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Article

Establishing the national spatial information infrastructure: research development innovation component (INIS-RDI)

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Abstract
At the European Community level, several issues have been identified regarding the accessibility, quality, availability, organization, and sharing of spatial data necessary for achieving the goals outlined in public policies and environmental management. To address these challenges, the establishment of an infrastructure for spatial information, known as INSPIRE, was mandated through Directive 2007/2/EC. This paper outlines the solution developed by the INFRAINIS project for distributing geospatial information, which aligns with the objectives of the INSPIRE Directive. The proposed solution will provide the technical means for entities holding geospatial datasets, coordinated by the National Research Authority of Romania, to publish these datasets in accordance with the INSPIRE Directive. The IT infrastructure developed will utilize a foundation of free and open-source software solutions that have been proven to be highly effective in other projects, while also offering lower implementation and administrative costs compared to proprietary solutions. Institutions holding relevant datasets will upload them to the platform via a web application that enables automatic publication as web GIS services. The INSPIRE themes that will be addressed include land cover, geology, soil, oceanographic features, geographical features, and maritime regions. This IT infrastructure is expected to reach Technology Readiness Level (TRL) 6, facilitating informed decision-making on policies and activities with direct or indirect environmental impacts. The proposed platform will also enhance access to harmonized spatial data for public authorities, researchers, academics, the private sector, non-governmental organizations (NGOs), and the general public.

Keywords: *INSPIRE, environment, geospatial information, IT infrastructure*

INTRODUCTION

The Infrastructure for Spatial Information in the European Community (INSPIRE) Directive 2007/2/EC is a European Union initiative to create a pan-European spatial data infrastructure (SDI) [1]. Its primary goal is to improve access to and sharing of spatial data-information with a direct or indirect geographic reference, like environmental measurements or land cover datasets. Before INSPIRE, the data resources often existed in isolated systems, managed by individual institutions or public authorities, which made it difficult to share or combine information across regions or sectors. The directive establishes the technical, legal and organizational conditions necessary for different data provider - such as environmental agencies, ministries and regional authorities - to share their information, thus ensuring that data can be located, accessed and used efficiently, not just within

individual countries/unit that produces it, but across the European Union. This ensures INSPIRE datasets are *discoverable, accessible, interoperable and reusable* allowing organizations and citizens to find, view, download, and integrate data across national borders [2÷4].
Since its adoption in 2007, implementation has progressed through key milestones, beginning with the legal transposition of the directive into national law by all EU states, though timelines for this varied [2,5,6]. Concurrently, common technical standards were established for data models, metadata, and services, which enhanced interoperability [2,7,8]. A structured monitoring and reporting system was also put in place, requiring annual quantitative and tri-annual qualitative reports from member states [2,6,9]. However, the actual country-specific implementation experiences vary significantly, depending on factors like national resources, coordination levels, and technical readiness [5,6,10,11].
INSPIRE is based on *3 key principles* that shape how spatial data should be handled. First, it emphasizes that *data should be collected once and maintained at the most effective level*. This principle reduces duplication of effort and avoids situations where multiple agencies collect similar data independently, wasting resources and producing inconsistent results. Instead, the organization closest to the source of the data maintains it, while others access it through shared services. Second, INSPIRE insists that *data from different sources must be combinable and usable together*, even if they were created by different organizations or in different countries. This requires common data models, code lists, and terminology so that integrating datasets becomes technically straightforward. When datasets are interoperable, organizations can build integrated applications - for example, combining hydrography data with transport networks to support flood risk management [12]. Finally, INSPIRE requires that *information should be easy to find, and users should clearly understand the conditions under which it can be accessed and used*. This transparency includes details on data quality, licensing, and any restrictions on use. The goal is to reduce uncertainty and facilitate confident, informed use of spatial data [3,7,10].
INSPIRE covers a wide range of data thematic categories (34 in number) relevant for public policies and environmental management. These data themes include environmental monitoring (such as air, soil or water quality), land use, transport networks, protected natural sites, hydrography (rivers, lakes and other water bodies), geology, elevation and many others [13÷16]. The implementation of INSPIRE is structured around *three main pillars*, each representing a critical step toward achieving a functioning spatial data infrastructure:
a) Metadata: Member states are required to create and maintain metadata that explains what a dataset contains and services, how it was created, its geographic extent, its quality, and the conditions under which it can be accessed or reused. Important metadata elements include keywords, the scale of the data, when it was last updated, data quality assessments, and license or usage restrictions. These metadata records must be made searchable through electronic catalogues so that users can locate datasets via national or European geoportals (such as the EU INSPIRE Geoportal) [3,17].
b) Interoperability of data: To ensure that datasets from different countries can be combined seamlessly, INSPIRE imposes the use of common data models and standardized schemas. Member states must transform their datasets to align with the INSPIRE Technical Guidelines. For metadata, standards such as ISO 19115 and ISO 19139 are used, while spatial data encoding often follows GML (Geography Markup Language). This ensures that the data is structured consistently and can be used across systems without manual conversion or interpretation [3,18].
c) Network Services: INSPIRE requires that datasets be accessible via online network services based on international standards. Four types of services support the full data lifecycle: *Discovery services (CSW)* that allow users to search for metadata and identify relevant datasets; *View services (WMS)* which enable users to view maps in a web browser or GIS application without downloading the data; *Download services (WFS, Atom, etc.)* that allow users to download datasets for further analysis and, last but not least; *Transformation services* that help convert or harmonize data so it complies with INSPIRE schemas, for example by converting national formats into standardized INSPIRE formats [3,19].
INSPIRE provides critical support across various domains by facilitating access to harmonized spatial data, benefiting a wide range of stakeholders. *Public authorities* use this standardized data for

environmental policy, underpinning key directives like the Marine Strategy Framework Directive and the Water Framework Directive through improved monitoring and reporting [15,20]. These authorities also leverage INSPIRE - compliant data for local and national spatial planning - including urban planning, natural resource management, infrastructure projects, and natural risk management [7,21], as well as specialized maritime spatial planning [15]. *Researchers and academics* use INSPIRE's geoportal for R&D activities, enabling cross-border collaboration by combining data for studies on climate, biodiversity, and risk assessment [4,10]. Additionally, the infrastructure serves the *private sector* for operational planning, decision-making, and service development; *NGOs* supporting environmental and rural development initiatives; and the *general public*, who gain access to quality spatial information to better understand their environment and related risks [4].

Realizing a full pan-European interoperability and reuse will likely require stronger user-driven deployment of data, more harmonization, and reduction of remaining legal/policy barriers.

In the Table 1 is presented a country-by-country status summaries, for EU Member States, based on the latest publicly available monitoring & reporting information for the INSPIRE Directive (Directive 2007/2/EC).

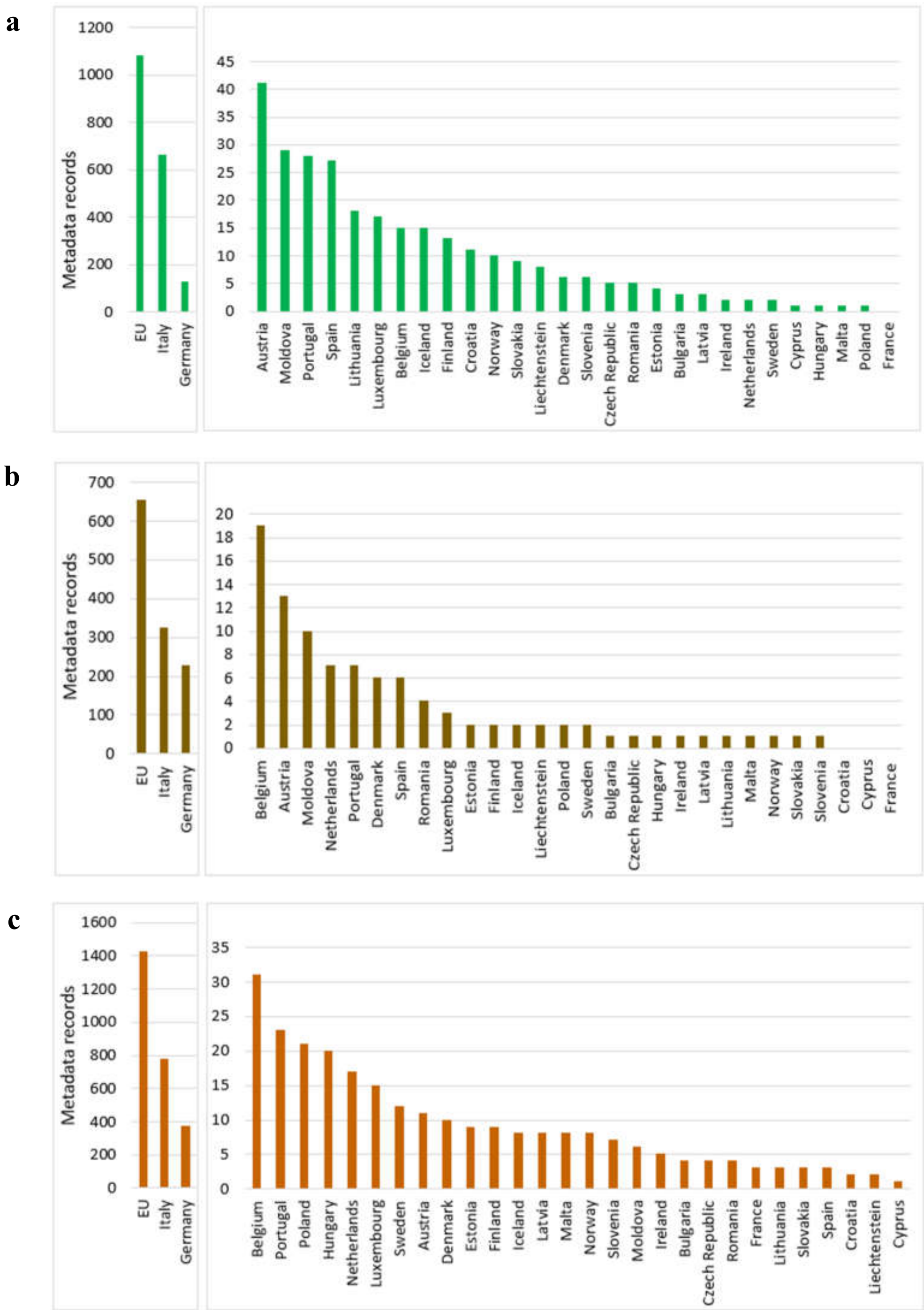
Table 1. INSPIRE links in UE Countries

Country	***Country Fiches (latest year links inside)***
Austria	https://inspire-mif.github.io/INSPIRE-in-your-Country/AT/Country_fiches/
Belgium	https://inspire-mif.github.io/INSPIRE-in-your-Country/BE/Country_fiches/
Bulgaria	https://inspire-mif.github.io/INSPIRE-in-your-Country/BG/Country_fiches/
Croatia	https://inspire-mif.github.io/INSPIRE-in-your-Country/HR/Country_fiches/
Cyprus	https://inspire-mif.github.io/INSPIRE-in-your-Country/CY/Country_fiches/
Czechia	https://inspire-mif.github.io/INSPIRE-in-your-Country/CZ/Country_fiches/
Denmark	https://inspire-mif.github.io/INSPIRE-in-your-Country/DK/Country_fiches/
Estonia	https://inspire-mif.github.io/INSPIRE-in-your-Country/EE/Country_fiches/
Finland	https://inspire-mif.github.io/INSPIRE-in-your-Country/FI/Country_fiches/
France	https://inspire-mif.github.io/INSPIRE-in-your-Country/FR/Country_fiches/
Germany	https://inspire-mif.github.io/INSPIRE-in-your-Country/DE/Country_fiches/
Greece	https://inspire-mif.github.io/INSPIRE-in-your-Country/EL/Country_fiches/
Hungary	https://inspire-mif.github.io/INSPIRE-in-your-Country/HU/Country_fiches/
Ireland	https://inspire-mif.github.io/INSPIRE-in-your-Country/IE/Country_fiches/
Italy	https://inspire-mif.github.io/INSPIRE-in-your-Country/IT/Country_fiches/
Latvia	https://inspire-mif.github.io/INSPIRE-in-your-Country/LV/Country_fiches/
Lithuania	https://inspire-mif.github.io/INSPIRE-in-your-Country/LT/Country_fiches/
Luxembourg	https://inspire-mif.github.io/INSPIRE-in-your-Country/LU/Country_fiches/
Malta	https://inspire-mif.github.io/INSPIRE-in-your-Country/MT/Country_fiches/
Netherlands	https://inspire-mif.github.io/INSPIRE-in-your-Country/NL/Country_fiches/
Poland	https://inspire-mif.github.io/INSPIRE-in-your-Country/PL/Country_fiches/
Portugal	https://inspire-mif.github.io/INSPIRE-in-your-Country/PT/Country_fiches/

Spatial data infrastructures similar to the European INSPIRE Directive have been developed by many states or groups of states, such as Canada [22], the Arctic countries (Canada, Finland, Iceland, Norway, Russia, Sweden, the U.S. and Denmark) with the Arctic SDI [23], or countries in Latin America and the Caribbean – GeoSUR [24].

In Romania, the INSPIRE Directive was transposed into national legislation by Government Ordinance 4/2010 which established the National Infrastructure for Spatial Information (INIS). A concrete example of this implementation is the project "*IT Services for the implementation within the National Meteorological Administration of a spatial data infrastructure compliant with the requirements, standards and regulations imposed by the INSPIRE Directive*", carried out between June 2019 and March 2020. This initiative aimed to create a system compliant with all requirements, standards, and regulations imposed by the INSPIRE Directive [25]. The resulting services were

successfully validated for INSPIRE compliance, covering dataset metadata, visualization service metadata, download service metadata, the search/discovery service, the visualization service and the download data service [26].
Both before and after the directive's adoption, dataset providers often had specific, non-standardized methods of generating and using datasets. This led to the faulty use and sharing of spatial data (e.g. lack of reference spatial data, deficiencies of existing software systems in ensuring compliance with INSPIRE norms, etc.).
Currently, there is no unit platform that covers all the steps required to publish INSPIRE-compliant geospatial datasets across organizations under the coordination of the ANC. An analysis of datasets on the INSPIRE portal [27] shows where Romania ranks in terms of the number of datasets for themes related to entities holding geospatial datasets under the coordination of the ANC (Figure 1).



d

e

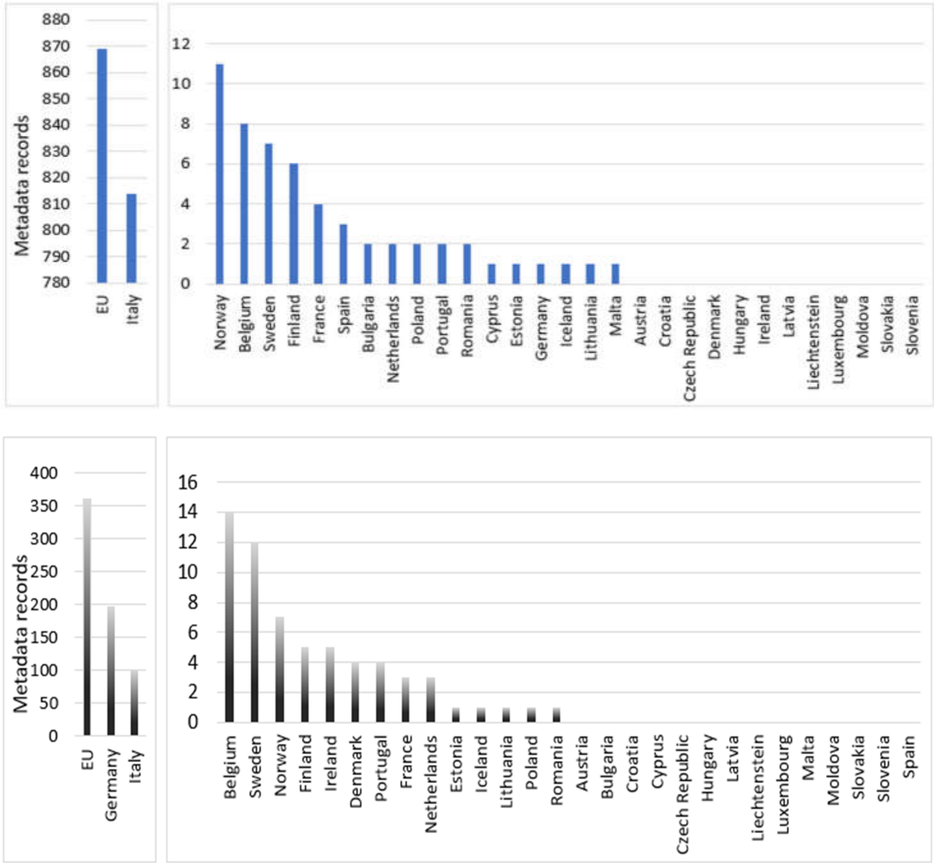


Fig. 1. Metadata records at EU level: (a) Land cover; (b) Soil; (c) Geology; (d) Maritime regions; (e) Oceanography geographical features

There are many aspects to consider to achieve 100% compliance with metadata, data interoperability, and network services implementation, which can require considerable effort in terms of human resources and time. Thus, this project aims to develop the INIS-RDI platform with functionalities for transforming, publishing, and validating datasets.

MATERIALS AND METHODS

This project specifically targets the implementation of several key INSPIRE themes, as outlined in Annexes II and III of the INSPIRE Directive: Land cover (Theme II.2.), Geology (Theme II.4.), Soil (Theme III.3.), Oceanographic geographical features (Theme III.15.), and Maritime Regions (Theme III.16.) [1].

The INIS-RDI platform developed within the project will allow data providers the following facilities: analyzing and transforming datasets; uploading and publishing datasets; automating repetitive and complex processes; scaling the platform to host new data and users; and aligning with the INSPIRE Directive.

This platform will enable the adaptation of its functionalities to the specific needs of the beneficiary research organizations. Thus, both the particular content of the metadata and its transfer from their own infrastructures to the developed platform, as well as its updating, will be considered. To achieve the measurable objectives, the components of the platform will be developed to ensure the following flows:

a) An integrated workflow: covers loading, modelling, transforming, and publishing geospatial data; can be configured and adapted to different roles and tasks; supports collaboration between different organizations; is fully automated, including metadata generation and management of all data and metadata with low effort, at high quality; supports configurable transformation of spatial datasets according to the INSPIRE GML data specifications; validates compliance with the INSPIRE specifications for data, metadata, and network services.

b) A workflow that automatically creates and publishes: INSPIRE visualization services as OGC WMS; advanced OGC WFS (Web Feature Service) services for direct access and download; vector, raster and data combinations; metadata for datasets and web services in the form of XML files and via the Discovery Service according to OGC CSW standards;
c) Easy publishing: publishing web services is much easier through different types of APIs and services, such as OGC Web Feature Services.

RESULTS AND DISCUSSION

The INFRAINIS project will result in a functional prototype (INIS-RDI platform) of the National Spatial Information Infrastructure compliant with the INSPIRE Directive. Both hardware and software components are integrated into a unified system that collects, transforms, validates, and publishes spatial datasets across multiple scientific and administrative domains.

System architecture

The proposed infrastructure is based on a modular and redundant architecture designed for high availability and data integrity. The architecture integrates GeoNetwork, GeoServer with AppSchema, PostgreSQL/PostGIS, HALE Studio and some custom development for INSPIRE data harmonization; automates data validation and publication workflows; and ensures a secure, scalable infrastructure that aligns with European interoperability requirements. It consists of several key components:
a) Processing subsystem: high-performance servers for data transformation and service hosting, configured in virtualized clusters to support parallel execution;
b) Storage subsystem: network-attached storage (SAN) ensuring redundancy, scalability, and fast access to large spatial datasets;
c) Communication subsystem: LAN switches for data exchange and a separate management network for secure administration;
d) Support systems: UPS units, climate control, structured cabling, and rack-mounted configurations to maintain stable operating conditions. The proposed architecture scheme is shown in Figure 2.
The architecture ensures seamless data flow between data providers and the INIS-RDI services through automated pipelines and validation mechanisms.

Platform modules

- **Organization Registration Module**, which enables the registration, management, and validation of organizations participating in the spatial data infrastructure, ensuring the consistent identification of data providers, service operators, and other institutional stakeholders.
- **Data Transformation Module,** which enables the conversion of spatial data from GeoPackage templates input formats into standardized, interoperable formats compliant with INSPIRE specifications and relevant ISO standards**Metadata Editing Module**, which enables the creation, updating, and validation of metadata files for datasets and services, in accordance with the INSPIRE specifications and relevant ISO standards;
- **Discovery Services**, which provide the capability to identify and locate available datasets and services based on the metadata published within the national infrastructure;
- **View Services**, through which users can access and visualize spatial data in a graphical, interoperable format using standard OGC protocols (WMS, WMTS);
- **Download Services**, which facilitate direct access to datasets in compliant and structured formats, for reuse in specialized applications and systems.

The implementation of these modules contributes to strengthening the institutional capacity for managing, publishing, and disseminating spatial data, providing a solid foundation for the development of the national INSPIRE infrastructure.

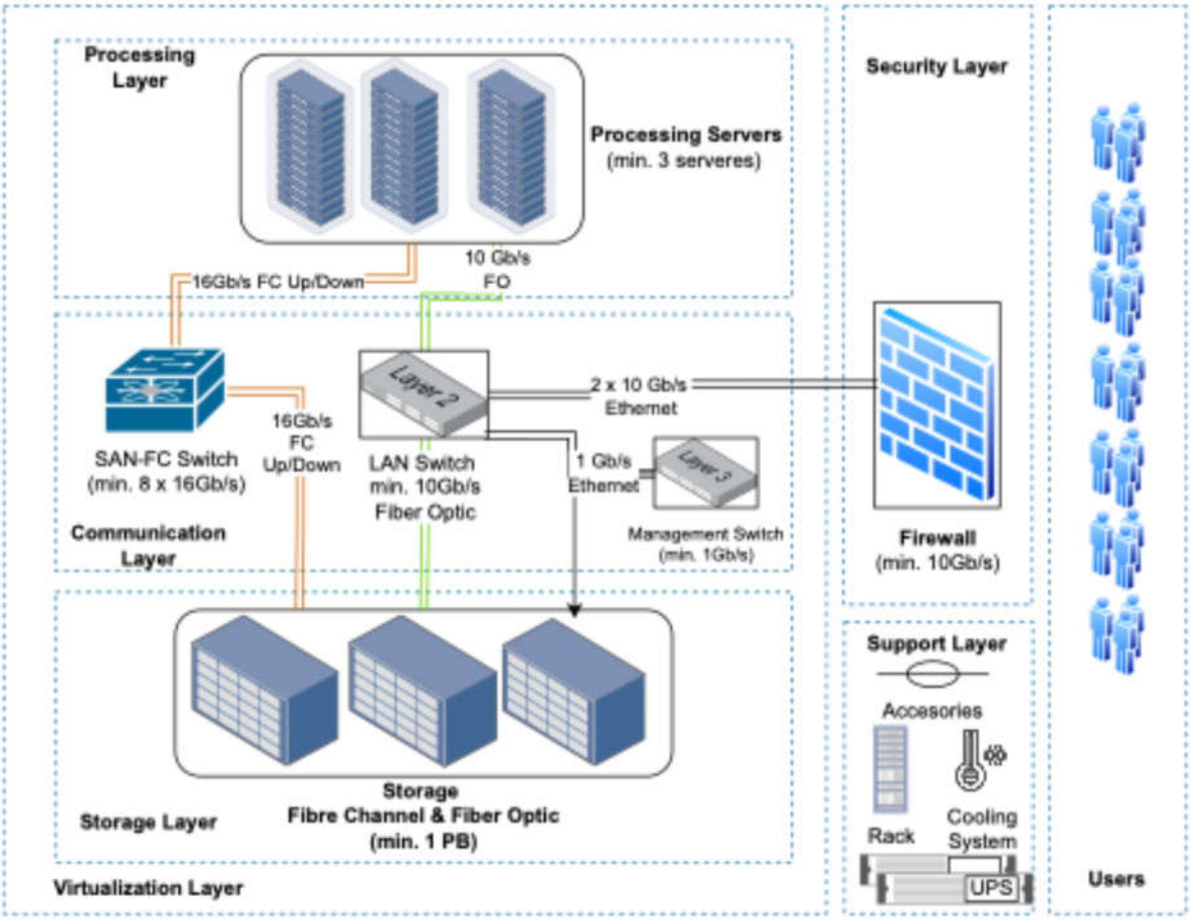


Fig. 2. General architecture of the INIS-RDI platform

Data transformation and INSPIRE compliance

In addition to the platform design, the project aims to define the transformation procedures for national geospatial datasets into formats compliant with INSPIRE data models and network services. Specific goals included:

a) analysis of existing datasets and their compliance with INSPIRE;

b) design of automated data transformation workflows;

c) implementation of standardized web services for discovery, visualization, and download (CSW, WMS, WFS);

d) validation of metadata, datasets, and services using the *INSPIRE Reference Validator* [28].

Platform software technological stack

The software environment integrates open-source geospatial technologies:

a) GeoServer (WMS/WFS services) for visualization and data access;

b) GeoNetwork (CSW services) for metadata management;

c) HALE Studio for data transformation and mapping to INSPIRE schemas;

d) PostgreSQL/PostGIS for spatial data storage and query optimization.

The system uses standardized OGC services to ensure interoperability and compliance with European spatial data infrastructure standards.

The system supports automated workflows for: registration and management of data providers (public institutions and agencies); creation, upload, and validation of metadata files in XML/ISO 19115 format; transformation of datasets (e.g., shapefiles, geopackages) into INSPIRE-compliant GML schemas; and validation and publication of services and metadata.

Validation and conformity results
Each data theme underwent a complete processing cycle: metadata creation, dataset upload, transformation, validation, and publication. The validation phase, performed using the official European INSPIRE Validator [28], confirmed full compliance for metadata and web services, with only minor warnings regarding coordinate system alignment in some datasets. The system's performance tests demonstrated stable operation with datasets up to 2 GB, maintaining processing times of 20-30 seconds per transformation and sub-second response times for published services.

CONCLUSIONS

The project results demonstrate that open-source technologies can effectively support large-scale INSPIRE implementations at the national level.
The integration of HALE Studio, GeoServer, and PostGIS creates a robust and flexible environment for transforming and sharing spatial data in compliance with European standards.
The INIS-RDI platform achieved a Technology Readiness Level (TRL) of 6, confirming that a functional prototype has been validated with real datasets.
The main challenges faced included: heterogeneity and incomplete metadata in source datasets, variations in institutional workflows and local coordinate systems, and the necessity for iterative schema refinement during the validation process.
This infrastructure provides a sustainable foundation for future research and operational applications in Romania, facilitating interoperability, open data sharing, and scientific collaboration within the European Research Area (ERA).

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