about our data generated during the project but is not the data itself
- A repository is an online-based platform where researchers can deposit their data (but not limited to) for mid (about 10-20 years) to long-term (more than 20 years, generally speaking) archival. Its primary objective is to open up and share the data. Trustworthy digital repositories are the ones certified by several international certification standards. In the framework of European Commission, they are the following:
    - Certified repositories (certification done by the standards such as Core-TrustSeal, Nestor Seal, ISO16363)
- Interoperability refers to the fact that the data coming from various sources can be integrated easily without losing the essence. Technically speaking, it is maintained by using the same formats for all the files to be integrated. From a semantic point of view, a dataset is interoperable if the same vocabularies are used between the different scientific communities. Once the repository is decided, for the sake of visibility, we can use standard vocabularies or ontologies to describe the data
- The documentation of our work is extremely important as it is the way to contextualise and describe the data. The documentation provides complete information about our data.

EU research organisations have a unique opportunity regarding achieving FAIRness in the sense that most FAIR criteria can be achieved by fulfilling INSPIRE requirements and recommendations. FAIR data (EU's Open Science policy) and INSPIRE dynamics are both pulling in the same direction. Both are legal drivers pushing interoperability practices defined by organisations such as OGC, W3C over two

decades. The implications being that there are already most of the tooling and practices, and so, less need to reinvent the wheel.

The Open Data Directive and more recently the European Data Act provides legal clarity to this as detailed hereafter.

2.2. From EU Open Data Directive to EU Data

One of the regulatory references supporting the FAIR data policy is certainly the European Directive (EU) 2019/1024 on Open Data, which in addition to setting minimum data re-use license criteria, also defines certain levels for each class and category of data minimum access and interoperability.

To these criteria must be added what has been established by the recent implementing regulation of the same directive, such as the Regulation (EU) 2023/138 laying down a list of specific high-value datasets and the arrangements for their publication and re-use. It defines the list and criteria for high-value datasets (HVD) which include most of the data in the geological domain and the Earth Sciences (Annex 1 contains the list of INSPIRE topics included in the "Earth Observation and Environment" category).

The Open Data Directive generically identifies three broad classes of data to which it should apply:

- High-Value Datasets (HVD): is a document the re-use of which is associated with important benefits for society, the environment, and the economy, in particular because of their suitability for the creation of value-added services, applications and new, high-quality and decent jobs, and of the number of potential beneficiaries of the value-added services and applications based on those datasets.
- Dynamic Dataset: is a document in a digital form, subject to frequent or real-time updates, in particular because of their volatility or rapid obsolescence; data generated by sensors are typically considered to be dynamic data.
- Research Dataset: is a document in a digital form, other than scientific publications, which are collected or produced in the course of scientific research activities and are used as evidence in the research process or are commonly accepted in the research community as necessary to validate research findings and results.

However, the definition for each one shows that dynamic datasets due to their typology can be considered as a subset of high-value datasets since they contribute to the knowledge and socio-environmental value of society. In consideration of what has been said, in the GSEU we must consider two large classes of data: research data, geological and geothematic data that are data of high value.

This statement is also confirmed by the types of data identified in the Earth Observation and Environmental data category given by the afore-mentioned Regulation (EU) 2023/138 that in its annex includes the priority list of data that fall under it. Annex A contains the list of data that fall under category 2 of the Open Data Directive "Earth observation and environmental data".

Furthermore, this regulation makes a clear reference to the importance of applying the INSPIRE technical rules for access and interoperability of data and services for what are considered spatial data (as defined above). Actually, in the premises to the point 9 states the following: *"In addition to Directive (EU) 2019/1024, other Union legal acts, including Directive 2007/2/EC of the European Parliament and of the Council and Directive 2005/44/EC of the European Parliament and of the Council may be of relevance*

for the re-use of public sector information falling within the scope of this Implementing Regulation, notably where those Union acts lay down common requirements for data quality and interoperability."

The most recent legal framework published by EU is the European Data Act (EU) 2023/2854, a Regulation on harmonised rules on fair access to and use of data (*Data Act – The path to the digital decade*, Publications Office of the European Union, 2022, **https://data.europa.eu/doi/10.2775/98413**). It complements the Data Governance Act (EU) 2022/868 which was the first deliverable of the European Strategy for Data (https://digital-strategy.ec.europa.eu/en) and became applicable in September 2023. While the Data Governance Act regulates processes and structures that facilitate voluntary data sharing, the Data Act ensures fairness in the digital environment by clarifying who can create value from data and under which conditions.

These two Acts are the pillars of the European Data Strategy aiming at making the EU a leader in data-driven society. Access to data and the ability to use it are essential for innovation, in particular when the volume of digital data produced by devices shows an exponential growth. This strategy also includes the creation of a single market for data allowing to flow freely within the EU and across sectors for the benefit of businesses, researchers and public administrations. This includes pooling European data in key sectors, with common and interoperable Data Spaces giving users rights.

The new rules introduced by the European Data Act define the rights to access and use data generated in the EU across all economic sectors and will make it easier to share data, in particular industrial data. Public sector bodies will be able to access and use data held by the private sector to help respond to public emergencies such as floods and wildfires, or when implementing a legal mandate where the required data is not readily available through other means. The Data Act also includes measures to promote the development of interoperability standards for data-sharing and for data processing services, in line with the EU Standardisation Strategy (COM(2022) 31).

It is clear that this framework fully applies to the large panel of geoscientific data and information produced by the Geological Surveys using an as large panel of digital devices: observations, measurements, samples, monitoring sensors, systematic investigation campaigns (field and airborne).
Entered into force in Jan. 2024, the European Data Act will become applicable in Sept. 2025

2.3. Connecting at Scale

In addition to the FAIR principles above, there is another element that is key to understanding opportunities and constraints around the data in EGDI and probably going forward into the Geological Service for Europe (GSE) -the Service that is being built by the GSEU project. The engagement necessary has additionally a scale dependency, be it at National, European or Global scale.

Nationally, for national surveys, there is a need to be compatible with national RI and Spatial Data Infrastructure (SDI) initiatives both to increase efficiency for the National Survey Organisations and to enhance the connections to regional initiatives such as at a European Scale like INSPIRE and the Open Data Directive. These connections will be most important for individual members but may also relate to interpretations of European Directives, such as the INSPIRE Directive (2007/2/EC) or more recently the Data Act. In addition, there are issues relating to cross-border harmonisation, which again need to be resolved by dialog, the majority of which needs to occur between National Surveys but may require reference to broader European or even Global initiatives. For example, cross border geological

classification may reference INSPIRE and the GeoSciML v4.1 encoding and codelists, which are in turn curated by the Open Geospatial Consortium and the linkage to The International Union of Geoscience Commission for the Management and Application of Geoscience Information (IUGS-CGI) Vocabulary Working Group, which operate at a global scale.

3. Working Group on Connecting to other initiatives

From the outset of the project, a Working Group was set up to identify what EGDI should be connecting to. Over a series of online workshops, this Working Group identified potential initiatives that needed to be considered and at the same time made or maintained the connections to principal initiatives.
The principle that was followed was built around the following objectives:

- Ensure the connectivity to and interoperability with a wide range of key European stakeholders: EU Open Data Portal, EU Inspire Geoportal, EOSC, RMIS and DestinE, etc
- Co-develop close links, interoperability and scientific use cases with Research Infrastructures, such as EPOS, with which several Geological Surveys are already closely engaged
- Address the requirements gathering in liaison with stakeholders and work with global standards bodies where necessary to ensure FAIR and open access for subsurface data at a European level
- Influence at a national level where possible in order to improve the FAIRness.

The main activities so far have been (i) to undertake a landscape analysis, (ii) to develop an Agile Story -the chosen method of working on tasks and subtasks in GSEU- around “Connection to EOSC”, and (iii) to ensure that the process is fully embedded in the EGDI workflow.

Finally, ongoing commitments to those that there are existing connections with have been maintained and built upon, and for key newer infrastructures such as EOSC the processes to expose our data have begun. In other cases, such as with the GREAT project, which is examining the issues and opportunities regarding specifically the Green Deal Data Space, preliminary meetings have been held.

The following sections explore the initiatives in the landscape analysis, then go on to explore the relationship and processes surrounding three key priority initiatives, namely EPOS, EOSC and GREAT.

3.1. Why Connect

During the landscape analysis identifying the initiatives, they were classified into three groups relating to what type of infrastructure they were. These are detailed hereafter as follows:

- Data Sharing Platforms or Networks
- Standards and Best Practices
- Wider Initiatives.

These high-level groupings helped to refine the data collection process. The reason for connecting was also identified. These reasons were varied but can be listed as follows:

- Requirements
- Data Analysis & Standards
- System Analysis
- Software development
- User Support
- Stakeholders.

There were further elements needed around types of connection needed:

- Type of connection: Interested in our data (with code list for how)?
- Physical: data or tool: Are we interested in their data (how)?
- Political: networking,
- Type of dissemination: harvesting, dump, WMS, WFS, web GIS viewer embedded in their website.

Finally, a first assessment was carried out on how the connection with the identified initiatives and infrastructure would be undertaken: who and how / which channel: webinar, direct, website, newsletter, etc.

3.2. Data Sharing Platforms or Networks

The following section presents a first subset of the landscape analysis result, i.e. operational infrastructures, several of them having already a connection with EGDI.

3.2.1. EOSC

The European Open Science Cloud (EOSC) is a pan-European project designed to create a virtual environment for sharing and accessing research data across borders and scientific disciplines. The EOSC Portal is the gateway to this environment, providing a single access point to a wealth of research resources and services.
Following the link below, one can learn more about the EOSC, its projects, and the partnerships that make it all possible. The EOSC is explained in more detail in section 4.2.
https://eosc-portal.eu/

3.2.2. EPOS

EPOS, the European Plate Observing System, is a multidisciplinary, distributed Research Infrastructure that facilitates the integrated use of data, data products, and facilities from the solid Earth science community in Europe.
EPOS brings together Earth scientists, national research infrastructures, ICT (Information & Communication Technology) experts, decision makers, and public to develop new concepts and tools for accurate, durable, and sustainable answers to societal questions concerning geo-hazards and those geodynamic phenomena (including georesources) relevant to the environment and human welfare. The relationships between EGDI and EPOS are explained in more detail in section 4.1.
https://www.epos-eu.org/

3.2.3. RMIS

The European Commission's (EC) Raw Materials Information System (RMIS) is developed by the Directorate-General (DG) Joint Research Centre (JRC) in cooperation with the DG for Internal Market, Industry, Entrepreneurship and SMEs (GROWTH). The RMIS is the Commission's reference web-based knowledge platform on non-fuel, non-agricultural raw materials from primary and secondary sources. During the MINTELL4EU project a small number of tailor-made web-GIS viewers were made to be included in the RMIS website in iFrames.

https://rmis.jrc.ec.europa.eu/.

3.2.4. OneGeology

OneGeology is an international initiative of the world's geological surveys and other international and regional geoscience organisations. Its aim is to provide access to global geoscience data via web services underpinned by commonly used geodata standards. OneGeology promotes exchange of know-how and skills enabling all potential users to participate. As a global project, it a coordinating activity that enables a community of geoscience organisations to share their geoscience data via web services.

The services are showcased through a web-enabled geoportal, and discoverable through a catalogue (also a service). The data services themselves are useable through any client that supports the services standards. The intention of the portal is to show that, through using common standards and protocols, data can be shared and work interoperably, independent of platform. https://onegeology.org/

3.2.5. eLTER

eLTER RI is an ecosystem and observation Research Infrastructure. It brings together a rich variety of terrestrial, forest, grassland, desert, tundra, freshwater, coastal and urban ecosystems, fully equipped with scientific tools for conducting novel research or years worth of data for utilizing the past for a more holistic approach. eLTER RI comprises National Research Infrastructures (NRIs), and European level Central Services (CS), such as data access, training and harmonised methods and parameters.

Countries supporting eLTER RI will provide infrastructure in the form of eLTER Sites (focal points for long-term ecosystem observation and research) and eLTSER Platforms (large areas facilitating socioecological research and exemplary stakeholder engagement). These national building blocks form the in-situ backbone of eLTER RI.
https://elter-ri.eu/

3.2.6. European Green Deal Data Space

The European Green Deal Data Space is called a federated ecosystem for resilience and sustainability. Primarily built to facilitate robust resilience and sustainability. The newly created Green Deal Data Space has been designed to deliver that. It provides access to projects and services that can be subsumed under this theme. And it goes far beyond previous dataspace offerings.

Designed as an open ecosystem, the Green Deal Data Space is claimed to be the first cross-domain data space for projects and services that allows users to offer their own solutions or search for and find resources for their own projects. An expert network in the Resilience & Sustainability Ecosystem Hub can be found at: https://green-deal-dataspace.eu/

3.2.7. European Open Data Space

The European open data space is seen as an essential element of the single market for data -an EU-wide interoperable data space that will enable the development of new products and services based on public data, and industrial and scientific applications. It focuses on the implementation of EU open data

and reuse policies under the legal acts adopted by the EU institutions. In 2021, the Publications Office of the EU was working on all four European open data space building blocks and their objectives:

- Providing a comprehensive catalogue of open data and citizen-centric reuse services
- Improving the interlinking and interoperability of open data with other sources of public-sector information, such as legislation, publications, and digital content
- Fostering the use of data from EU content through the organisation of EU Datathon competitions and data visualisation events
- Contributing to the implementation of data governance and policies across the EU institutions. https://digital-strategy.ec.europa.eu/en/policies/strategy-data

3.2.8. Open Data Cube

The Open Data Cube (ODC) is an open-source solution for accessing, managing, and analysing large quantities of Geographic Information System (GIS) data - namely Earth Observation (EO) data. It presents a common analytical framework composed of a series of data structures and tools, which facilitate the organisation and analysis of large, gridded data collections.

The Open Data Cube was developed for the analysis of temporally rich earth observation data, however the flexibility of the platform also allows other gridded data collections to be included and analysed. Such data may include elevation models, geophysical grids, interpolated surfaces and model outputs.
https://www.opendatacube.org/

3.2.9. EIGL

The Energy and Industry Geography Lab is a tool for geographical data related to energy, industry, and infrastructure. The tool makes it possible to find and filter energy-related data and create and share maps displaying this data.
The Energy and Industry Geography Lab enables analyses and assessments that support Europe's transition to climate neutrality. The tool is developed and maintained by the Joint Research Centre of the European Commission.
A tailor-made export of data about mineral occurrences and mines from the EGDI/MIN4EU database has been constructed to be added to the EIGL database. These data are now shown on the EIGL portal.
https://energy-industry-geolab.jrc.ec.europa.eu/.

3.2.10. EMODNET

The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy. These organisations work together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products.

This "collect once and use many times" philosophy benefits all marine data users, including policy makers, scientists, private industry and the public. It has been estimated that such an integrated marine data policy will save at least one billion Euros per year, as well as opening up new opportunities for innovation and growth.

The Marine Geology section of EGDI presents several data layers shared by EMODnet, e.g., seabed substrates and sea-floor Quaternary geology.

https://emodnet.ec.europa.eu/en

3.2.11. RESEERVE

RESEERVE project aimed to map the raw materials of West Balkan countries. The six ESEE (Eastern and South-Eastern Europe) countries include Albania, Bosnia and Herzegovina, Croatia, Serbia, Montenegro and North Macedonia. These countries have recently not been included in the existing data platforms. Therefore, the aim of the project was the creation of the West Balkan Mineral Register for primary and secondary raw materials. The register now enables the integration of the region into a pan-European minerals intelligence network and brings it closer to the common mineral market. Some selected data have been harvested from the MIN4EU, a subset of EGDI 2D central database dedicated to mineral occurrences, mineral deposits and mines in Europe.
https://reseerve.eu/

3.2.12. ENVRI

The ENVRI community is a community of Environmental Research Infrastructures, projects, networks and other diverse stakeholders interested in environmental Research Infrastructure matters. The community also includes e-infrastructures supporting the Research Infrastructures in data solutions.
https://envri.eu/

3.2.13. Data.Europa.eu

This portal is a central point of access to European open data from international, European Union, national, regional, local and geodata portals. It consolidates the former EU Open Data Portal and the European Data Portal. The portal is intended to:

- give access and foster the reuse of European open data among citizens, business and organisations
- promote and support the release of more and better-quality metadata and data by the EU's institutions, agencies and other bodies, and European countries
- educate citizens and organisations about the opportunities that arise from the availability of open data.

The portal is a key recipient of INSPIRE datasets from EuroGeoSurveys National Geological Surveys.
https://data.europa.eu/en

3.2.14. EuroGOOS

EuroGOOS, is the European Global Ocean Observing System. EuroGOOS identifies priorities, enhances cooperation and promotes the benefits of operational oceanography to ensure sustained observations are made in Europe’s seas underpinning a suite of fit-for-purpose products and services for marine and maritime end-users.

EuroGOOS is the European component of the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO (IOC GOOS). EuroGOOS Secretariat is located in Brussels, serving forty-six members and supporting five regional systems in Europe.
EuroGOOS working groups, networks of observing platforms (task teams), and regional systems (ROOS), provide fora for cooperation, unlock quality marine data and deliver common strategies, priorities and standards. These many EuroGOOS networks work towards integrated, sustained and fit-for-purpose European ocean observing, underpinning the EOOS framework.
https://eurogoos.eu/

3.2.15. GAIA-X

This is about a Federated and Secure Data Infrastructure in Europe. Gaia-X says that it strives for innovation through digital sovereignty. Its goal is to establish an ecosystem, whereby data is shared and made available in a trustworthy environment. Its stated intention is to give the control back to the users by retaining (i) sovereignty over their data, and (ii) sovereignty on the data transaction and transition.

It claims that its outcome will not be a cloud but a federated system linking many cloud service providers and users together in a transparent environment that will drive the European data economy of tomorrow.
https://gaia-x.eu/

3.2.16. DDE

The Deep-time Digital Earth (DDE) is a big science program dedicated to facilitating innovation in understanding the Earth's evolution and applications as well as the Sustainable Development Goals utilising Big Data analytics, internet cloud computing, data mining, machine learning and AI. The primary goal of the DDE programme is to harmonise 'deep-time' digital geological data. Deep-time data are data relating to the changing processes that the Earth has experienced through the millions of years of geological time. They include data on the evolution of life and climate, tectonic plate movement and the evolution of the planet's geography. Through DDE, data will be made available in easily used 'hubs' providing insights into the distribution and value of Earth resources and materials, as well as Earth hazards. Data brought together in new ways may provide novel glimpses into the Earth's geological past and its future.
https://www.ddeworld.org/

3.2.17. Arctic SDI

The Arctic SDI and the Arctic Spatial Data Infrastructure is a collaborative initiative of the National Mapping Agencies of the eight Arctic nations (Canada, Denmark, Iceland, Norway, Russia, Finland, Sweden, and USA) with a goal to promote partner-based development of an Arctic spatial data infrastructure. The aim of the infrastructure is to allow access to interoperable data and tools supporting monitoring and decision making for politicians, governments, policy makers, scientists, private enterprises and citizens in the Arctic.
The National Mapping Agencies provide authoritative, reliable, and interoperable data from their own holdings. As a collaborative initiative, the Arctic SDI can facilitate and enter into partnerships to deliver access to data from other reliable authoritative sources to ensure that spatial data is easier for Arctic stakeholders to access, validate and combine with other data.
https://arctic-sdi.org/

3.3. Standards and best practices

The following section presents a second subset of the landscape analysis result, i.e. a rather exhaustive list of standards and best practices, most of them being applicable and/or used to/by EGDI, e.g., OGC, CGI, INSPIRE, FAIR, UNFC.

3.3.1. OGC

OGC is the home of geospatial innovation, collaboration, and standards. This thirty years old international membership organisation supports a diverse community of 550+ businesses, government agencies, research organisations, and universities, working together to make location information FAIR. Therefore, through a large panel of working groups and well-established procedures, OGC designed several widely used interoperability data models and standards such as the web services: WMS, WFS, WMTS, WCS, CSW.

Under OGC, the Geoscience Domain Working Group was set up by BRGM and BGS in 2017.
https://www.ogc.org/

3.3.2. CGI

The International Union of Geoscience Commission for the Management and Application of Geoscience Information (IUGS-CGI). CGI's mission is to foster the interoperability and exchange of geoscience information, by active community leadership, collaboration, education, and the development and promotion of geoscience information standards and best practice.

CGI's vision is that geoscience information can be exchanged, understood, and used without limitation, that geoscience information can be readily integrated with standards-based information from other knowledge domains, that geoscience information is semantically rich and structured to enable seamless interaction in all environments, that global education about the management, modelling, exchange, and use of geoscience information enables its best possible application, for the benefit of all society. https://cgi-iugs.org/

3.3.3. INSPIRE

The INSPIRE Directive issued in 2007 aims to create a European Union Spatial Data Infrastructure (SDI) for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. This European Spatial Data Infrastructure will enable the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policymaking across boundaries.

INSPIRE is based on the infrastructures for spatial information established and operated by the Member States of the European Union. The Directive addresses 34 spatial data themes needed for environmental applications, including several geosciences namely, e.g. geology, mineral resources.
https://knowledge-base.inspire.ec.europa.eu/index_en

3.3.4. INSPIRE GeoPortal

The INSPIRE Geoportal is the central European access point to the data provided by EU Member States and EFTA (European Free Trade Association) countries under the INSPIRE Directive. The Geoportal allows:

- monitoring the availability of datasets in scope
- discovering suitable datasets based on their descriptions (metadata)
- accessing the selected datasets through their view or download services.

The metadata used in the Geoportal are regularly harvested from the discovery services of EU Member States and EFTA countries.
https://inspire-geoportal.ec.europa.eu/srv/eng/catalog.search#/home

3.3.5. FAIR

In 2016, the 'FAIR Guiding Principles for scientific data management and stewardship' were published in Scientific Data. The authors intended to provide guidelines to improve the findability, accessibility, interoperability, and reuse of digital assets. The principles emphasise machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention) because humans increasingly rely on computational support to deal with data as a result of the increase in volume, complexity, and creation speed of data.

FAIR principles are presented and discussed in paragraph 2.1 here above.
https://www.go-fair.org/

3.3.6. RDA

The Research Data Alliance (RDA) was launched as a community-driven initiative in 2013 by the European Commission, the United States Government's National Science Foundation and National Institute of Standards and Technology, and the Australian Government's Department of Innovation with the goal of building the social and technical infrastructure to enable open sharing and re-use of data.

RDA has a grassroots, inclusive approach covering all data lifecycle stages, engaging data producers, users and stewards, addressing data exchange, processing, and storage. It has succeeded in creating the neutral social platform where international research data experts meet to exchange views and to agree on topics including social hurdles on data sharing, education and training challenges, data management plans and certification of data repositories, disciplinary and interdisciplinary interoperability, as well as technological aspects.
https://www.rd-alliance.org/

3.3.7. CODATA

CODATA is the Committee on Data of the International Science Council **(**ISC**)**. CODATA exists to promote global collaboration to improve the availability and usability of data for all areas of research. CODATA supports the principle that data produced by research and susceptible to be used for research should be as open as possible and as closed as necessary. CODATA works also to advance the interoperability and the usability of such data: research data should be intelligently open or FAIR. By promoting the policy, technological and cultural changes that are essential to promote

Open Science, CODATA helps advance ISC's vision and mission of advancing science as a global public good.
https://codata.org/

3.3.8. IGSN

The International Generic Sample Numbering system. The objective of the IGSN is to implement and promote standard methods for identifying, citing, and locating physical samples with confidence by operating an international IGSN registration service. The IGSN Organisation works with DataCite to provide a globally recognised persistent identifier for sample identification and tracking that facilitates the efficient sharing of samples and their associated metadata among researchers, institutions, and databases.
https://ev.igsn.org/

3.3.9. DataCite

This global community shares a common interest: to ensure that research outputs and resources are openly available and connected so that their reuse can advance knowledge across and between disciplines, now and in the future.

As a community, DataCite makes research more effective with metadata that connects research outputs and resources–from samples and images to data and preprints. DataCite enables the creation and management of persistent identifiers, integrate services to improve research workflows, and facilitate the discovery and reuse of research outputs and resources.
https://datacite.org/

3.3.10. CoreTrustSeal

CoreTrustSeal is an international, community based, non-governmental, and non-profit organisation promoting sustainable and trustworthy data infrastructures. To manage its finances, CoreTrustSeal is a legal entity under Dutch law (CoreTrustSeal Foundation Statutes and Rules of Procedure) governed by a Standards and Certification Board composed of twelve elected members representing the Assembly of Reviewers.
CoreTrustSeal offers to any interested data repository a core level certification based on the Core Trustworthy Data Repositories Requirements. This universal catalogue of requirements reflects the core characteristics of trustworthy data repositories. The CoreTrustSeal Data Repository Application Management Tool is available to support applications.
https://www.coretrustseal.org/

3.3.11. ESIP

Created by NASA in 1998, Earth Science Information Partners (ESIP) was formed in response to a National Research Council recommendation calling for the involvement of community stakeholders in the development of NASA's Earth Observing System Data and Information System (EOSDIS) as a critical element of the U.S. Global Change Research Program. Since its inception, ESIP has continually grown and attracted a diverse group of partners, which now includes more than 120+ partner organisations. ESIP partners include federal data centers, government research laboratories, research

universities, education resource providers, technology developers, and various nonprofit and commercial enterprises.

ESIP has developed substantial collaboration tools and infrastructure to support this work. They use these tools to facilitate connections across traditional boundaries—organisations, sectors, disciplines, systems and data—allowing our partners and participants to leverage their collective expertise and technical capacity to address common challenges related to Earth science data. Their initiatives and collaborations result in knowledge, and the development of standards and best practices that make data discoverable, accessible and usable by scientists, decision-makers and the public. ESIP's status as a leading collaboration network has made it the go-to place to forge consensus on emerging data-related topics.
https://www.esipfed.org/

3.3.12. UNFC

The United Nations Framework Classification for Resources (UNFC) provides countries, companies, financial institutions and other stakeholders a futuristic tool for sustainable development of energy and mineral resource endowments. UNFC applies to energy resources including oil and gas; renewable energy; nuclear energy; minerals; injection projects for the geological storage of CO2; groundwater; and the anthropogenic resources such as secondary resources recycled from residues and wastes.
https://unece.org/sustainable-energy/sustainable-resource-management/united-nations-framework-classification

3.3.13. ENERGISTICS

Energistics provides the global upstream oil and gas industry with an open consortium to define, develop and maintain data standards. Energistics is dedicated to informing, educating and supporting all stakeholders to ensure a rapid and effective adoption of the standards in the pursuit of interoperability, efficiency and data integrity.
https://energistics.org/

3.3.14. OSDU

The Open Group OSDU Forum delivers an Open Source, standards-based, technology-agnostic data platform for the energy industry that stimulates innovation, industrialises data management, and reduces time to market for new solutions.
The OSDU Forum seeks to reduce data silos to enable transformational workflows, accelerate the deployment of emerging digital solutions for better decision making and create an open, standards-based ecosystem that drives innovation for the energy industry.
https://osduforum.org/

3.3.15. ISO TC 211

International Standards Organisation Technical Committee 211 for Standardisation in the field of digital geographic information.
This work aims to establish a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth.

Within the scope of geographic information, these standards may specify methods, tools, and services for data management. Data management is understood to include acquiring, processing, analysing, accessing, presenting, and publishing data for users and systems.

The work shall link to appropriate standards for information technology and data where possible and provide a framework for the development of sector-specific applications using geographic data. https://www.iso.org/committee/54904.html

3.4. Wider initiatives

The following section presents the third and last subset of the landscape analysis result while opening up the spectrum from the organisation point of view.

3.4.1. IUGS

The International Union of Geological Sciences (IUGS), founded in 1961, with 121 national members, representing over a million geoscientists, is one of the World's largest scientific organisations. It encourages international co-operation and participation in the Earth sciences in relation to human welfare and is a member of the International Science Council (ISC). Membership is open to countries or defined regions. IUGS believes that it is of mutual benefit to establish close links with other organisations engaged in geoscience activities, and especially those organisations whose work relates to some of the major activities of IUGS.
https://www.iugs.org/

3.4.2. CCOP

The Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) is the international intergovernmental organisation in geological sciences in East and Southeast Asia. CCOP was authorised by the United Nations in 1966. Its main responsibilities are to organise and to coordinate the cooperation between East and Southeast Asian countries in the fields of energy policy and technology, mineral resources and coastal zone management, groundwater, geological hazard prevention, environmental protection, geo-information management and so on. Through project cooperation, technology transfer, information exchange, and capacity building, CCOP has made outstanding contributions to the sustainable economic and social development of East and Southeast Asia, and to the improvement of the quality of life of local people.
https://ccop.asia/Index

3.4.3. OSGeo and FOSS4G

The OpenSource for GeoSpatial (OSGeo) main focus is fostering the development, maintenance and use of free and open source software for geospatial, open standards, and open data. The democratising nature of the field creates a basis for sharing geographic data, promotes cooperation between organisations and individuals, and enables the application of data in solving the most diverse everyday problems, being the basis for such fields as map applications, logistics, transport, infrastructure planning, organising rescue work in disaster areas, etc.

FOSS4G (Free and Open-Source Software for Geospatial) is the community annual conference organised by volunteers, with a focus on building a diverse and sustainable open community, sharing experiences, technical implementations and learning from each other.
https://www.osgeo.org/

3.4.4. DestinE

Destination Earth is a flagship initiative of the European Commission to develop a highly accurate digital model of the Earth (a digital twin of the Earth) to model, monitor and simulate natural phenomena, hazards and the related human activities. These ground-breaking features assist users in designing accurate and actionable adaptation strategies and mitigation measures.

DestinE unlocks the potential of digital modelling of the Earth system at a level that represents a real breakthrough in terms of accuracy, local detail, access-to-information speed and interactivity.
By pushing the limits of computing and climate sciences, DestinE is an essential pillar of the European Commission's efforts towards the Green Deal and Digital Strategy.
https://destination-earth.eu/

3.4.5. AASG

The Association of American State Geologists (AASG) represents the directors of the state geological surveys in the states and Puerto Rico. The responsibilities of each state survey vary, depending upon legislation and traditions. Most function as an information source for government and society. Some have regulatory roles for topics such as water, oil and gas, mining, and land reclamation. The State Geologists began formal meetings with the U.S. Geological Survey in 1879, the year that organisation was established. Since 1908, the Association has met regularly to discuss issues of common interest and to initiate united actions when warranted.
https://www.stategeologists.org/

3.4.6. EPOS GIM

The EPOS Geological Information and Modelling (GIM) Thematic Core Service (TCS): develops and consolidates information and data infrastructures produced by the geological international community; provides virtual access to geological data, maps, and models; allows users to retrieve consolidated information produced by research facilities and share and publish their data and content on the EPOS' ICS-C platform for data, data services and software.
The implementation of actual connections between EGDI and EPOS data portal is further detailed in section 4.1.
https://www.epos-eu.org/tcs/geological-information-and-modeling

3.4.7. GEO/GEOSS

The Group on Earth Observations (GEO) is a global collaboration dedicated to understanding our Earth in all its complexity. As a collaborative intergovernmental body, GEO is dedicated to co-producing user-driven Earth Intelligence solutions. By collecting and sharing vital information, ranging from satellite images of forests to oceanic temperature readings and beyond, GEO provides a comprehensive view of our planet's well-being, allowing us to monitor and safeguard its health. These are not just datasets;

they're the tools that inform decisions, shaping policies and initiatives worldwide that guides society towards a sustainable future.
https://earthobservations.org/

A central part of GEO's mission is to build the Global Earth Observation System of Systems (GEOSS). GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS links these systems to strengthen the monitoring of the state of the Earth. It facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organisations within GEO. Further, GEOSS ensures that these data are accessible, of identified quality and provenance, and interoperable to support the development of tools and the delivery of information services. Thus, GEOSS increases our understanding of Earth processes and enhances predictive capabilities that underpin sound decision-making. This 'system of systems', through its GEOSS Platform. It provides access to data, information and knowledge to a wide variety of users.
https://old.earthobservations.org/geoss.php

4. Deep Dive Connections

As stated in the Introduction, some of the connections are longstanding or do not require the detailed analysis to prioritise them for action. In this section, we will explore two of the clearest connections that are required, firstly to the EPOS Research Infrastructure, representing much of the research geoscience data in Europe. Secondly, connections to the European Open Science Cloud, a leading approach in Europe to bringing research data together and providing tools and platforms for their cross-domain analysis. The third initiative is European Data Spaces. This is a new area for Geological Survey engagement and exploration is only just beginning.

4.1. EPOS – European Plate Observing System

The European Plate Observing System (EPOS, www.epos-eu.org) is a multidisciplinary pan-European Research Infrastructure (RI) for solid Earth science. It aims at providing integration, accessibility, use and re-use of data, data products and services. It results from a construction process through a series of research and development projects funded by the European Commission over more than ten years.

In 2018, the European Commission granted the legal status of EPOS European Research Infrastructure Consortium (ERIC). Based in Italy (INGV-Istituto Nazionale di Geofisica e Vulcanologia), EPOS ERIC has currently eighteen members and one participating as an Observer. Two more countries will join the EPOS ERIC Consortium in 2024. Seven additional countries are included in the EPOS integration plan and provide data and services through the data portal. The wide range of solid Earth domain is represented by ten thematic communities (Figure 2).

The European Commission Open Science agenda contains the ambition to make FAIR principles and open data the default standard for the results of EU-funded scientific research. Then, EPOS committed to include them in the design of the technical architecture as well in the best practices shared by the data and services providers. Therefore, EPOS Sustainability Phase project (H2020 - 2020-2022) had a specific objective to “foster EPOS readiness with EOSC and FAIR Data”. In practice, it was involved in the European Open Science Cloud (EOSC) as pilot for the implementation of this e-Infrastructure.

4.1.1. EPOS Delivery Framework

The federated approach adopted by EPOS led to design and implementing the Delivery Framework. The data and services provided by the national research infrastructures and data centers are integrated from the ten Thematic Communities (TCS – Thematic Core Services) and made interoperable with the central hub of the Integrated Core Services (ICS-C). This e-infrastructure enables FAIR data management and access to up to 264 data assets (as on 31/01/2024) through the EPOS Data Portal (https://www.ics-c.epos-eu.org/). The main architectural concepts underpinning the portal are the rich-metadata, the service-driven data provision, and the usage of semantics. The more than 260 services provided by 26 countries deliver more than 30 different data types and formats described by more than 20 different types of metadata.

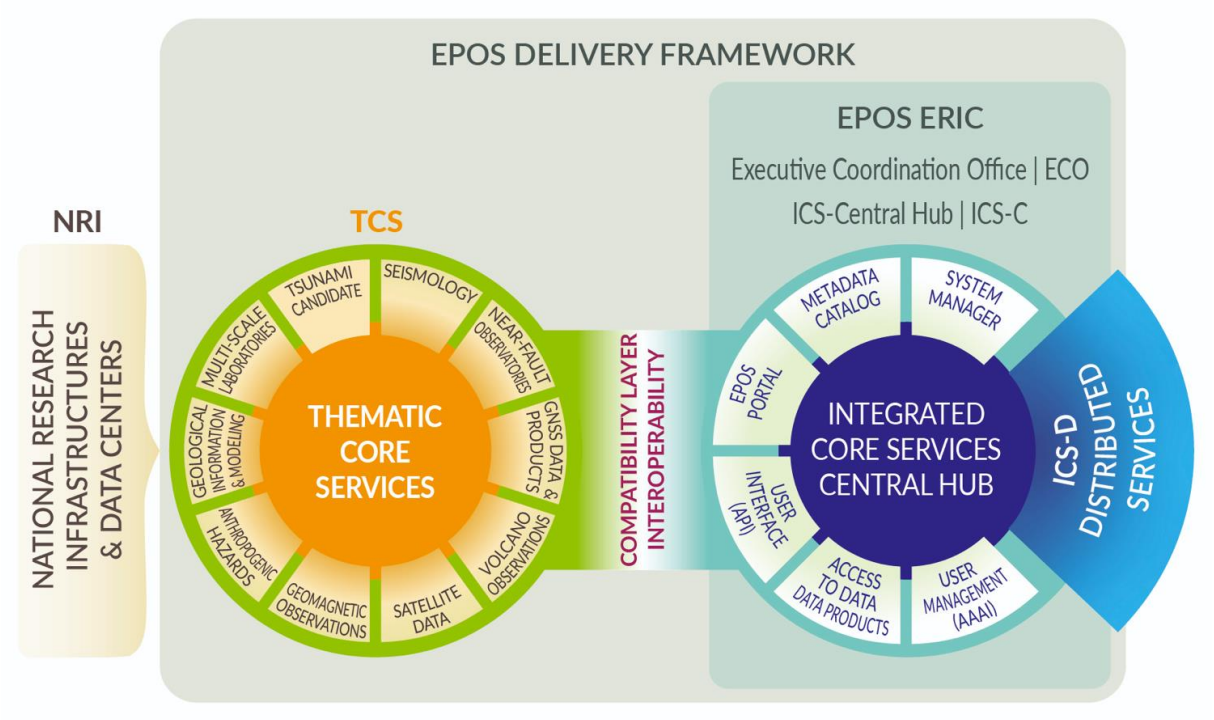

Figure 2. Main elements of the EPOS architecture.

Figure 2 shows the three main components:

- Data generation in National Research Infrastructures
- Federated data management by the Thematic Core Services: community governance layer to ensure effective management of thematic-specific data and services for their integration and provision within EPOS
- Data integration and access by the Integrated Core Services including the Central Hub (ICS-C) and Distributed Services (ICS-D): e-infrastructure for data and services integration and accessibility through the EPOS Data Portal.

The ICS Central Hub (ICS-C) is jointly hosted by BRGM (France) and BGS (United Kingdom) with duplication mechanisms for 24/7 availability and backup. The data services are regularly monitored (15 mn) by GEUS (Denmark). After a Pilot Operational Phase (2020-2022), the Delivery Framework including (1) the central hub, (2) 250+ thematic data services, and (3) the data portal was launched in operation in April 2023.

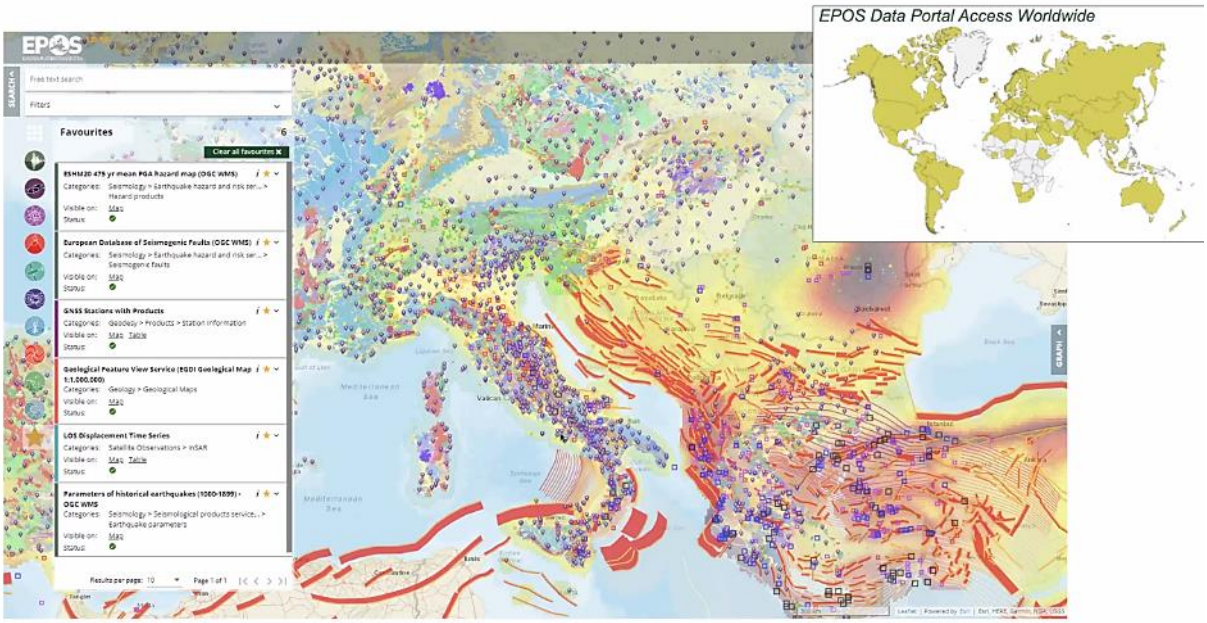

Figure 3. Solid Earth data sets on the EPOS Data Portal.

The geographical extension of several data sets exposed by EPOS is far beyond the European borders: seismic monitoring networks, volcanic activity, anthropogenic hazards, and offshore scientific boreholes.

More than a portal, EPOS offers a platform to access multi-disciplinary data and services that are quality controlled by their respective producer organisations and research networks. These reliable and organised contents are made accessible in compliance with the technical and semantic interoperability rules and more broadly with the FAIR principles.

4.1.2. Thematic Core Services Geological Information and Modelling (TCS GIM)

During the earlier phase of EPOS construction (EPOS Implementation Phase Project, 2015-2019), several European Geological Surveys teamed up as a continuation of their respective activities in the standardisation and interoperability activities (INSPIRE, IUGS/GCI, OGC). These were national surveys from Denmark (GEUS), Ireland (GSI), Italy (ISPRA), and France (BRGM). In addition, academia were represented by the Department of Earth Sciences, Uppsala University, Sweden, and the Helmholtz Centre Potsdam, German Research Centre for Geosciences, Germany. The Geological Information and Modelling TCS GIM was formally established in 2019 under the umbrella of EuroGeoSurveys (EGS), and through the extension of the initial group. The Geological Surveys of Czech Republic (CGS), Slovenia (GeoZS) and U.K. (BGS) joined. The TCS GIM consortium is chaired by EGS, co-chaired by CGS, and coordinated by BRGM. BGS oversees the stakeholder panel (to be established). The data and product services are provided under the umbrella of EGS. Three IT contact points representing as many web service end points are in place at BRGM, GEUS and GeoZS.

The Thematic Core Services implemented by the Geological Information and Modelling group represent a selection of basic geological topics useful for the other TCS communities (Fig. 4).

Four couples of data services are exposed by TCS GIM on the EPOS Data Portal:

- Boreholes: view and download
- Geological map at 1:1,000,000: view and download
- 3/4D models: view and download
- Mines: view and download

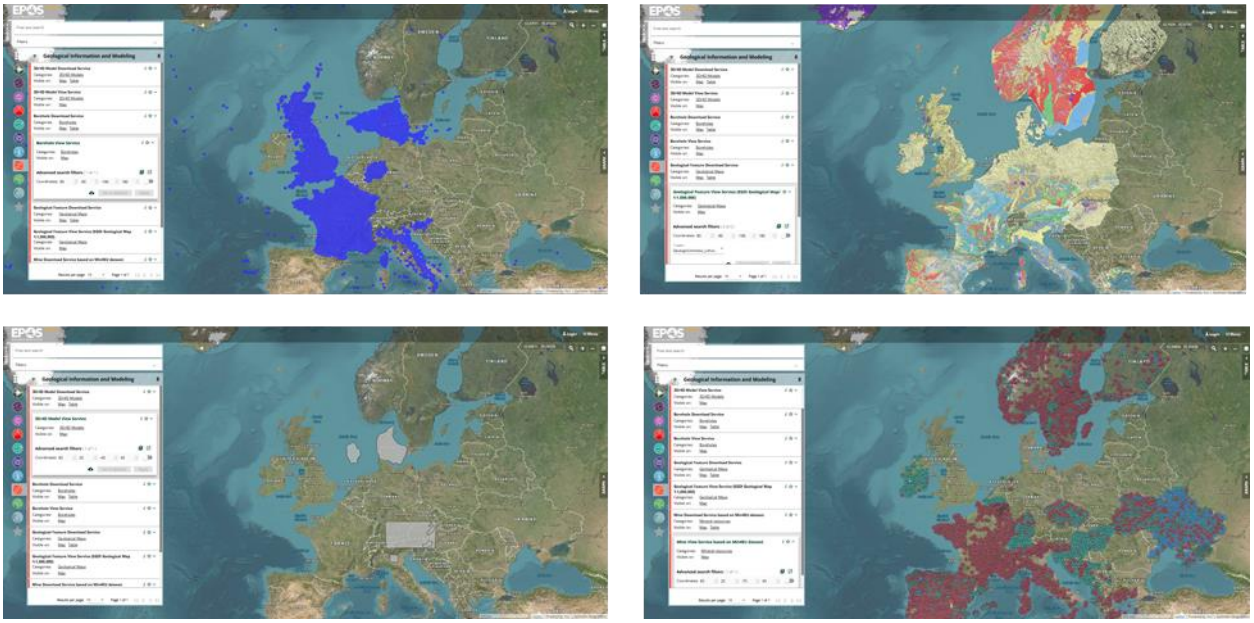

Figure 4. TCS GIM services on the EPOS Data Portal: Boreholes, Geological map at 1:1,000,000, 3D/4D Models and Mines.

The same data is shown on the EGDI Data Portal, but on that there is not in the same way a distinction between view and download. In addition, the GIM community uses geoscience domain-controlled geoscience vocabularies through the European Geoscience registry (INSPIRE Register Federation) https://data.geoscience.earth/ncl/. This is complemented by a multi-disciplinary project vocabulary and a multilingual keyword thesaurus.

4.1.3. EGDI Connection to EPOS

European and international interoperability implementation frameworks are well described and used (e.g., INSPIRE, ISO, OGC, and IUGS/CGI). It can be difficult for data providers to deploy web services that support the full semantic data definition (e.g., OGC ComplexFeature) to expose several millions of geological entities through web-enabled data portals as required by pan-European platforms such as EPOS. Then, during the EPOS Implementation Phase Project, the TCS GIM group implemented and innovatively extended two standardised descriptions, i.e. GeoSciML-Lite and EarthResourceML-Lite, with an important reuse of content from Linked Data Registries. The TCS GIM members designed and agreed upon the corresponding data models (BoreholeView and ModelView) to be implemented at each data provision end point, i.e. the TCS GIM consortium members. Since then, the set-up evolved to take advantage of the pan-European geological map and minerals resources databases centralised by EGDI.

The virtual access to the GIM data services through the EPOS Data Portal is provided by the EGDI central system for the following thematic domains: geological map, mines and 3D/4D models. All data

for these domains originate from EGS members. As for the boreholes, the data is a combination of data from EGS members, from Helmholtz Centre Potsdam, and from Uppsala University.

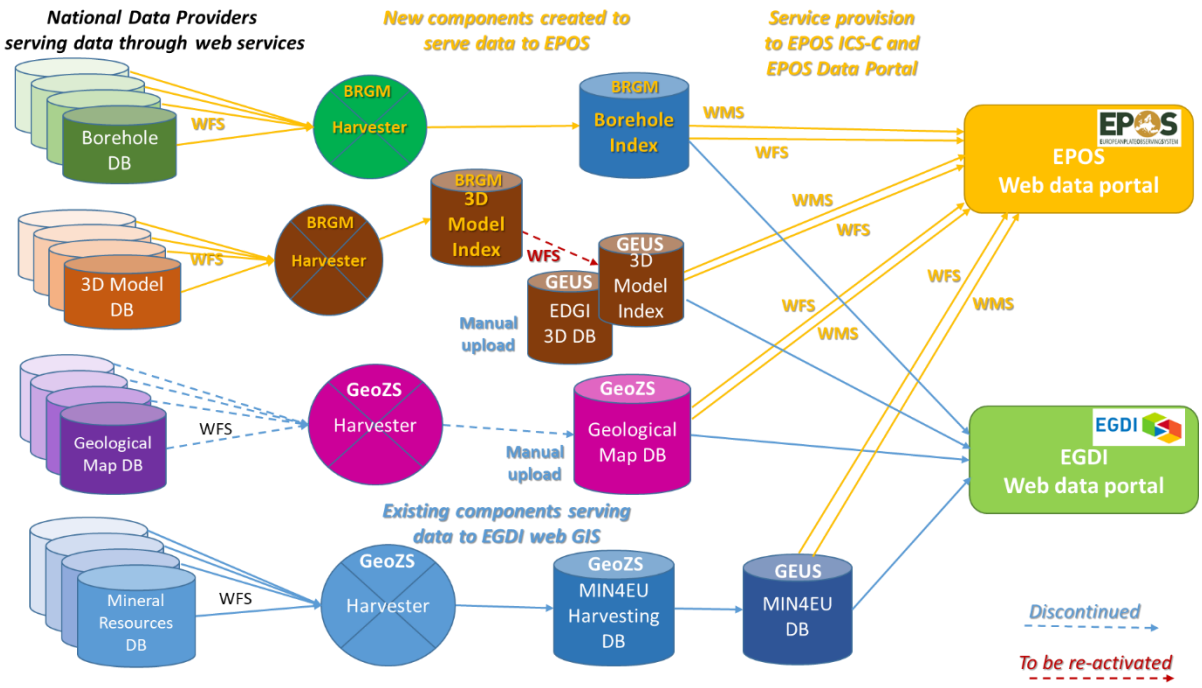

Figure 5. Workflow of data web services to EPOS and EGDI platforms.

a) Geological map service

The pan-European onshore surface geology at 1:1,000,000 scale assembles national digital maps produced by the respective countries. As a result of a couple of EU-funded projects, mainly OneGeology-Europe and GeoERA, this transnational map can be harvested from INSPIRE-compliant web feature services on GeologicUnit exposed by 23 EGS Geological Surveys. The harvesting mechanism is hosted by GeoZS, Slovenia, which is also in charge of publishing the outgoing web services for geological map data to be accessible (1) on the web-GIS EGDI portal, and (2) on the EPOS Data Portal. However, the geological map being by essence a stable data set (updated every decade in best cases), the harvesting mechanism is presently inactive.

The two-fold service is an implementation of the GeologicFeatureIndex model and offers to the users:

- Geological Feature View Service (WMS): the surface geology entities are described as geological units forming an almost continuous map across Europe on the EPOS Data Portal. This data service consists in two layers showing Age or Lithology. The user can switch between the two layers by choosing one from the "*Layers" drop-down list in the "Advanced search filters" section.
- Geological Feature Download service (WFS): it enables the user to search for GeologicUnit by matching a set of criteria such as location and other properties that are defined in the specification based on GeoSciML-Lite (e.g., lithology, age…); INSPIRE code lists are used.

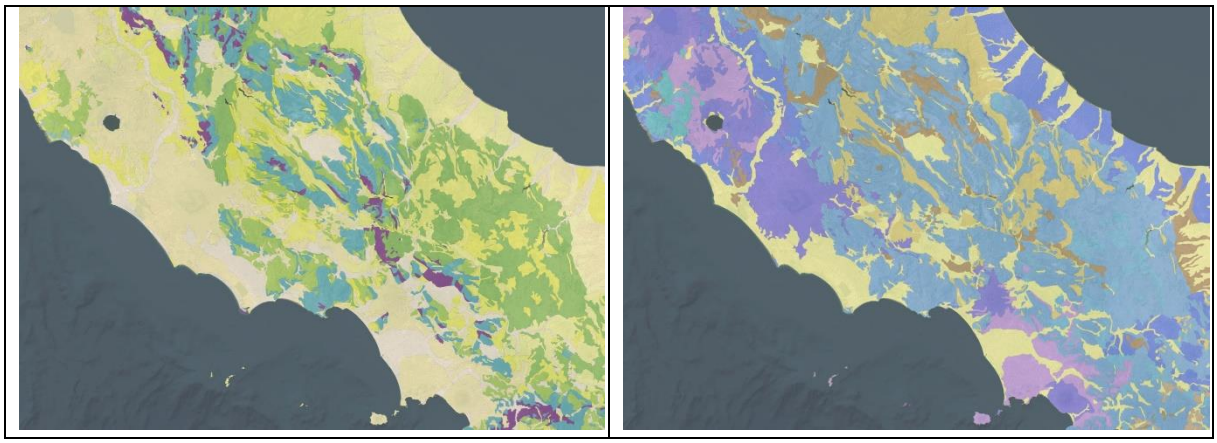

Figure 6. Geological map service on the EPOS Data Portal - Surface geology displayed by age and by lithology.

The search is proposed by the EPOS data portal native filter functions, or by querying the Geological Feature View Service or Geological Feature Download Service with CQL-Filters added to the WFS query.

b) Mineral resources (mines) service

This data set was compiled over more than 15 years in a series of European mineral inventory projects (e.g., ProMine, Minerals4EU, Mintell4EU). Most geological surveys host data on raw materials, however, data are typically organised in different ways from one country to another based on different geological traditions, legal frameworks, etc. The latest EU-funded Mintell4EU project built on previous projects to collect a selection of these national/regional raw material data using a harvesting mechanism to populate the Minerals Inventory database hosted by GeoZS, Slovenia. This system is operated by GeoZS for collecting and validating these European mineral resources data and it includes technical routines to ensure a rigorous control of the data quality. As on date, this process involves 36 providers from 31 member countries of EuroGeoSurveys.

On a regular basis, the database content is transferred to the EGDI central database hosted by GEUS, Denmark, to enable the visualisation in a harmonised way on dedicated web maps on the EGDI web portal. In addition, two web services are exposed by GEUS to the EPOS Data Portal through the implementation of the MineralResourcesIndex data model derived from the MIN4EU model to enable the data diffusion:

- Mine View Service (WMS): the European mines are displayed using a first set of descriptors (name, status, activities and associated products, citation),
- Mine Download Service (WFS): in addition to the geographical search provided by the EPOS Data Portal interface, the user can interact with the mines with dedicated descriptors (e.g., commodity, geologic history, type of mineral occurrence type, etc.).

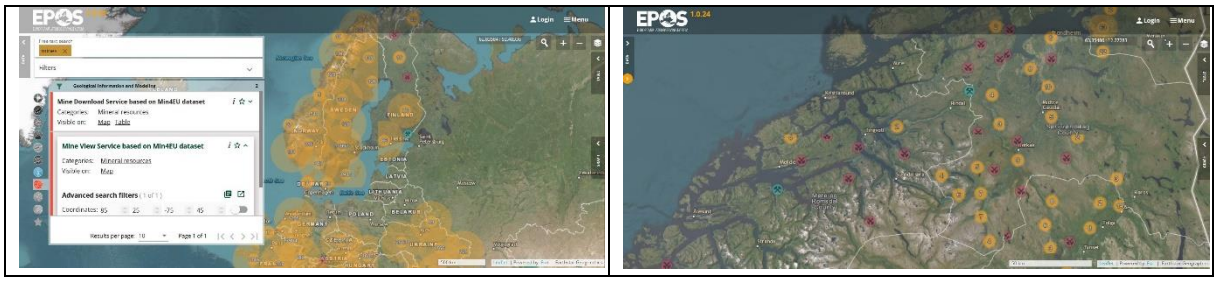

Figure 7. Mines data service on the EPOS Data Portal.

c) 3D/4D models service

This service is an implementation of the ModelIndex data model and contains discovery information for 3D geological models of any kind. TCS GIM developed this *ad hoc* semantic specification, as no previous one was available. After being individually uploaded by the producers using a dedicated functionality of the EGDI portal, the 3D models are stored in the 3D central database of EGDI and the ModelIndex is populated accordingly. Two web services are exposed by GEUS to the EPOS ICS-C:

- The 3D/4D Model View Service (WMS): It consists in one layer that displays the geographic extent of the models and provides discovery data such as the purpose, geographic extensions and well as the associated report and a preview link when available.
- The 3D/4D Model Download Service (WFS): It consists in one layer that displays the geographic extent of the models and provides information like the View Service. They are searchable using the “Advanced Search Filters”.

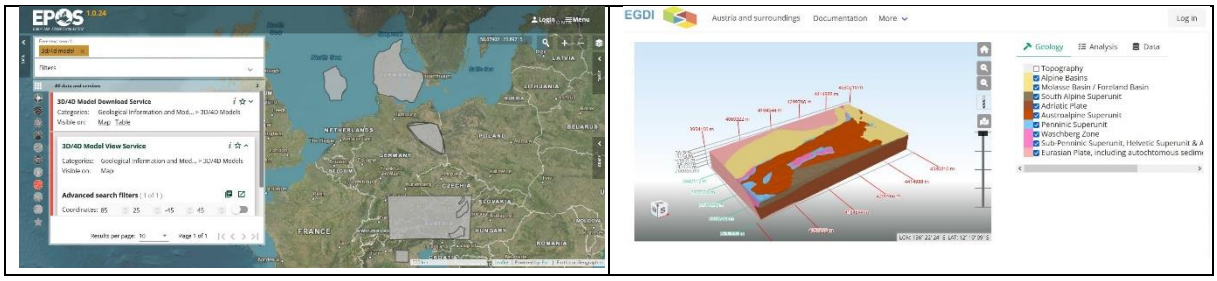

Figure 8. 3D/4D Models data service on the EPOS Data Portal.

d) Boreholes service

The data set exposed in EPOS includes onshore and offshore boreholes made available by the TCS GIM members (over 2.2 million boreholes as on 31/10/2022). It includes boreholes drilled for scientific, private and commercial purposes. The national geological surveys (e.g. BRGM, BGS, GEUS, ISPRA, GSI) expose data sets as part of their public service mission, often comprising several hundred thousands of boreholes. Another member of the TCS GIM Consortium, the Department of Earth Sciences of Uppsala University (Sweden), provides a deep borehole data set compiled from projects and expeditions of the International Continental Scientific Drilling and International Ocean Discovery Programs (ICDP/IODP).

However, it proved to be difficult for several data providers in several earlier pan-European projects to deploy the OGC services with full semantic data definition (OGC Complex Feature) for the view and

download of thousands to millions of geological entities. To overcome this implementation difficulty and be technically inclusive, the TCS GIM community designed a data architecture based on SimpleFeature exposed in form of an index. This fully Linked Data-oriented simple data payload provides the relevant link to semantically richer ones.

Index data services are exposed by each data provider according to the TCS GIM specifications (EPOS-Geo-SciML-Lite profile11). They are in return harvested at the TCS GIM central borehole index node at BRGM level for quality check, European consolidation and exposition to EPOS ICS-C and Data Portal.

Two services are offered to the users:

1. The Borehole View Service (WMS) enables the user to discover and interact on a map with the available boreholes. A click on a Borehole provides the user with a set of descriptors that are defined in EPOS GeoSciML-Lite profile (e.g., depth, purpose, drilling method, availability of borehole logs, source documents, geological description, link to monitoring equipment, etc.),
2. The Borehole Download Service (WFS) enables the user to search for boreholes matching a set of criteria such as location, and many other properties that are defined in the specification based on GeoSciML-Lite (e.g., drilling method, core length, access to the physical core, to logs, to water level, etc..

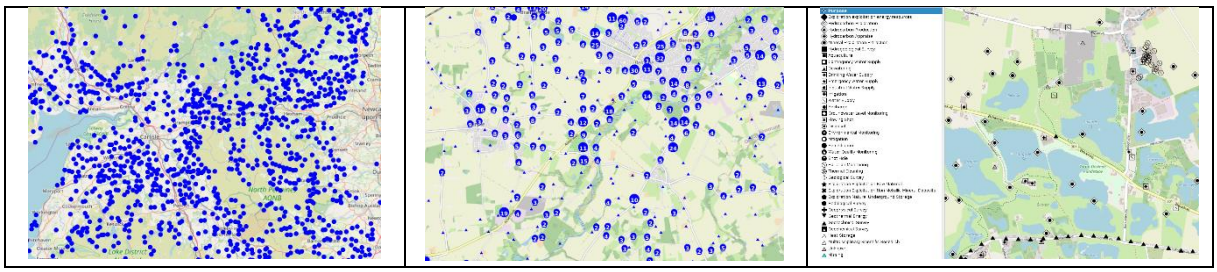

Figure 9. Borehole data service on the EPOS Data Portal: small, medium and large-scale visualisation.

With such a bulky data set, the visualisation of the boreholes turns out to be challenging and precise filtering of data before download and interaction is indispensable. By default, the display of Borehole Download Service is therefore limited to a small area. The user can modify the search / display area by using the “Advanced coordinates” functionality.

The Borehole View Service consists of three layers (Fig. 9). Only one layer is visible at any zoom level, transitioning from "Cluster Group" to "Stacked Point" to "Purpose" when zooming in. In small map scale, the "Cluster group" layer provides an overview over where boreholes are available. At medium map scale, the "Stacked point" layer informs about boreholes by providing their location or the number of boreholes in a cluster where individual location cannot be resolved. At large map scale, the "Purpose" layer displays individual boreholes with a symbol representing the purpose for which the borehole was drilled.

The Borehole View Service consumed by the EPOS ICS-C is also integrated in the EGDI web platform.

4.1.4. Lessons Learnt

The connection between EPOS ICS-C and EGDI platforms extends the visibility of both data infrastructures while providing to the end users access to multidisciplinary data sets (260+ in case of EPOS; 800+ in case of EGDI). The portfolios of thematic domains addressed by both platforms are different and complementary. The metadata records of data EGDI sets accessible through the EPOS Data Portal include a link to the reference data sets in EGDI.

Several lessons can be drawn from the development of these respective data web services over a decade.

On the semantic side:

- The use of 'View' services (e.g. BoreholeView, GeologicUnitView, ...) to support the easy discovery of geospatial features proved to be a good solution. Those view services are based on international standards and apply W3C “Spatial Data On The Web” best practices. They do not convey the full breadth of information modelled in their underlying standards but enough for discovery/view simple features. This design choice simplifies data exposition (data provider side) and re-use (client side) as data payload are easier to both set up and understand
- Associating this approach with improved coupling of the EGDI metadata catalogue to EPOS ICS-C would ensure a maximum visibility thus reuse of the datasets produced by the EGS projects
- The DCAT-AP new international standard on DataSets / DataServices proved to be adapted and robust to implement the metadata catalogue
- Using a Linked Data Registry tool for "controlled vocabulary" both within EGS projects (https://data.geoscience.earth/ncl/) and EPOS itself (registry epos : https://registry.epos-eu.org/ncl/). These Linked Data Registry systems are complementary to metadata and data services
- However, the datasets produced by EGS projects would gain better visibility in EPOS provided the EGDI metadata catalogue complies with the approach, i.e. it implements natively EPOS_DCAT_AP.

On the technical side:

- When data must be exposed to an external platform (as EPOS) through OGC services, the user-friendliness on that portal may be poorer than on the provider’s portal. Therefore, the destination platform may request a copy of the data set from EGDI rather than just connecting to web services
- However, this produces the co-existence of multiple instances of the concerned data set. This procedure generates a database governance issue upon contents which are up-to-date for a few moments only
- Rather than a systematic and complete delete-copy process involving the production and transport of large size files, a publication-subscribe mechanisms is lighter. Any change in the original database is declared in a message including the actual content changes. Through a server-to-server messaging system, the destination database is updated only with the necessary content. Both databases can then be maintained with an equivalent level of freshness

- EPOS metadata is only fed through a GitLab project (pushing files) and not natively connected to communities' production system. This adds an extra burden on each TCS community to ensure that any update regarding metadata in their systems are properly propagated to the file required by EPOS ICS-C
- OGC services (WMS, WFS) proved yet another time their usefulness in standardised data discovery and that they contribute to achieve FAIRNess especially when coupled with semantics to structure their payload
- However, on the client side, EPOS ICS-C data portal does not make presently the best use out of TCS GIM services
- For example, it is not because the data portal client expects JSON based data flows (GeoJSON) that the structure of such flow has to be "flat". Since there is no regulation nor technical limitation about this, the EPOS Data Portal needs to be more flexible and improved to enable a better reuse of data exposed by TCS GIM flows. This would subsequently benefit to other TCSs
- When thousands of features are served with a WMS, TCS GIM tested and validated a server side solution (GeoServer PointStacker) that enables to cluster data representation on the server side. This enables proper map navigation on large geospatial datasets and is only feasible on the server side. Indeed, doing this on the client side requires too many vector features to reach the client side, hence making it rather aggressive on the client components (and on the network)
- Another type of OGC services would be worthwhile being implemented by both EGS and EPOS communities: Observation services (compliant to OGC/ISO 19156 Observations, measurements and samples standard). As such, exposing data produced by monitoring sensors but also borehole logs through OGC SensorThings API Part 1 will lead to achieve a higher level of FAIRNess on these types of data.

4.2. EOSC – European Open Science Cloud

The EOSC aims to offer European researchers and professionals in science, technology, human and social sciences a European virtual space for managing their research data. It includes open and transparent services for storing, managing, analysing and re-using research data across borders and scientific disciplines, by bringing together existing infrastructures and services.

The EOSC is an ongoing process to continue to make research in Europe more open and productive. This gives all European researchers access to scientific data, services and e-infrastructures to analyse data. This shall rely mainly on existing services and e-infrastructures. The EOSC is free at the point of use.

EOSC is comprised of a portal, a community, and a partnership:

- Portal: (https://eosc-portal.eu/) where European researchers have access to scientific data, services and infrastructures for analysing data. The portal has dedicated pages for (1) researchers, (2) providers, and (3) businesses. Indeed, the initial effort is to develop the basic functions of a stable EOSC system that provides access to data, services, and infrastructure for the public research community. The scope of the EOSC has been extended beyond the research communities to the wider public and private sectors

- Community: The EOSC brings together researchers and engineers from all scientific domains and EU countries. It is not only about sharing data, services and infrastructures, it is also about sharing expertise and working together on better solutions. It is a place for researchers and engineers from all scientific fields in terms of data and services as well as skills. Services for storing, managing, analysing and re-using data for research innovation and education can be registered on the platform
- Partnership: EOSC is one of co-programmed Partnerships of the European Union. As such, it is governed by three partners: the European Commission, the EU member states and associated countries (as represented in the EOSC Steering Board) and the users and providers, represented in the EOSC Association. It is not necessary to be member of the Association to benefit from the EOSC services, nor in case of application for financial support through the Horizon Europe program.

Within Horizon Europe, the EOSC is part of the Research Infrastructure program of the first pillar. For 2023 / 2024, 11 calls are foreseen with a total volume of 130 M€ / The Research Infrastructures work programme is structured around five “Destinations”, one of which is fully dedicated to the European Open Science Cloud: Destination – Enabling an operational, open and FAIR EOSC ecosystem (INFRA-EOSC). This “Destination” aims at delivering a “Web of FAIR Data and Services” for Science in Europe: a trusted virtual environment supporting Open Science.

The EOSC Association is the legal entity established to govern the European Open Science Cloud. It was formed in July 2020 with four founding members and has since grown to more than 250 Members and Observers. The Association membership is jointly responsible for delivering the objectives agreed in the Memorandum of Understanding signed by the European Union and EOSC Association to form the official Partnership.

SRIA and MRA

The overall purpose of the EOSC Strategic Research and Innovation Agenda, or SRIA, is to define the general framework for future research, development and innovation activities in relation to the EOSC. The current version of the SRIA (1.1) was finalised in November 2022. The Multi-Annual Roadmap (MAR) defines a set of priorities for future investment in EOSC. It is part if the EOSC SRIA. The EOSC Association is currently preparing the MAR for the 2025-27 period.

Several milestones for the setting up of the EOSC:

- In May 2015, the European Commission proposed creating a European Open Science Cloud (EOSC) to the Competitiveness Council. The aim was to federate existing research data infrastructures in Europe and realise a web of FAIR data and related services for science, making research data interoperable and machine actionable following the FAIR guiding principles
- In March 2018, the European Commission published the EOSC Implementation Roadmap detailing the main action lines of the first EOSC implementation phase until 2020
- The European Commission provided financial support to implement the EOSC by means of projects under the EU Framework Programme for Research and Innovation (Horizon 2020)
- In July 2020, an EOSC Association was set up to provide a single voice for advocacy and represent the broader EOSC stakeholder community. This association became operational in 2021

- EU countries and countries associated with Horizon 2020, represented in the EOSC Governance Board, agreed unanimously to run the EOSC as a co-programmed European Partnership under Horizon Europe (2021-2017)

The process whereby the EGDI data contents may be made visible and searchable through the EOSC Portal (EOSC Marketplace" is described in the next sections.

4.2.1. EOSC for researchers

The user community includes a wide panel of researchers including scientists, students, lecturers, teachers and citizen scientists. The dedicated page on the EOSC portal (Fig. 10) proposes access to both contents and tools through search engines:

- Explore and contribute
  - Discover research outputs: Find datasets, scientific publications and software for research activities
  - Publish research outputs: store, backup, archive data, publications and software
- Tools
  - Access computing and storage resource: find HPC, IT centres for science, cloud computing and online storage
  - Process and analyse: verify, organise, transform data, then export it in the format you need
  - Access training materials: lessons, courses, videos.

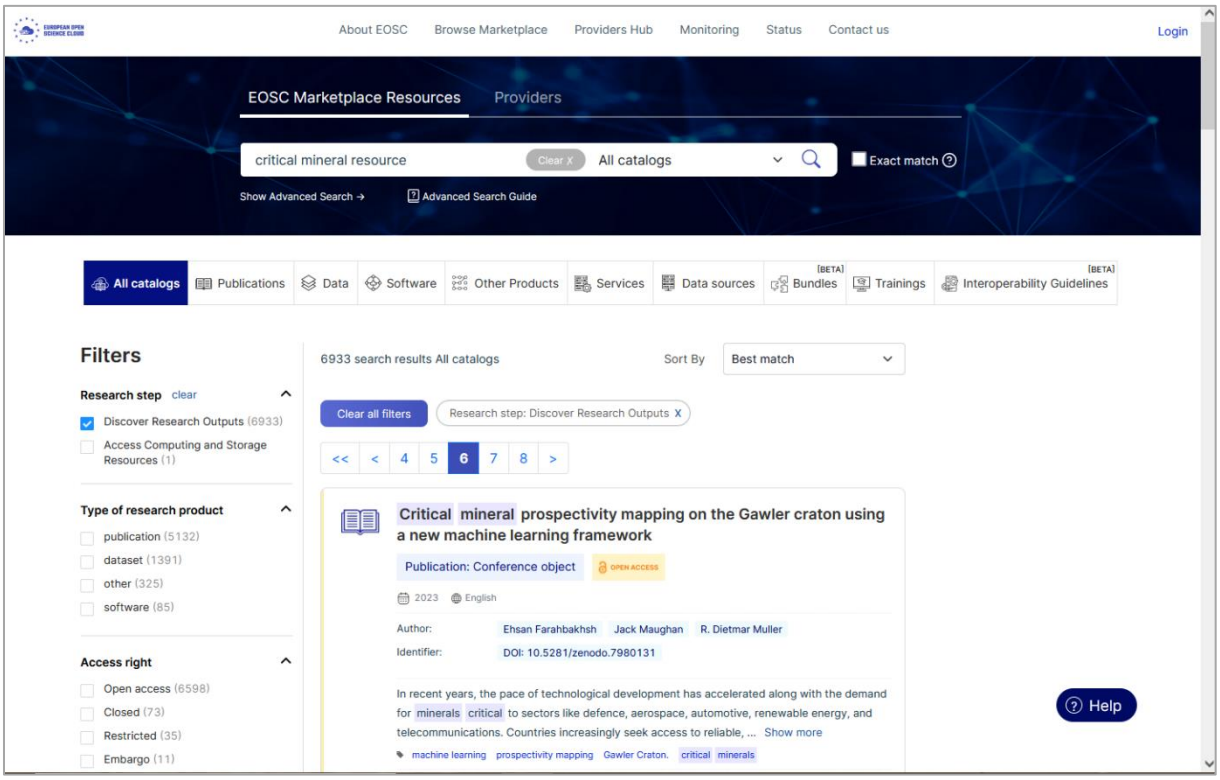

Figure 10. EOSC Marketplace: search user interface for resources.

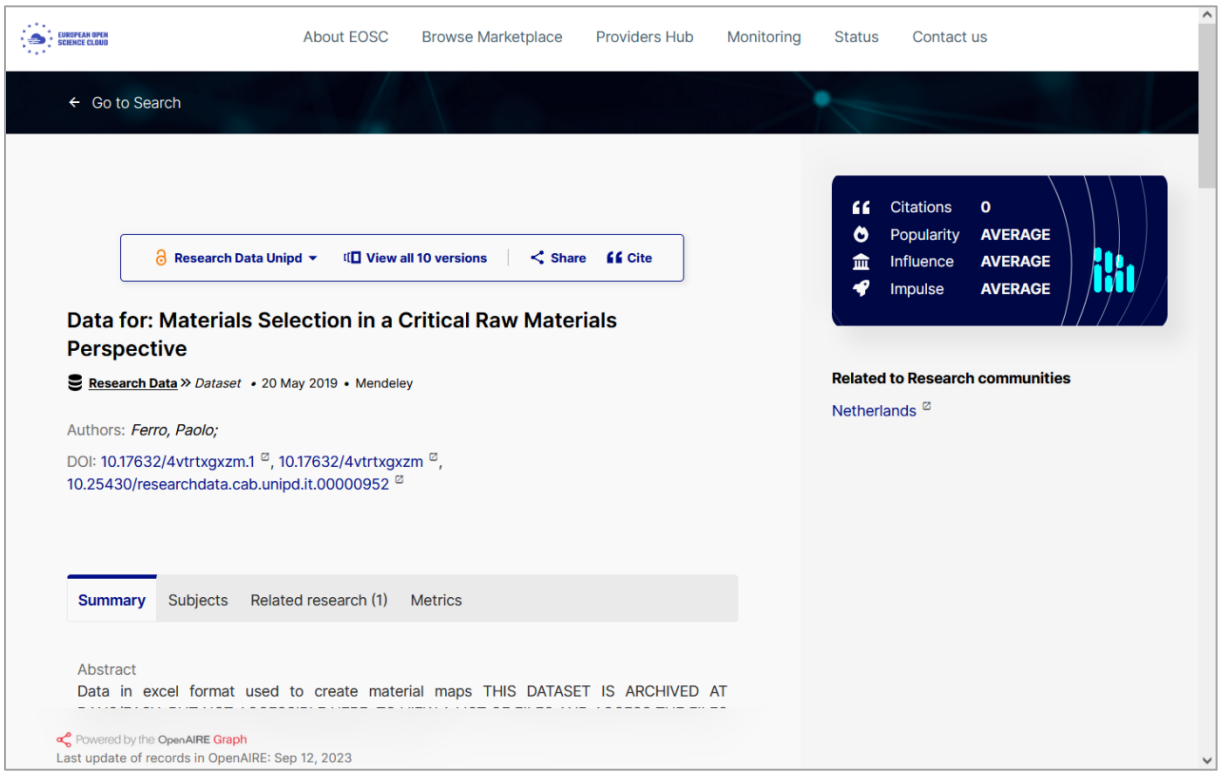

Figure 11. EOSC Marketplace: result of a search for Critical Raw Materials.

4.2.2. EOSC for providers

The “Providers” dedicated page (Fig. 12) on the EOSC portal is rather straight forward while proposing to:

- Contribute to EOSC: onboard resources, access application programming interfaces, access the providers dashboard (provider and resource key figures)
- Become an EPOS provider: application, documentation, statistics

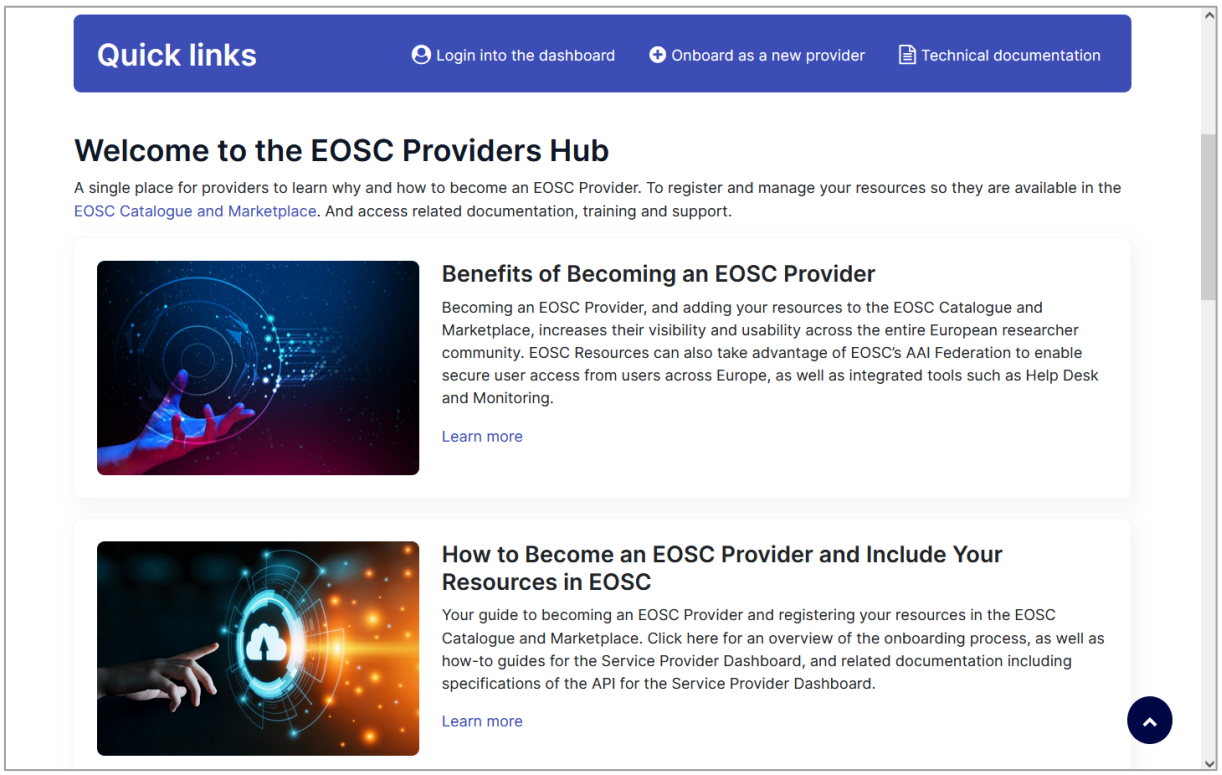

Figure 12. EOSC Providers Hub home page.

Currently, the EOSC handles four type of resources:

- *Research Products* (e.g. research data, research software, publications, other products) deposited and made available via such data sources
- *Catalogues of services* (e.g. community or national catalogues),
- *Services* (e.g. computing, storage, scholarly communication, thematic, etc.),
- *Data Sources* (e.g. repositories, data archives, software repositories, library archives, publishers, etc.).

Resources refer to all the possible types of research service, asset, and collections thereof that can be included in the EOSC Catalogue and Marketplace. Figures 13 and 14 present the onboarding process.

Presently, it seems that quite a few references searchable in the "Marketplace" come from an automatic harvest of "resources" from scientific publications without having the related data set(s) actually accessible because not registered as such by a provider

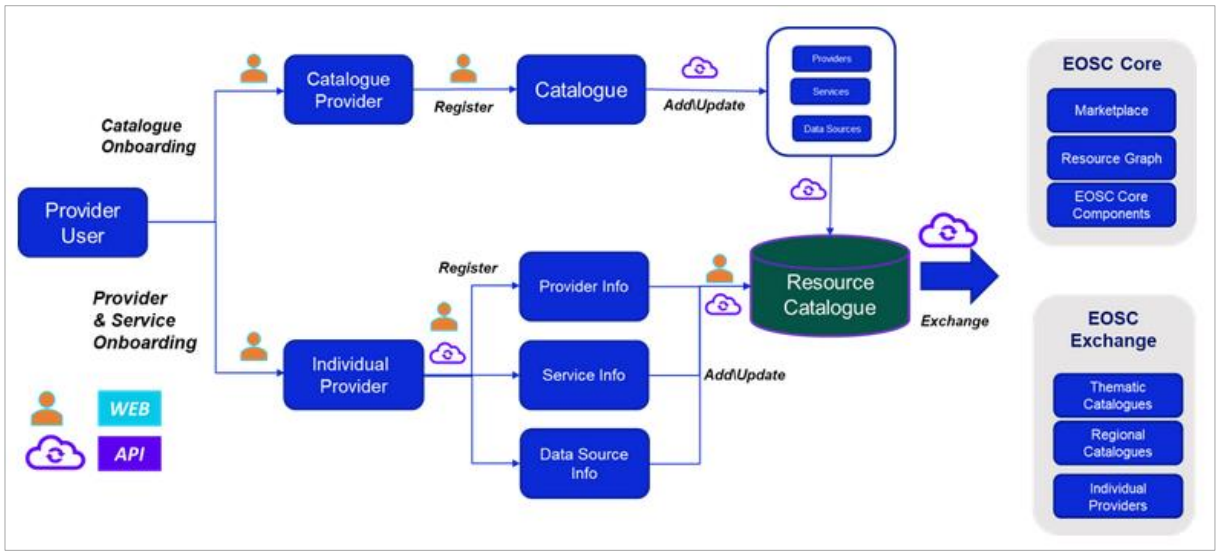

Figure 13. EOSC Onboarding process for provider, catalogue and services.

Research products are not directly onboarded to the EOSC but they are indirectly linked to the EOSC through Data Sources that refer to them. To be onboarded, data sources must be at least TRL8. A Data source must support automatic harvesting of the related metadata descriptions. Data source needs to comply with specific harvesting protocols (OAI-PMH, FTP, others) and also to provide metadata compliant with OpenAIRE guidelines for literature (3.0, 4.0) and data archives. The guidelines are defined in the EOSC Interoperability Framework Guidelines for Research Products.

Information required about the providers and their resources are the following:

- EOSC Provider Profile
- EOSC Resource Profile
- EOSC Catalogue Profile
- EOSC Data Source Profile
- EOSC Research Product Profile

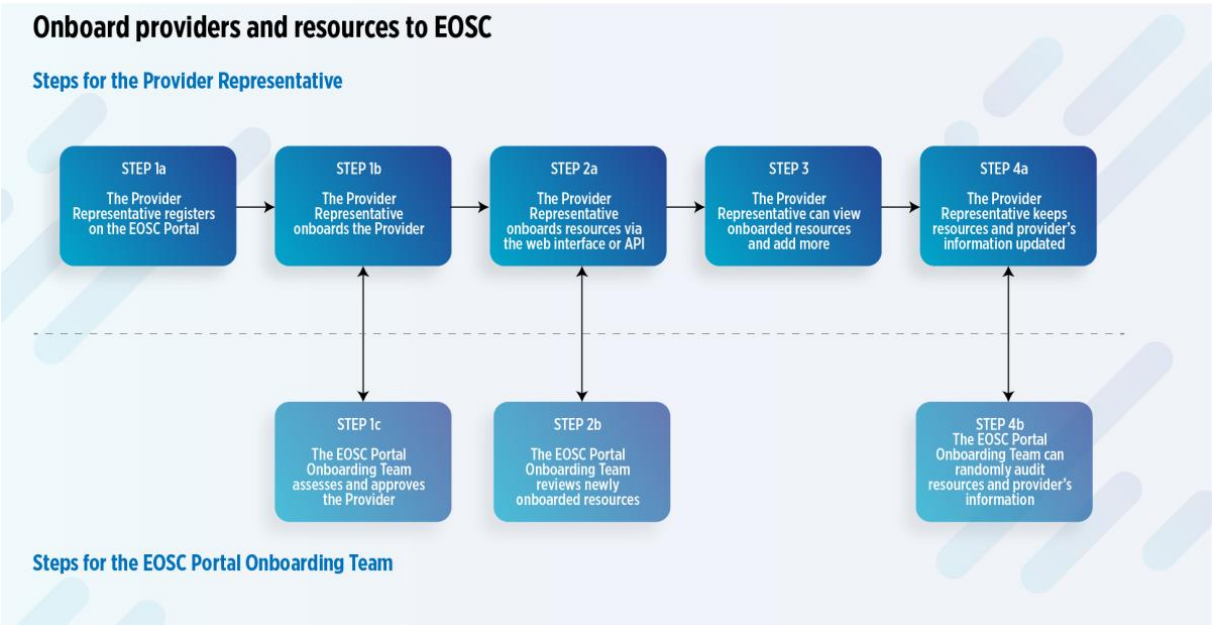

Figure 14. EOSC Onboarding process for providers.

Main steps to become a provider:

- Self registration and the EOSC Team reviews the registration
- The new provider onboards a first resource to the EOSC Catalogue
- The EOSC team reviews the quality and interoperability of this resource
- After the first resource has been validated in the EOSC Catalogue, the provider is invited to onboard additional resources
- Audits of providers and resources are conducted by the EOSC team.

4.2.3. Why connect EGDI to EOSC

The EOSC is an all-in-one platform for those who developed services to store, manage, analyse and re-use data for research, innovation, and educational purposes. Being a virtual research environment, it enables users to easily discover cross-domain data collections and services outside and complementary to EGDI geoscience data sets, even if these external resources are distributed and based on different metadata and ontologies.

Sharing data and services on such an open science platform is now a must as per the Horizon Europe program to publish the project results. The research activities are more visible, more known, and the work has a larger impact for information and re-use. In addition, there are practical and technical advantages of being a provider in the EOSC:

- communities become part of an interconnected scientific ecosystem where the resources and services can be accessed via a seamless AAI (Authentication and Authorisation Infrastructure) federation and can be discovered and reused beyond community boundaries
- increase the utility of the proposed services by linking with compatible services or products through the EOSC Interoperability Framework

- Get statistics about access requests and customer feedback of the newly extended user base.

The EOSC is also a gateway for web-based processing environment by synchronising data from the distributed data repositories to the HPC and cloud computing resources.

Participating in the EOSC is recognised as a valid contribution to improving Open Science both in Europe and at national level a well. Any contribution in the EOSC constitutes an asset when applying for project funding and often also when asking for support at institutional and/or European level.

4.2.4. Connect EGDI to EOSC

In the framework of the Geological Service for Europe, the EGDI has its place in the EOSC to extend the visibility, use and re-use of the 800+ data layers capitalised by the European Geological Surveys. EuroGeoSurveys may be an observer member of EOSC. As part of the eight ambitions of Horizon Europe's Open Science programme, EOSC offers the community in Europe and beyond a set of services enabling the FAIR principles of research data management to be implemented. In order to provide access to the services, repositories and infrastructures made available in Europe for researchers, the next steps may be as follows:

1) Further describe the particular pre-requisites applicable to EGS for becoming an EOSC Provider and EGDI to be onboarded as an EOSC Data Source,
2) Assess the feasibility on various aspects (technical readiness of EGDI system, FAIRness level, data license, etc.)
3) Prepare a decision process Go-NoGo by EuroGeoSurveys National Delegates, thematic Experts Groups, General Secretariat and Executive Committee,
4) If positive, engage with the onboarding steps.

4.3. Data Spaces / GREAT

The GREAT project, funded by the Digital Europe program, aims to establish the Green Deal Data Space Foundation and its Community of Practice which builds on both the European Green Deal and the EU's Strategy for Data. The project, which concludes early 2024, will deliver a roadmap for implementing and deploying the Green Deal Data Space (GDDS), an infrastructure that will allow data providers and initiatives to openly share their data to tackle climate change in a multidisciplinary manner.

There are four pillars of the GREAT project to inform the next stages of the GDDS; An architecture pillar, a Datasets pillar, a Governance pillar and a Community pillar. Each will deliver reccommendations to be followed up in the next phase of development.

The GDDS Implementation Roadmap report (https://www.greatproject.eu/wp-content/uploads/2023/11/D6.1-Roadmap.v1.0-2-3.pdf) details timelines (figure 15) and plans.

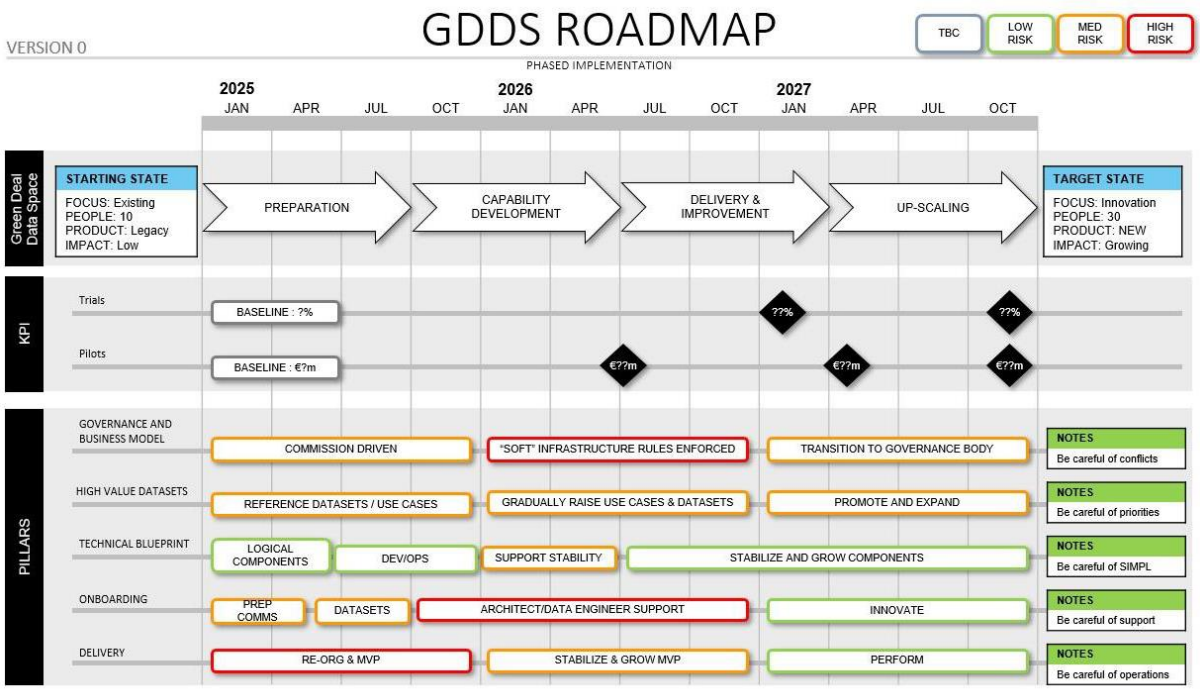

Figure 15. Green Deal Data Space road map and time lines

The GSEU project WP7 has been in discussion with the GREAT project and held a deep-dive meeting in January 2024. In this initial meeting, each party explained their position and resources and began discussions about completeness and standardisation of data. The GREAT team explained that their implementation roadmap is aiming for January 2025 and the EGDI team expressed their interest in being part of that process.

The GREAT team also mentioned the possible Architecture of the GDDS while currently looking at the Data Space middleware called "SIMPL" to facilitate the connections. This middleware has been developed in another EU-funded project. It is further described here:
https://digital-strategy.ec.europa.eu/en/policies/simpl
https://digital-strategy.ec.europa.eu/en/funding/cloud-edge-federations-and-data-spaces-made-simpl

The next stage will be to develop a working prototype similar to the Mobility Data Space (https://mobilitydataspace-csa.eu/), as a reference point.

It was explained that the GDDS is a central place to answer to three major thematic focused questions surrounding the Green Deal, (i) 2030 Biodiversity Strategy, (ii) Zero Pollution Action Plan, and (iii) Climate Change Adaptation Strategy.

- At the end of this GREAT-GSEU/WP7 deep-dive meeting, the next stages were agreed as:
- As soon as the architecture is finalised; possibly built using the SIMPL protocol we could connect some EGDI datasets to the GDDS;
- This would begin with High priority data sets: maybe several EGS / EGDI data sets could be identified as priority in a list;

- It was agreed that if there is possibility to join the GREAT / GDDS implementation project, EGDI would be willing to participate, which will facilitate the connections EGDI-GDDS.

As can be seen from these three examples (EPOS, EOSC and GREAT) at very different stages of maturity, there will need to be different approaches and the resource constraints will mean that this kind of cooperation will be impossible across the board. In the following section, we will discuss the need for a prioritisation process and how important and relevant horizon scanning is for EGDI.

5. Recommendations

This preliminary report, delivered shortly after the conclusion of the first year of the five-year GSEU project can only set the scene for the next phases of connecting to other initiatives. In the sections preceding this one, we have looked at the “why”, the “what” and the “how” of some examples. In this section there are two key areas remaining. Firstly, about the prioritisation of the unachievable list of potential connections listed in section 3. Secondly, a look at how to maintain such a list of initiatives, as new ones will come among during the course of such a five-year project.

5.1. Prioritisation

The landscape work that has gone into section 3 of this report is based on the vast experience across the members of the GSEU WP7 consortium. Nearly all of the listed initiatives have had some connection with individual members or groups of members over the past. Indeed some of them described above have been seen as key stakeholders such as EPOS and have a special relationship already. Others such as relations with the Open Geospatial Consortium (OGC) or the International Union of Geoscience Commission for the Management and Application of Geoscience Information (IUGS-CGI) have ebbed and flowed over time. However, in the case of these two institutions, they provide key standards and vocabularies to support FAIR geoscience data.

As such, prioritisation will be needed to provide best utility and value to EGDI. This can be seen as an activity that fits alongside the five years of the GSEU project, which also potentially provides the opportunity to build a roadmap of engagement.

Standards and FAIR are fundamental to the requirements of EGDI and the GSEU project. Providing data in formats suitable for certain external communities should also be fundamental, although perhaps of slightly lower priority.

Connecting to broader political initiatives is outside the scope of this report and is being addressed by GSEU WP8. However, there is a requirement to engage with some of the international geoinformatics initiatives which looking forward may not have any European engagement. Take responsibility in the global community of geoscientists and benefitting from their expertise and pre-existing work, whilst contributing for the common good.

5.2. How to Maintain a RADAR of Future Initiatives

It is through the continued engagement, even low-level engagement such as attending webinars, conferences or signing up to mailing lists, that the community will build its knowledge of the horizon. There are semi-formalised techniques such as maintaining a technology radar that could also be employed if resources allowed. Figure 16 shows one of them.

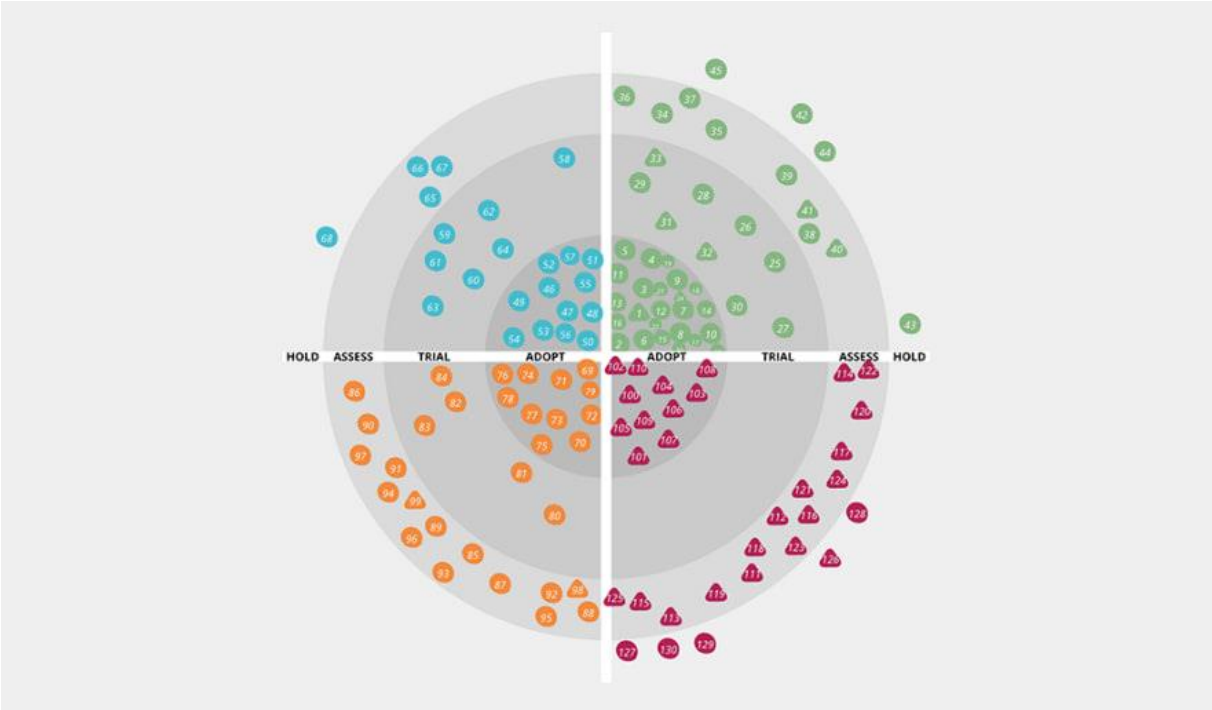

Figure 16. Technology Radar

There are two elements to the assessment. The quadrants represent different areas of technology through a lifecycle. In the case of EGDI, this could be data accession, standardisation, API technologies or similar. The rings represent the stage of an adoption lifecycle. Each of the blips represent the mapping of one of these technologies. This provides a simple way, especially across a distributed team, to identify progress in assessing, discarding, or adopting new technologies. Even those that have been seen on the horizon using the simple connection protocols identified above.

6. Conclusion

In this report, we have discussed the reasons to connect to other infrastructures. We have listed and described the overall landscape of initiatives that are identified at a European and global level in which the EDGI and GSEU are key elements. We have also demonstrated the “how” of connecting with three examples, one over 10 years of close integration, one that has been on the horizon for many years and has a formal onboarding process. Finally, one that is ambitious and is developing its understanding of the challenges and opportunities whilst at the same time building a community, which hopefully EGDI can be a key sub-surface contributor to.

This is a first report of two that this report has set the landscape and scene for. The second will be able to report on the connections to each of the initiatives identified above and on the developments of this list that have been identified and adopted or discarded as being of value to EDGI in GSEU and in the future to EGDI as a central pillar of the Geological Service for Europe.

6.1. Next Steps / Next Report

After the publication of this report, the GSEU WP7 team will have to continue the prioritisation process to identify which initiatives and how they will connect to them. The next report will be delivered at month 54 and we look forward to writing it and the new developments and external communities that the EGDI has connected to.

7. Appendix I – Consortium Partners

#	Partner Name	Acronym	Country
1	EuroGeoSurveys	EGS	Belgium
2	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek	TNO	Netherlands
3	Sherbimi Gjeologjik Shqiptar	AGS	Albania
4	Vlaamse Gewest	VLO	Belgium
5	Bureau de Recherches Géologiques et Minières	BRGM	France
6	Ministry for Finance and Employment	MFE	Malta
7	Hrvatski Geološki Institut	HGI-CGS	Croatia
8	Institut Royal des Sciences Naturelles de Belgique	RBINS-GSB	Belgium
9	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	PGI-NRI	Poland
10	Institut Cartogràfic i Geològic de Catalunya	ICGC	Spain
11	Česká Geologická Služba	CGS	Czechia
12	Department of Environment, Climate and Communications - Geological Survey Ireland	GSI	Ireland
13	Agencia Estatal Consejo Superior de Investigaciones Cientificas	CSIC-IGME	Spain
14	Bundesanstalt für Geowissenschaften und Rohstoffe	BGR	Germany
15	Geološki zavod Slovenije	GeoZS	Slovenia
16	Federalni Zavod za Geologiju Sarajevo	FZZG	Bosnia and Herzegovina
17	Istituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy
18	Regione Umbria	-	Italy
19	State Research and Development Enterprise State Information Geological Fund of Ukraine	GIU	Ukraine
20	Institute of Geological Sciences National Academy of Sciences of Ukraine	IGS	Ukraine

21	M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine	IGMOF	Ukraine
22	Ukrainian Association of Geologists	UAG	Ukraine
23	Geologian Tutkimuskeskus	GTK	Finland
24	Geological Survey of Serbia	GZS	Serbia
25	Ministry of Agriculture, Rural Development and Environment of Cyprus	GSD	Cyprus
26	Norges Geologiske Undersøkelse	NGU	Norway
27	Latvijas Vides, ģeoloģijas un meteoroloģijas centrs SIA	LVGMC	Latvia
28	Sveriges Geologiska Undersökning	SGU	Sweden
29	Geological Survey of Denmark and Greenland	GEUS	Denmark
30	Institutul Geologic al României	IGR	Romania
31	Szabályozott Tevékenységek Felügyeleti Hatósága	SZTFH	Hungary
32	Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport	VBS (DDPS)	Switzerland
33	Elliniki Archi Geologikon kai Metalleftikon Erevnon	HSGME	Greece
34	Laboratório Nacional de Energia e Geología I.P.	LNEG	Portugal
35	Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos	LGT	Lithuania
36	Geologische Bundesanstalt	GBA	Austria
37	Service Géologique de Luxembourg	SGL	Luxembourg
38	Eesti Geoloogiateenistus	EGT	Estonia
39	Štátny Geologický ústav Dionýza Štúra	SGUDS	Slovakia
40	Íslenskar Orkurannsóknir	ISOR	Iceland
41	Instituto Português do Mar e da Atmosfera	IPMA	Portugal
42	Jarðfeingi	Jardfeingi	Faroe Islands
43	Regierungspräsidium Freiburg	LGRB	Germany
44	Geologischer Dienst Nordrhein-Westfalen	GD NRW	Germany

45	Landesamt für Geologie und Bergwesen Sachsen-Anhalt	LfU	Germany
46	Vlaamse Milieumaatschappij	VMM	Belgium
47	Norwegian Petroleum Directorate	NPD	Norway
48	United Kingdom Research and Innovation - British Geological Survey	UKRI-BGS	UK