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JRC SCIENCE FOR POLICY REPORT

INSPIRE • A Public Sector Contribution to the European Green Deal Data Space

A vision for the technological evolution of Europe's Spatial Data Infrastructures for 2030

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Contents

Abstract

Directive 2007/2/EC (INSPIRE) entered into force in 2007 with the goal to establish a European Union (EU) Spatial Data Infrastructure (SDI) to support EU's environmental policies. The Directive was complemented by a complex legal framework detailing requirements on data provision, which was in turn accompanied by technical guidelines and the establishment of a governance structure involving Member States in the maintenance and evolution of the Directive. After more than 10 years since its inception and at the end of its legally defined roadmap leading to the evaluation by 1 January 2022, INSPIRE has entered a new milestone as the European Commission's recent focus on the green and digital transformation holds the potential to make it a key tool for the successful (environmental) data sharing in Europe.

The objective of this report is twofold. First, we summarise the main developments of the pan-European INSPIRE SDI happened so far from the technical and organisational perspectives, describing the current implementation state of play through multiple dimensions: data availability, governance approaches, available technological stack, influence and role of standardisation bodies and community development. This precedes a critical assessment of what has, and has not, worked well in the development of the infrastructure. Building on such lessons learnt, in the second part of the report we offer a vision for the future evolution of the INSPIRE SDI with a five to ten year horizon in mind. This ambitious vision takes into consideration the current EU policy context as well as the disruptive technological trends bringing new data sources, actors, standards and architectures as new players in the (geospatial) data sharing field. The vision is structured around a set of legal, organisational and technological actions, which are largely extensible to any policy-driven SDI. This makes the lessons learned from INSPIRE also applicable to the broader field of data initiatives.

The key conclusion of this report, embedded in the vision, is that in order to remain fit for purpose it is desirable that traditional SDIs evolve from complex and highly specialised frameworks to more sustainable, flexible and agile data ecosystems, lowering the entry level to non-specialists and welcoming an increased participation from less traditional stakeholders (e.g. open source software communities, standardisation bodies and early adopters) in addition to data providers and users. Concretely, at the European level this highlights the need to simplify and modernise the INSPIRE technological framework and to establish a distributed governance structure at multiple levels. It would be hard to imagine a more effective way for INSPIRE to blend within the common European data space envisioned by the recent European Strategy for Data, allowing a seamless and user-centric data exploitation to address an increasing range of societal needs.

Foreword

Mikel Landabaso

Director, Growth and Innovation Directorate, European Commission Joint Research Centre (JRC)

The INSPIRE Directive was adopted in 2007 with the objective of establishing an EU-wide Spatial Data Infrastructure to support European environmental policies. From the inception of the Directive in the early 2000's, the Joint Research Centre has been at the heart of the work on the European INSPIRE infrastructure, from the design of the specifications for metadata, data sharing and interoperability to coordinating its technical implementation, operating its core infrastructure components and developing reusable software components.

Sitting in-between the twin digital and green transitions, the INSPIRE experience provides a successful case study on how digital assets are valuable to progress towards ambitious environmental policies. Organisational and governance-related challenges are not to be underestimated, and they will be key for the set-up of the upcoming European data spaces under the European data strategy. By sharing our experience, we would like to contribute to the debate on the technical, organizational or legal enablers that are required for a successful deployment of such data spaces.

In almost 15 years of technical implementation of this large-scale European data-sharing infrastructure, the JRC had a unique opportunity to examine, in real life scenarios, the benefits and challenges that data bring into our quest to digitally transform our societies. We know data can be the "oil" that will fuel the digital economy, but in order to be useful, data need to be fit for further processing, in particular by Artificial Intelligence applications. The JRC has the ambition to keep working towards this end, and contribute to make the next years Europe's digital decade.

Rob van de Velde

Director, Dutch National Spatial Data Infrastructure executive committee (Geonovum)

Over the last decade, the INSPIRE Directive led not only to the development of a European Spatial Data Infrastructure, but it boosted the development of national SDI's as well. INSPIRE embraced the open standards of the Open Geospatial Consortium, thus acting as a launching customer. The current widespread use of these open standards and the development of our national data platform for open spatial data all started with INSPIRE, but nowadays serves a broad range of applications, also well beyond the INSPIRE scope.

In the Netherlands, we believe that our next challenge is to make spatial data truly FAIR for every data user, regardless whether this user is a geospatial expert or novice. By making geospatial data FAIR for all data users, far beyond the boundaries of the traditional geospatial community, we are unlocking the full power of location to all kinds of data users, including developers, data journalists and citizens. When we succeed in making spatial less special (by embracing common technologies and standards such as API's and the standards of the web), we're enabling powerful data-driven approaches, including digital twinning, to our current big societal challenges.

I am delighted to see that the vision for the technological evolution of Europe's Spatial Data Infrastructure, as presented in this report, is very much in line with our national strategy. As a result, I hope and believe that INSPIRE will -once again- boost these developments, thus resulting in a pan-European Spatial Data Infrastructure that is truly application-driven and is contributing to the large challenges we nowadays face in Europe.

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The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission. All errors remain the sole responsibility of the authors.

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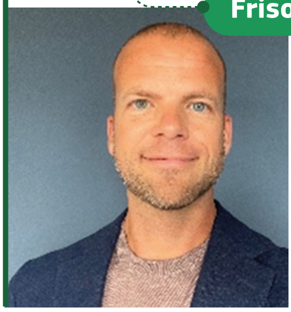

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Executive summary

This science for policy report provides an overview of the state of play of the INSPIRE infrastructure and summarises the lessons learned from the past 14 years of implementation of the Directive. Positioning those lessons within the contemporary policy and technological context has allowed the authors to define a **vision for the future evolution of INSPIRE as the public sector contribution to the emerging European data spaces, and in particular the Green Deal data space**.

Policy context

Data is central to the digital transformation of our societies and economies. That is why, as part of the *Europe Fit for the Digital Age* priority of the European Commission, the European Strategy for Data (European Commission, 2020a) aims at the establishment of a single market for data. This would not only enable companies to innovate at scale, but also facilitate the decision and policy making processes. The single market for data is to be implemented through sector-specific data spaces (including Green Deal, agricultural, mobility, finance, health, industry and public sector) that pool together data from multiple sources – private, public and personal in a sustainable manner, following principles that adhere to European values and the existing legal framework. The different **technological, organisational and legal enablers for the data spaces are still being conceptualised.** Data spaces are a means to an end. Once they become operational, the improved accessibility and availability of data will feed into novel application areas such as Artificial Intelligence and Digital Twins (Nativi et al., 2021). Considering this important agenda, INSPIRE can play an important role as the public sector contribution to the implementation of the European Strategy for Data.

In 2021, the implementation of the Directive entered the last mile and is coming to the end of the legally defined roadmap. With the forthcoming evaluation of the Directive which is due by 1 January 2022, the time is appropriate to take stock of the achievements and drawbacks and pave the way for the future. Data provided through the infrastructure, if conceptualised, operated and further developed in a user-centric manner, would become a main support and driver of public sector innovation. This can only be achieved through considering the complexity of organisational, technological and legal dimensions altogether. To this end, here we provide our lessons learned from the past, anticipate the forthcoming changes and technological trends, and give our perspective on how INSPIRE should evolve in order to remain fit for purpose.

The **target audience of this science for policy report is manifold**. First, it would benefit the INSPIRE stakeholders on the national and international levels, as the findings and the outlined vision will contribute to the ongoing debate around the evaluation of the Directive and the new INSPIRE Maintenance and Implementation Work Programme 2021-2024. Second, the summary of the lessons learned, in particular about what worked well, and what did not since the entry into force of the Directive would inform the scoping of the European data spaces at multiple levels of governance. Finally, the findings provided here will contribute to the ongoing process of modernising Spatial Data Infrastructures (SDIs) and their fusion into sustainable, general-purpose data ecosystems.

Key conclusions

The key conclusion drawn from the work presented in this report, also embedded in our vision for the future, is that SDIs as we have known them for the past two decades should, in order to remain fit for purpose, **evolve from complex and highly specialised geospatial data frameworks**, where legal obligations are enforced by strict technical specifications, to **flexible, open, agile, and self-sustainable data ecosystems**. In order to achieve this, it is desirable that the entry level to the data ecosystem is lowered and the sharing and consumption of data by communities is diversified as much as possible. Participation and active contribution of software communities, standardisation bodies and early adopters is at least as important as the traditional role of data providers. Collaboration between those different stakeholders can significantly be facilitated by contemporary platforms and open source technologies. Given that the contemporary context is characterised with more and more data being made available from an ever increasing number of sources, we should not consider 'spatial' data to be 'special' anymore. At the same time, the spatial dimension of data remains a powerful means for an integrated and combined use of datasets which are otherwise very difficult, if at all possible, to use together.

All of this shows the pressing need to **blend SDIs, including INSPIRE, within a larger European data space**, thus enabling various actors to seamlessly discover, access and use data for whatever final purpose, being it a research study, a policy intervention or a business application in any geospatially-related domain. To support this challenging objective, this science for policy report demonstrates the need for a simplification and modernisation of the INSPIRE technological framework in a user-centric and agile manner.

Keeping in mind that technology evolves, and will continue to evolve, at a rapid pace, **concrete actions are to be taken not only at the purely technical level**, by e.g. welcoming new standards and approaches for data encoding and sharing, **but also at the legal and organisational (governance) levels**. Regarding the latter, no intervention specific to a single level of governance (e.g. the national, or regional) will suffice if planned in isolation. It is important to emphasise here that, although the level of ambition defined in this report is high, the INSPIRE community is not starting from scratch. First, increased availability of data, mature ecosystems of software components, long-term relationships with standardisation bodies and early adopters, the healthy community and well-established governance structures, existing legal frameworks on the European and national levels, are among the key ingredients that pave the way for the future development. Second, the recently established **INSPIRE Maintenance and Implementation Work Programme 2021-2024 defines concrete actions** – built on the lessons learnt from the past – **to make INSPIRE evolve into a sustainable data ecosystem** for the environment, thus supporting the priorities around the green and digital transformation, and in particular for the forthcoming European data spaces.

The report concludes with our **initial proposal for a concrete INSPIRE reference architecture to be adopted in the years to come**. Such an architecture does not have the ambition to be encompassing all possible technical details, since we are aware that the emergence of the next technological trends would quickly make such details obsolete. On the contrary, it attempts to condense at a conceptual level the various aspects covered in this report and illustrate the interplay between different interconnected actors within an increasingly rich ecosystem of technologies and approaches, to ultimately trigger a debate with the community on what future technological evolution INSPIRE shall undertake. The architecture and our findings are backed up with a concrete example (provided in ***Section 7***) illustrating how the modernised INSPIRE infrastructure would be used as an integral part of the European data spaces.

Main findings

The most important findings provided in this report defined several **concrete actions that are necessary in order to make the vision a reality**. Those are intentionally aligned with the time horizon of the new INSPIRE Maintenance and Implementation Work Programme 2021-2024.

First, on the legislative level, it is important to **avoid overspecification** and keep references to concrete technical provisions outside of the legal framework, thus ensuring that the technical framework can easily be modified within the remit of existing EU law. In addition, the adoption of a recognised and **simple licensing framework** such as Creative Commons will catalyse data sharing. The new developments under the Open Data Directive, in particular the forthcoming implementing act on the high-value datasets would provide the legal foundation for sharing the data under open standardised licenses.

Second, on the governance level, the overall approach to SDIs should ideally be neither top-down, nor bottom-up, but shared across multiple levels of governance. The new policy context and the evaluation of the INSPIRE Directive provides an excellent opportunity for rethinking the existing maintenance and implementation governance structures for ensuring that INSPIRE can 'blend in' within a broader data ecosystem. It would be beneficial if data intermediaries, representatives of standardisation organisations, and even more so the communities of data users become an integral part of the governance structure together with data providers.

In addition, it is important to emphasise that rigid linear processes which root all developments into a particular standard or technology nowadays make very little sense. Instead, **an agile approach based on extensive experimentation (sandboxing) should be endorsed** which respects the overall principles and concepts but **can easily be tailored to the needs of different stakeholders**. Along those lines, the newly established procedure for **INSPIRE good practices** provides a pragmatic way forward for introducing and agreeing on new technologies and approaches in a collaborative manner. The same applies for the **management of INSPIRE artefacts** (application schemas and data models) which is currently being operationalised **through a transparent and inclusive approach**. The governance of INSPIRE central infrastructure software components (including the INSPIRE Geoportal, Validator and Registry) would ideally be **based on strategic partnerships with relevant communities**, and wherever possible **reuse existing and mature open source components**.

Finally, on the technical level, it remains important to **continue working on improving the findability** (through metadata) **and accessibility of the data** (through network services). It would be beneficial if relevant activities are continued and further streamlined through a transparent, well documented monitoring process complemented by generic open source software tools. At the same time, it is essential to ensure **INSPIRE's neutrality and the opportunity to embrace well-adopted standards and technologies**. With that objective in mind, it is advisable that the adoption of a given technology or standard remains a community-driven exercise, and ensuring good client and server support up front for each technology or standard to be adopted would ideally be a key part of this process. While the good practices procedure, reinforced by the release plan and governance approach for the INSPIRE artefacts, provides the means for adoption of such prominent approaches and standards, the **way in which obsolete technologies are to be phased out is still to be developed**.

Acknowledging the fact that INSPIRE is a multi-purpose infrastructure supporting a versatile number of very different use cases, it is important to **avoid wherever possible custom extensions of existing standards**, as they are both difficult to maintain, and might not be well supported by existing technology.

By applying the **well-known interaction patterns of Application Programming Interfaces (APIs) to the exchange of spatial data**, the power of spatial data and spatial analysis will no longer be restricted to a relatively small groups of spatial data specialists (that understand the specific interaction patterns of the geospatial community) but **will become available to all web and software developers**, regardless of their level of geospatial experience.

Another challenge to be addressed relates to the discoverability of the data. By making **spatial data indexable by search engines, the discovery of data is no longer limited** to those who are aware of the existence of web-based catalogues of spatial data.

As far as the infrastructures that can accommodate the data are concerned, the **opportunities for exploiting the emerging trend of European technological sovereignty** and the federated infrastructure provided by initiatives such as GAIA-X have to be further investigated. They have the potential to not only provide a scalable environment, but also to provide out-of-the-box technological enablers such as authentication mechanisms and certification.

Related and future JRC work

The ambitious agenda suggested by this report is only feasible if the community behind INSPIRE is engaged and addresses in a synergetic manner the different outstanding challenges. The policy context, including the legislative initiatives put forward to implement the European Strategy for Data, combined with the momentum related with the evaluation of the Directive and the new INSPIRE Maintenance and Implementation Work Programme, as well as the actions proposed in **the Digital Europe and Horizon Europe programmes provide us with the instruments** for operationalising and further investigating the work on data-driven innovation. The Joint Research Centre (JRC) remains the technical coordinator for the implementation of the INSPIRE Directive. However, with the new policy demands and user requirements in mind, the scope of activities is rapidly evolving in order to keep pace with new technological and policy challenges and emerging opportunities. From that perspective, we have a strong interest in **seeing INSPIRE within the broader context of self-sustainable data ecosystems** and continuing to **investigate the different organisational, technological and socio-economic enablers for data sharing** in Europe.

1

Introduction

The overall objective of **Directive 2007/2/EC (INSPIRE)** (European Union, 2007) is to establish a European Union (EU) Spatial Data Infrastructure (SDI) for the purposes of EU's environmental policies and policies or activities which have an impact on the environment. The overarching vision for a European SDI has not changed since the inception of the Directive, and is to promote cross-border data sharing and put in place easy-to-use, transparent, interoperable spatial data services which are used in the daily work of environmental and other policy makers and policy implementers across the EU at all levels of governance as well as businesses, science and citizens. With the last deadlines for INSPIRE implementation in 2021, the implementation of the Directive has entered a new phase. However, looking back on the past implementation cycle of the INSPIRE Directive, we observe that implementation is still delayed, and gaps are only closing slowly. The INSPIRE case is still more convincing in theory than in practice. In addition, when compared to 14 years ago, today's technological scenery is radically different (Kotsev et al., 2020). Alternative data sources such as digital sensors, Earth Observation platforms and citizen contributions are challenging the role of the public sector as the main producer and owner of geospatial information. The private sector is also playing an increasingly important role in the creation, storage, maintenance and provision of data (including personal data), but also in the extraction of value from existing data through the application of sophisticated, often proprietary, algorithms. Under these external pressures, public authorities are left with no other chance but to adapt and redefine their role in the attempt to cope with this rapidly changing context.

On the other hand, in recent years, use cases and consequently demand for data have evolved. Spatial analyses have increased in number and type and are now a widespread practice in many services of the Commission. Spatial analyses support policy making in domains such as environment, statistics, agriculture and transport, or other community data programmes such as Copernicus. This requires the integration and processing of diverse types of geospatial data, with an increasingly wider scope and higher spatial quality and better resolution. In addition, the adoption of the UN 2030 Agenda for Sustainable Development (United Nations, 2015) and of the related indicator framework for monitoring the Sustainable Development Goals (SDGs) also results in greater demand for various types of data, including geospatial information. In response to these growing needs, several Directorates-General (DG) of the European Commission and European Agencies have agreed that the Commission needs more and better-quality geospatial data from official sources with European or at least EU coverage.

In her political guidelines, Commission President von der Leyen stressed the need for Europe to lead the transition to a healthy planet and a new digital world. This twin challenge of a green and digital transformation must go together and direct us towards more sustainable solutions which are resource-efficient, circular, and climate-neutral. Data is at the centre of this transformation and data-driven innovation will contribute to the implementation of the objectives of the **European Green Deal** (European Commission, 2019a).

Directive 2019/1024/EC, also known as the **Open Data Directive** (European Union, 2019), which revises the PSI Directive (European Union, 2003a), entered into force in July 2019 with the focus on open data and the re-use of public sector information, including the implementing act on high-value datasets that is currently (September 2021) under preparation. The new Directive aims to address the issues, which were detected during the evaluation in 2018, affecting the full exploitation of the potential of public sector information for the European economy and society. It also encourages the access to and re-use of public and publicly funded data and recognises INSPIRE as a good practice.

To use the major potential of data in support of the Green Deal priority actions on climate change, circular economy, zero pollution, biodiversity, deforestation and compliance assurance, a Common European Green Deal data space will be developed following the **European Strategy for Data** (European Commission, 2020a). The centrepiece action of the European Commission Directorate-General for Environment (DG ENV) to develop this Green Deal data space will be a **GreenData4All initiative**, which (following an evaluation/impact assessment of the INSPIRE Directive due by the 1st of January 2022) will aim to review and revise two pieces of existing legislation:

- Directive 2003/4/EC on public access to environmental information (European Union, 2003b);
- The INSPIRE Directive dealing with geospatial data for the environment (European Union, 2007).

These two legal instruments complement each other as the backbone of the environmental information management covering the whole of EU environmental policy. As a legal framework for the dissemination of information, they support all Member States to adhere to the good governance policy principles of transparency and participation.

The INSPIRE Directive, however, does more than only facilitate the access to environmental information. Its EU added-value becomes most obvious when the Member States need information to support their decision making for managing the environmental, social and economic risks and crises, related to the changing climate, environmental degradation, and man-made or natural disasters that do not stop at borders (e.g., floods, the pollution of air and water, and even pandemics like the COVID-19 crisis). In such situations, Member States need powerful digital decision support systems. Such systems demand the efficient and obstacle free access to many diverse types of data (e.g., data on critical infrastructures, industrial facilities, population and health data, vulnerable and protected areas, on the meteorological and atmospheric conditions, on transport networks, buildings and cadastral parcels, etc.), that are all in the scope of the INSPIRE Directive.

Furthermore, the development of the Green Deal data space goes along with the introduction of data and services for reusable data, setting up a European data ecosystem for the circular economy, starting a pilot on zero emissions using available data and creating a digital twin of the planet earth - Destination Earth (Nativi et al., 2021). The European Spatial Data Infrastructure created by INSPIRE – if it is set up, operated and further developed in a user-driven way – can become a main support of this development through its data and its services.

Building on this context, the objective of this report is to critically assess the development of the pan-European INSPIRE SDI 14 years after its inception, and, considering the current context from both a policy and technological perspective, to offer a vision for its evolution with a five to ten year horizon in mind. To achieve this, the report is roughly organised in two parts according to the following logic. After this introduction (***Section 1***), the first part introduces the INSPIRE legal and technical framework and the central INSPIRE infrastructure components (***Section 2***) and describes the current implementation state of play in terms of data availability, existing governance mechanisms, available technological stack as well as influence and role of standardisation bodies and the community (***Section 3***). ***Section 4*** concludes the first part by presenting a number of technological and organisational lessons learnt from the INSPIRE implementation happened so far, analysing approaches that have or have not worked well. The second part starts with a presentation of the context where the evolution of INSPIRE will take place, looking at the policy dimension already outlined in this introduction (***Section 5***) as well as the technological dimension (***Section 6***) characterised by new data sources and innovative trends. ***Section 7*** represents the core of the report as it defines the vision for the technological evolution of INSPIRE in the years to come together with the actions at the legal, organisational and technological level required to make this vision a reality. ***Section 8*** concludes the report by offering an initial proposal for a concrete INSPIRE reference architecture to be adopted in the years to come.

2

A brief introduction to INSPIRE

2.1 Legal and technical framework

The legal framework was set by the INSPIRE Directive (European Union, 2007) and interdependent legal acts, called **Implementing Rules** that were published in the form of Commission Regulations or Decisions. By design, the infrastructure itself is built upon the SDIs established and operated by EU Member States that are then made compliant with the Implementing Rules, covering the INSPIRE core components: **metadata, network services, interoperability of spatial datasets and services, data sharing** and **monitoring and reporting**, together with the obligation to establish a national coordination body (Cetl et al., 2019).

The Directive does not require the collection of new data. Instead, existing data from public authorities is to be harmonised to fit the agreed data models. Also, the SDI shall be developed and implemented in a decentralised and distributed manner, following a set of fundamental principles (European Union, 2007):

- Data should be collected only once and kept where it can be maintained most effectively;
- It should be possible to combine seamless spatial information from various sources across Europe and share it with many users and applications;
- It should be possible for information collected at one level/scale to be shared with all other levels/scales; detailed for thorough investigations, general for strategic purposes;
- Geographic information needed for good governance at all levels should be readily and transparently available;
- It should be easy to find what geographic information is available, how it can be used to meet the needs, and under which conditions it can be acquired and used.

The INSPIRE Directive and Implementing Rules include legally binding requirements that describe, usually on an abstract level, what Member States must implement (see ***Figure 1***). Instead, the non-binding **Technical Guidance (TG) documents** specify how the legal obligations could be implemented in practice, referring to existing geospatial standards where appropriate. Implementation of the TG documents maximises the cross-border and cross-thematic interoperability of INSPIRE spatial datasets and services and ensures interoperability with other sectors.

The **thematic scope of INSPIRE** includes 34 cross-sectoral categories, named themes (see ***Figure 2***), listed in the three annexes of the Directive and reflecting two main types of data: spatial reference data (presented in Annex I and partly in Annex II), which define a location reference that the remaining themes (in Annex III and partly in Annex II) can then refer to.

The TG documents on the interoperability of spatial datasets and services, also known as **Data Specifications**, contain agreed data models based on a generic conceptual data model (Tóth et al., 2012), common encoding rules, harmonised vocabularies, and registers. Together they form the key pillars of data and service interoperability

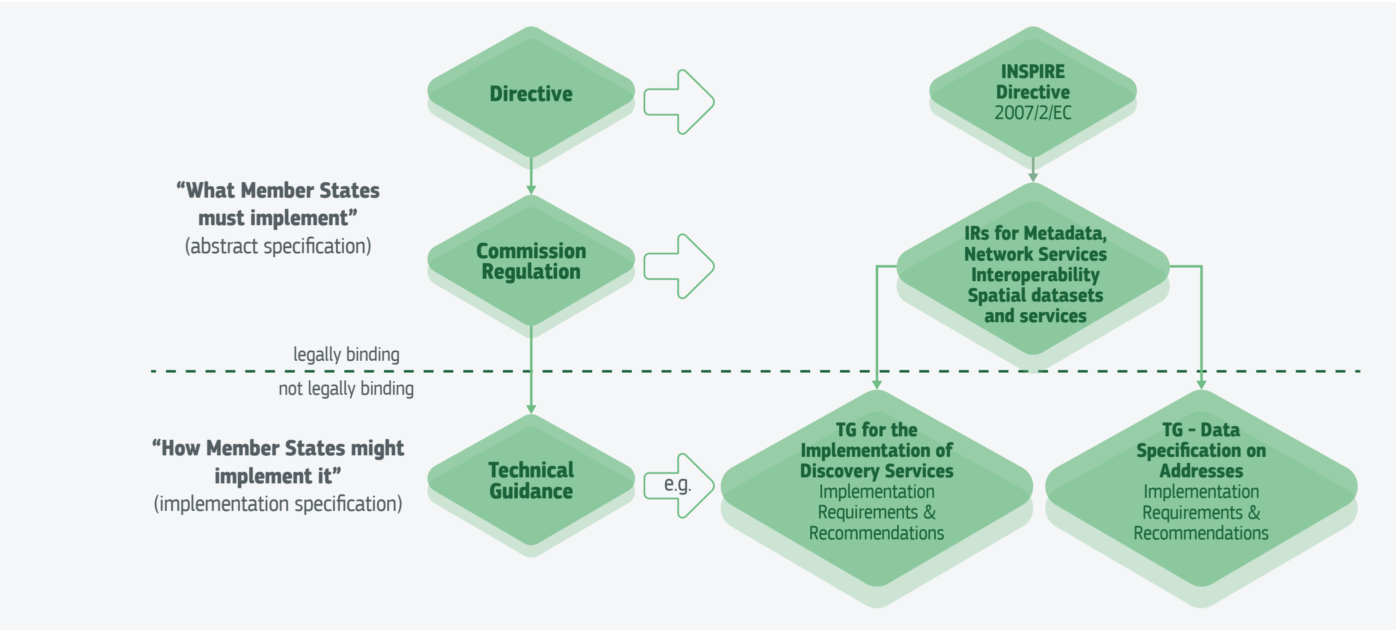


Figure 1. Relationship between the INSPIRE Implementing Rules and Technical Guidance documents

Source: JRC, 2021.

Figure 2. INSPIRE themes, organised in three Annexes

Source: JRC, 2021.

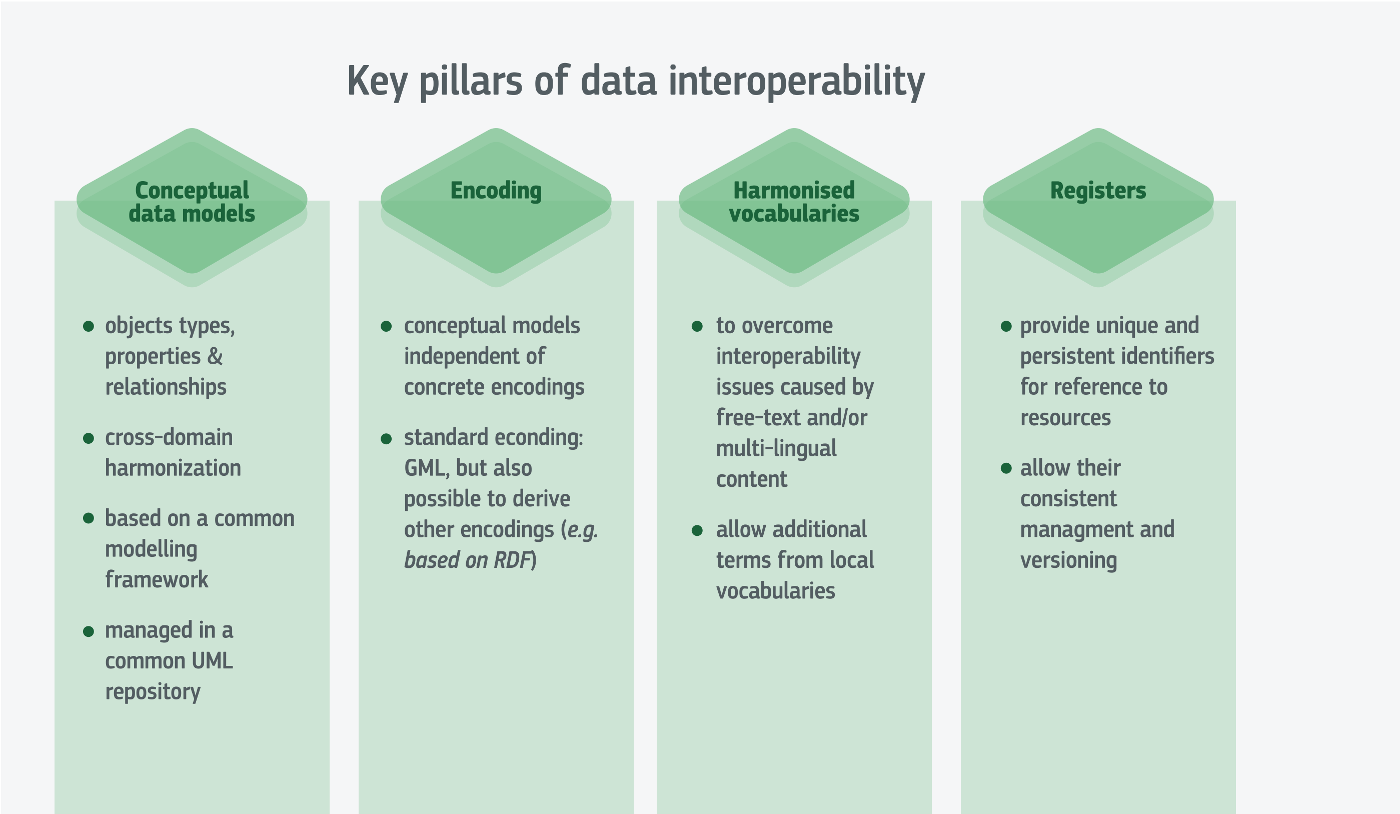


Figure 3. Pillars of data interoperability in INSPIRE Source: JRC, 2021.

(see ***Figure 3***). They ensure coherence within the infrastructure and promote the reuse of data and information according to the 'once-only' principle.[1]

The methodology for the development of individual Data Specifications followed a commonly agreed pattern based on the ISO 19131:2007 standard (International Organization for Standardization, 2007). The resulting data models for each theme are part of the legal provisions of the Directive.

Data and metadata are shared through web-based services, referred to as network services (European Commission, 2009) and based on a Service-Oriented Architecture (SOA)[2] approach (see ***Figure 4***). Network services are implemented through **well-established international standards**, mainly developed by the Open Geospatial Consortium (OGC)[3]. The related TG documents illustrate how data providers establish access to metadata for discovery services through the Catalogue Service for the Web (**CSW**) (Open Geospatial Consortium, 2007). Similarly, for view services, the interactive visualisation of georeferenced content involves guidance using the Web Map Service (**WMS**) (Open Geospatial Consortium, 2006) and Web Map Tile Service (**WMTS**) (Open Geospatial Consortium, 2010) standards. Download services also have guidelines that recommend the use of **ATOM** feeds (The Internet Society, 2005), Web Feature Service (**WFS**) (Open Geospatial Consortium, 2014), Web Coverage Service (**WCS**) (Open Geospatial Consortium, 2018) and Sensor Observation Service (**SOS**) (Open Geospatial Consortium, 2012), for appropriate types of data. Other spatial data services, forming a service bus alongside the network

1 *https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/Once+Only+Principle*

2 *https://www.opengroup.org/soa/source-book/soa/p1.htm*

3 *https://www.ogc.org*

Box 1

Players in the INSPIRE community engaged as members in the OGC have supported the development of our open standards over many years. European requirements have been raised and brought up in the relevant OGC working groups. The uptake of standards like OGC API - Features has been enormous and demonstrates the need for - and benefits of - international coordination of standards development. Further, the close coordination between OGC and the JRC has led to fruitful results.

Athina Trakas, Open Geospatial Consortium (OGC)

services, are mainly implemented at the national level and support data transformations, including coordinate transformations. In addition to all the above, there are generic services, e.g. registry services that contribute to the proper functioning of the infrastructure.

The deadline for Member States to transpose the INSPIRE Directive into their national legislation was 15 May 2009. The implementation process started immediately after, following an **implementation roadmap**[4] based on several deadlines according to the type of resource (metadata, discovery, view and download services) and the Annex the datasets refer to, with full implementation foreseen for 2021 (see ***Figure 5***). Although most of the milestones have been already reached, there are still some activities to be completed, especially regarding data and metadata harmonisation and conformity which is crucial for the overall interoperability (see also ***Section 3.1***).

2.2 Central infrastructure components

This section describes the central components of the INSPIRE infrastructure. They are the software tools supporting Member States public bodies in the implementation of the requirements emerging from the INSPIRE Directive and related Implementing Rules and are developed, operated and maintained by the JRC.

2.2.1 INSPIRE Geoportal

The entry point to the INSPIRE infrastructure is the **INSPIRE Geoportal**[5], depicted at the top of the INSPIRE architecture in ***Figure 4***. It serves as a central access point to the data and services from public organisations in the EU Member States and European Free Trade Association (EFTA) countries which fall under the scope of INSPIRE. The INSPIRE Geoportal enables cross-border data discovery, visualisation, and download. The Geoportal does not store any geospatial data. It simply acts as the main client application of the whole INSPIRE infra-

4 *https://inspire.ec.europa.eu/inspire-roadmap*

5 *https://inspire-geoportal.ec.europa.eu*

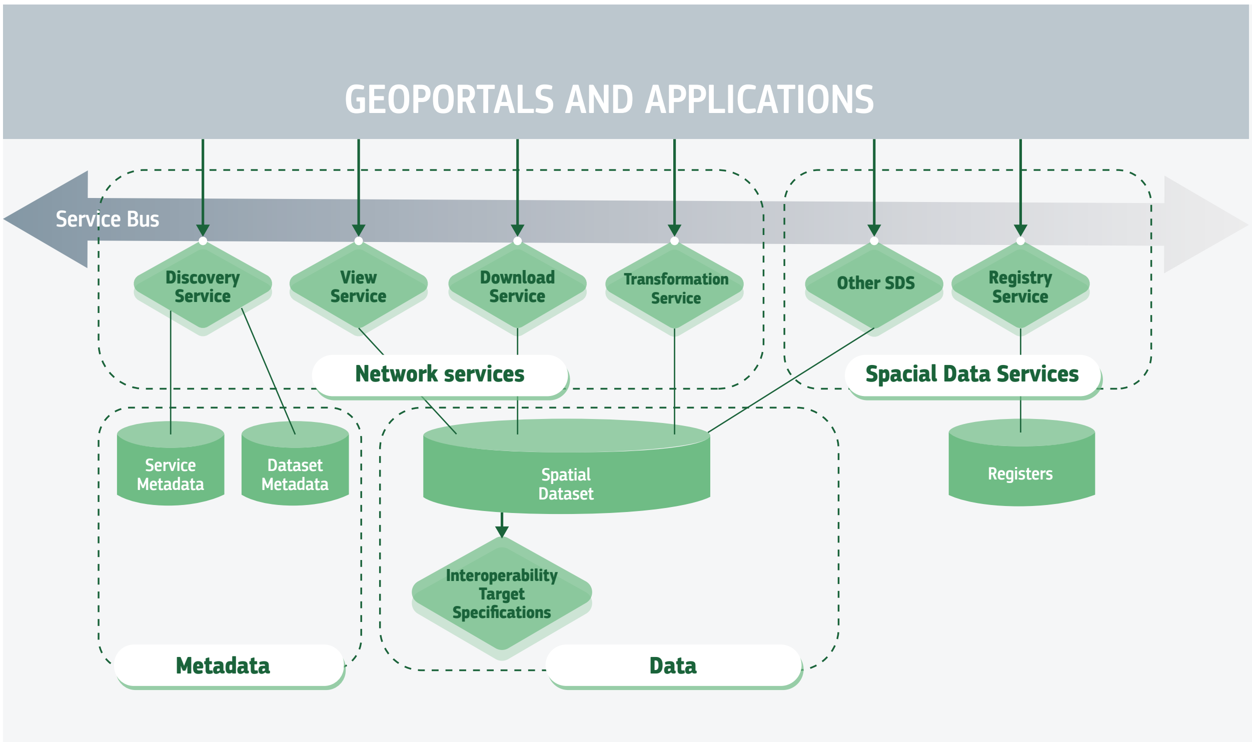


Figure 4. Distributed Service-Oriented Architecture of INSPIRE

Source: JRC, 2007.

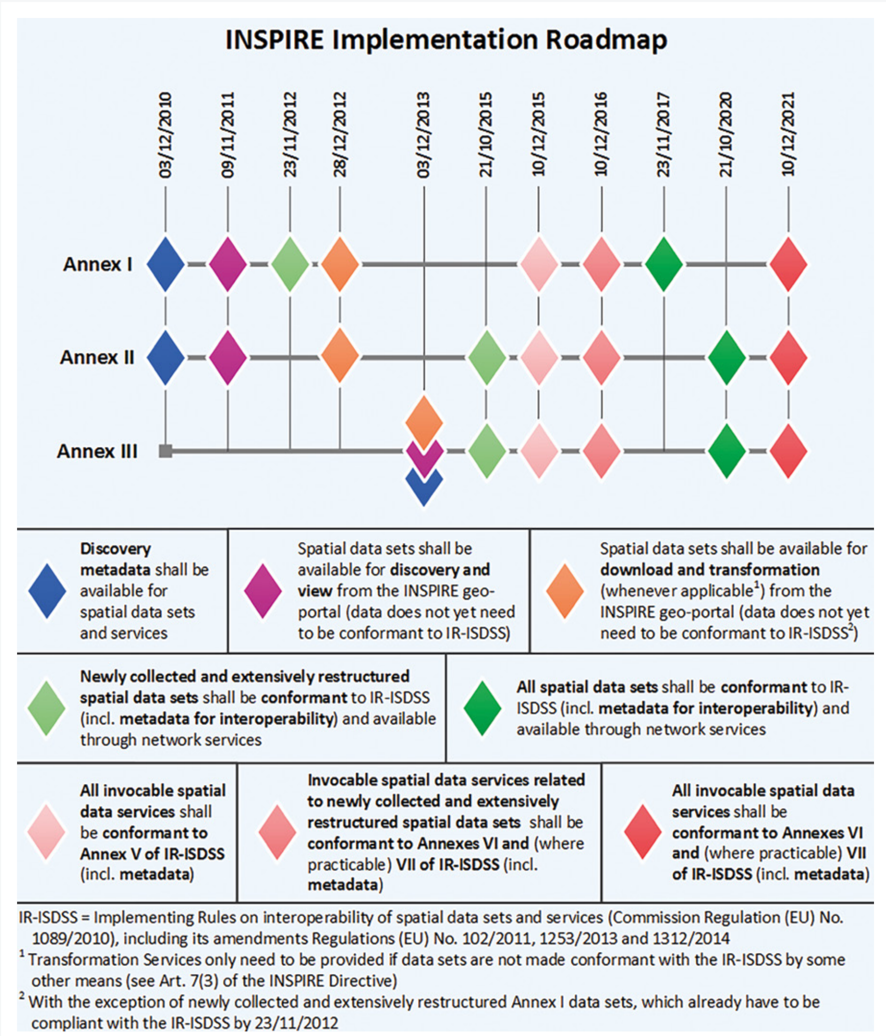


Figure 5. INSPIRE implementation roadmap

Source: JRC, 2010.

structure by exposing data through the harvesting of the CSW endpoints made available by Member States. Alongside the INSPIRE Geoportal, which is operated by the European Commission, there are also national geoportals operated by single countries. Links to national geoportals are available in the INSPIRE Knowledge Base (IKB) section *INSPIRE in your country*.[6] The Geoportal, whose landing page is shown in ***Figure 6***, offers overviews of the availability of datasets by country and thematic area and provides ready-to-use data either through interoperable network services or by direct download, to maximize their exploitation by third-party GIS clients and applications.

As shown in ***Figure 6***, the INSPIRE Geoportal provides access to datasets through two different viewers:

1. A **High-Value Datasets viewer**, which displays the availability and provides access to the datasets from all EU Member States and EFTA countries datasets that also qualify as high-value datasets (see ***Subsection 5.1.2***); these also include the priority datasets used for environmental reporting[7], which can be filtered by environmental domain, environmental legislation and country;
2. An **INSPIRE Thematic Data viewer**, which displays the availability and provides access to the datasets from all EU Member States and EFTA countries falling under the scope of the INSPIRE Directive, filtered by data theme and country; the full country overview with datasets available as of October 2021 is shown in ***Figure 7***.

2.2.2 INSPIRE Reference Validator

The **INSPIRE Reference Validator**[8], which is also reachable from the landing page of the INSPIRE Geoportal (see ***Figure 6***), is the tool used by INSPIRE data providers, solution providers and Member States national coordinators to check whether datasets, network services and metadata meet the requirements defined in the INSPIRE TG documents. For each type of resource, the tests available in the INSPIRE Reference Validator – whose landing page is shown in ***Figure 8*** – are organized into **Abstract and Executable Test Suites** (ATS and ETS). The former consist of high-level, human-readable translations of TG requirements into tests, while the latter represent machine-executable descriptions of tests. For each type of resource, ATS and ETS are organised into a number of conformance classes. All the ATS and ETS included in the INSPIRE Reference Validator are agreed upon by the technical sub-group of the INSPIRE Maintenance and Implementation Group (MIG-T) and are published under open source licenses[9]. Finally, the INSPIRE Reference Validator is based on the open-source **ETF testing framework**[10], i.e. the software where INSPIRE ETS are run, which is also developed by the JRC and partially funded by the ELISE (European Location Interoperability Solutions for e-Government) Action[11] of the ISA² (Interoperability solutions for public administrations, businesses and citizens) Programme[12]. The result of a test performed in the INSPIRE Reference Validator is a test report, where all the tests run are listed and the outcome of each test is indicated. For the tests failing validation, an explanation of each error is provided so that users can more easily spot the mistakes and fix them.

2.2.3 INSPIRE Registry

The **INSPIRE Registry**[13] is the application providing a central access point for managing and shar-

6 *https://inspire.ec.europa.eu/INSPIRE-in-your-Country*

7 *https://wikis.ec.europa.eu/display/InspireMIG/Action+2016.5%3A+Priority+list+of+datasets+-for+e-Reporting*

8 *https://inspire.ec.europa.eu/validator*

9 *https://github.com/inspire-eu-validation*

10 *https://etf-validator.net*

11 *https://ec.europa.eu/isa2/actions/elise_en*

12 *https://ec.europa.eu/isa2/home_en*

13 *https://inspire.ec.europa.eu/registry*

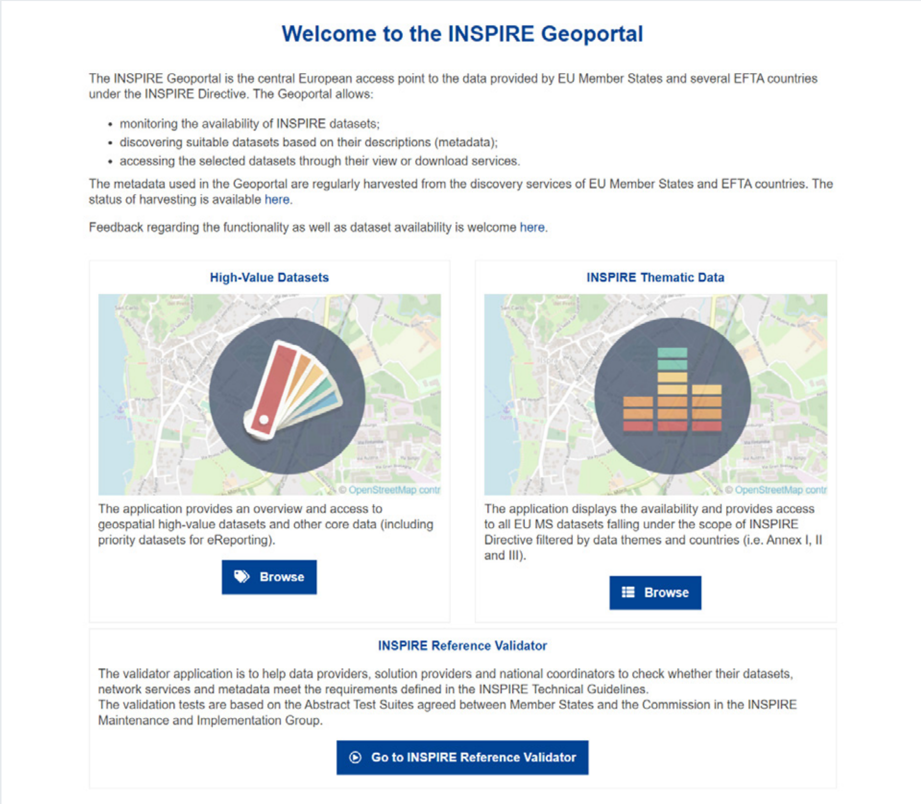


Figure 6. Landing page of the INSPIRE Geoportal

Source: JRC, 2021.

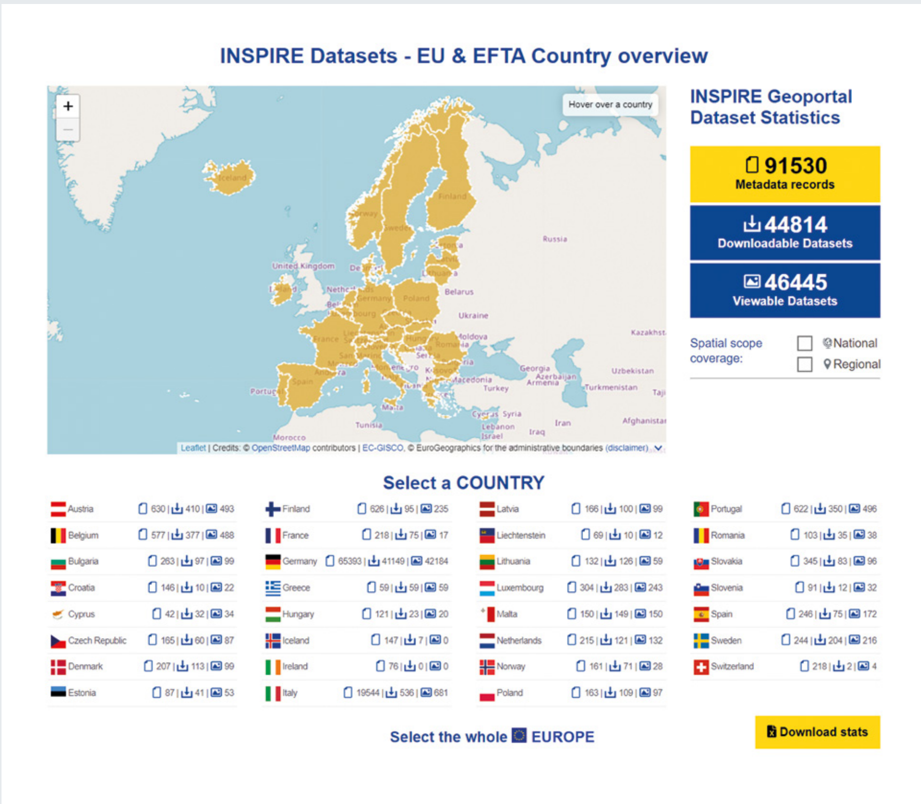


Figure 7. INSPIRE Geoportal Thematic Data viewer displaying datasets availability for all EU Member States and EFTA countries as of October 2021

Source: JRC, 2021.

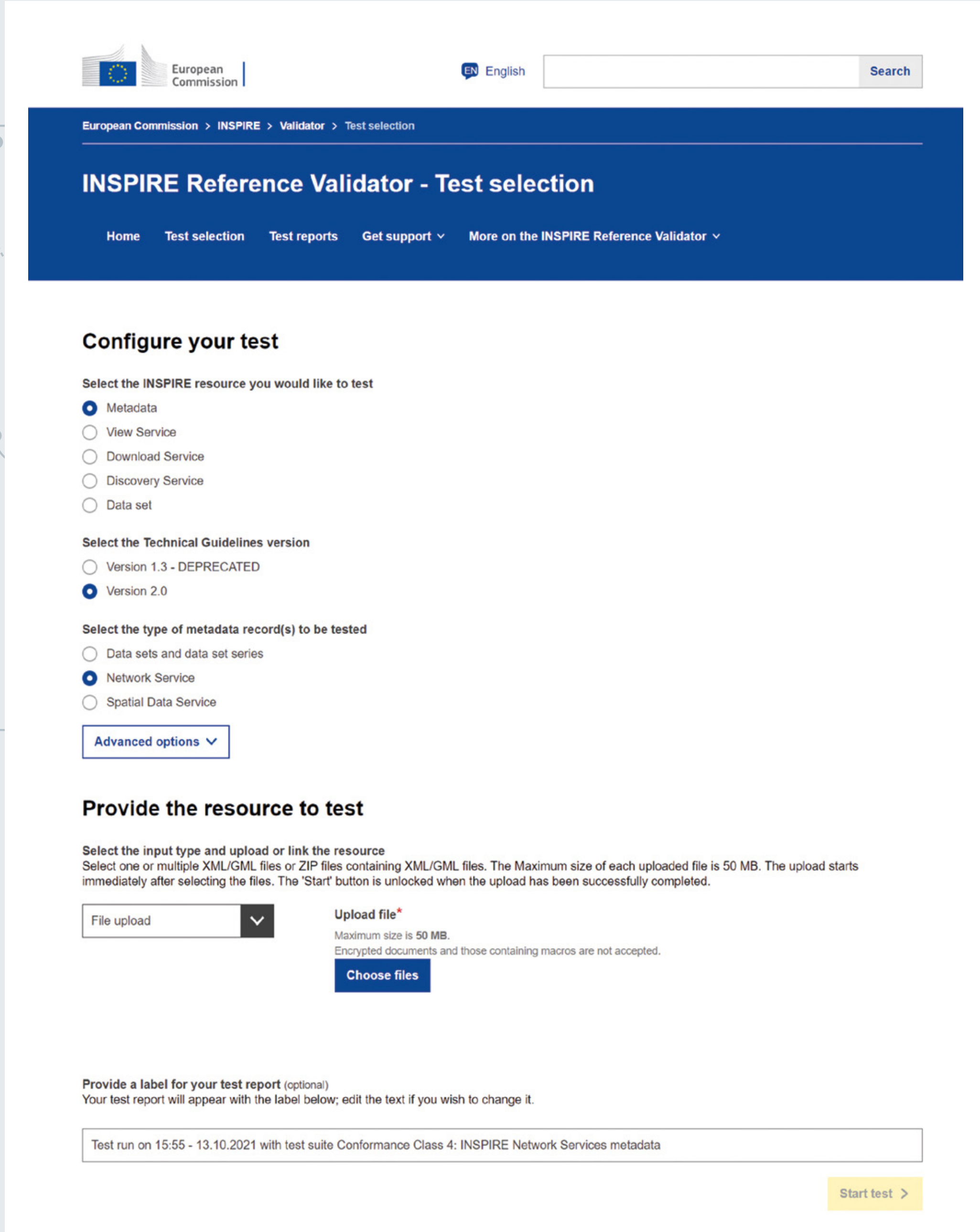


Figure 8. Landing page of the INSPIRE Reference Validator Source: JRC, 2021.

ing INSPIRE reference codes, including INSPIRE themes, code lists, application schemas and discovery services. For each of those reference codes, which are grouped in multiple registers, the INSPIRE Registry provides clear descriptions (in multiple languages) and references through unique identifiers, allowing them to be easily looked-up by humans and retrieved by machines.

The content of the registers is based on the INSPIRE Directive, Implementing Rules and TG documents. The INSPIRE Registry, whose landing page is shown in *Figure 9*, is thus a key tool to ensure semantic interoperability between systems and applications exchanging INSPIRE data. It currently provides access to 10 registers, overall including more than 10000 reference codes in

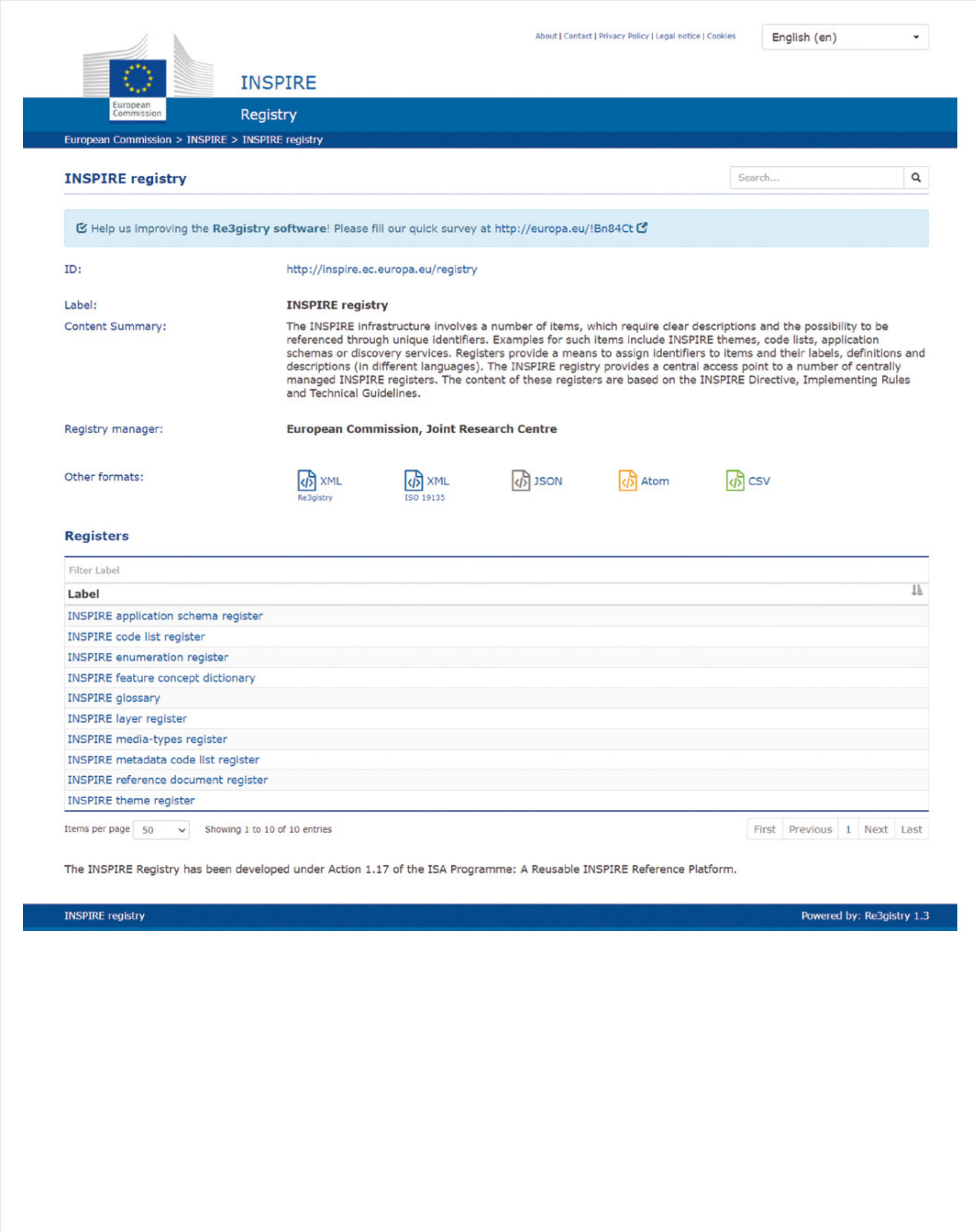


Figure 9. Landing page of the INSPIRE Registry

Source: JRC, 2021.

23 languages and served in 7 different formats (HTML, XML, ISO 19135 XML, RDF, JSON, ATOM and CSV).

The INSPIRE Registry is an instance of the **Re3gistry open-source software**, also developed by the JRC and funded by the ELISE Action of the ISA[2] Programme. Released under the EUPL v1.2 license[14], the Re3gistry is used by a number of public and even private institutions worldwide, including several EU Member States, to support them in the consistent management and update of their reference codes (see ***Section 4.3***).

14 *https://github.com/ec-jrc/re3gistry*

3

Implementation state of play

In this section we present an overview of the latest state of the infrastructure with the intention to define a baseline which can then be used to pave the way for the evolution of INSPIRE. Given the complexity of the developments under INSPIRE, it is difficult, if at all possible, to provide such an overview through a single point of view. That is why, in writing this section, we adopt five different, yet interdependent perspectives. We consequently investigate the INSPIRE 1 data availability, 2 governance mechanisms, 3 technological stack, 4 standardisation and regulation, and 5 community engagement.

3.1 Data availability

The latest assessments of INSPIRE data availability were performed at the end of 2019 and at the end of 2020 as a result of the yearly **Monitoring and Reporting** process, based on the resources made available by EU Member States and EFTA countries on December 15 of each year. In contrast to all the previous rounds of Monitoring and Reporting, the one performed in 2019 was the first driven by Commission Implementing Decision (EU) 2019/1372 (European Commission, 2019b). This defined a total of 19 implementation indicators, to be calculated – for the first time – in a fully automated way based on the metadata harvested from EU Member States and EFTA countries national catalogues using the INSPIRE Geoportal and the INSPIRE Reference Validator (see ***Section 2.2***). Such indicators are organized into 5 categories, measuring: the availability of spatial data and services; the conformity of metadata; the conformity of spatial datasets; the accessibility of spatial datasets through view and download services; and the conformity of network services. While in the first category the indicators are expressed as absolute values, i.e., they measure the number of available metadata satisfying certain properties, the indicators in the remaining four categories are expressed as percentages (i.e. measuring the fraction of resources satisfying a specific requirement), which are a direct measure of performance and allow country-by-country comparisons.

The results of the INSPIRE 2019 Monitoring and Reporting are described in detail by Minghini et al. (2020), while those for the INSPIRE 2020 Monitoring and Reporting were first presented during the 64th MIG-T meeting in January 2021 (JRC INSPIRE Team, 2021). The 2019 and 2020 results are also published online in dedicated dashboards[15,16]. The outcomes of the two processes are similar. The values of the indicators calculated for the EU Member States and the EFTA countries falling under the scope of INSPIRE (31 countries in total) show that **the status of implementation of INSPIRE is very heterogeneous across countries, and there is no single country which has yet achieved a full implementation** according to the INSPIRE roadmap (see ***Figure 5***).

The total number of metadata records available at the end of 2019 was approximately equal to 260 thousand, including about 160 thousand records for datasets and dataset series and the remaining 100 thousand records for spatial data services. The spider graph shown in ***Figura 10*** represents together the mean values of 5 indicators, all calculated as percentages and overall

15 *https://inspire-geoportal.ec.europa.eu/mr2019.htm*

16 *https://inspire-geoportal.ec.europa.eu/mr2020.html*

Box 2

There is massive opportunity and need around environmental data. Environmental data is going to influence day-to-day decision making of everybody. Be it that you want to know what emissions are like in a potential vacation spot or that you need to evaluate which policy options really work. As the INSPIRE community, we have already achieved a lot towards making this possible. Across more than 30 countries and 20.000 organisations, we have agreed on shared specifications, have made more than 180.000 datasets discoverable, more than 40.000 accessible and more than 20.000 interoperable. Interest in these datasets is sharply rising. Just across the INSPIRE network services that our company provides, we see millions of requests every day.

Thorsten Reitz, Wetransform GmbH

summarising the main results of the 2019 Monitoring and Reporting: conformity of metadata for spatial datasets (indicator MDi1.1), conformity of metadata for spatial data services (indicator MDi1.2), accessibility of spatial datasets through view and download services (indicator NSi2), conformity of spatial datasets (DSi2), and conformity of network services (indicator NSi4).

The results shown in ***Figura 10*** make it possible to draw some general conclusions on different aspects of INSPIRE implementation (Minghini et al., 2020). First, the accessibility of datasets through both view and download services – which is a proxy for the actual usability of the whole infrastructure – is still low on average, with some countries scoring values equal or close to 0%. The reasons for this low performance are several, ranging from the actual lack of network services to issues with the resource linkages (i.e. lack of correct links between the dataset and service metadata) and the availability of access-protected or unstable services. The average conformity of metadata is also low on average, although this can be partially explained by the introduction of the INSPIRE Reference Validator as the tool used to check the conformity, as opposed to the self-declarations of conformity by EU Member States used until 2018. The values of DSi2, measuring the conformity of spatial datasets, are again very heterogeneous across countries and low on average, with some countries providing very few or no interoperable datasets at all. A similar conclusion applies to the conformity of network services, which is high for several countries while some others score per-

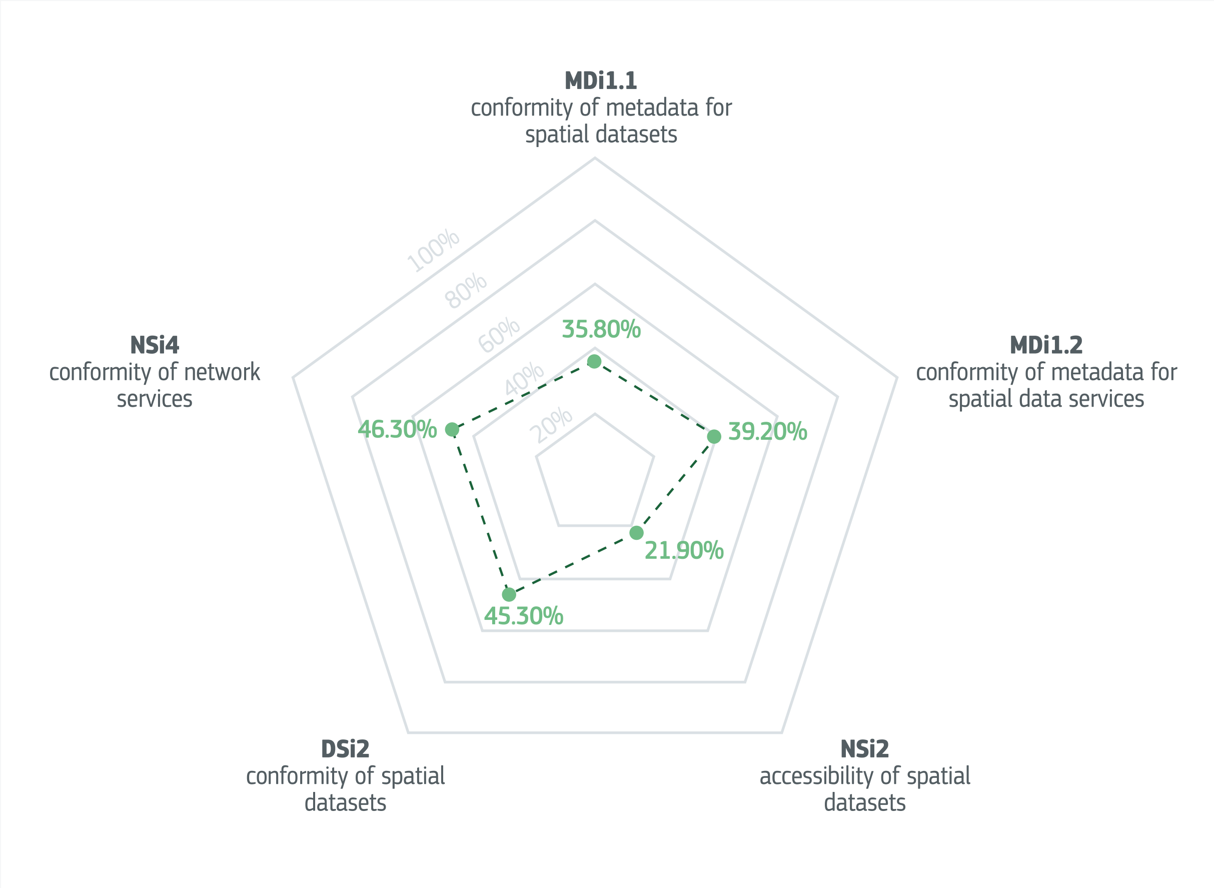


Figure 10. Spider graph representing the mean values of indicators MDi1.1, MDi1.2, NSi2, DSi2 and NSi4

Source: Minghini et al. (2020).

centages equal or close to 0% (although the lack of conformity does not necessarily imply the lack of accessibility of the datasets served by those network services).

The results achieved in the 2020 Monitoring and Reporting process overall confirmed the substantial differences in implementation across EU Member States and EFTA countries, with some countries performing very well (i.e., scoring, for all the percentage indicators, values equal or close to 100%) and some others clearly lagging with all such values still close or equal to 0%. However, a positive trend can be generally identified compared to 2019, considering that almost all the percentage indicators increased of at least 10% (JRC INSPIRE Team, 2021).

3.2 Governance mechanisms

The **INSPIRE Coordination Team (CT)** consists of staff of the European Commission from DG ENV, DG JRC, DG ESTAT, DG AGRI, and staff of the European Environment Agency (EEA). Its role is to coordinate the implementation and further evolution of the infrastructure, including alignment and cross-fertilisation with other EU policies. In 2013, a Commission expert group called **INSPIRE Maintenance and Implementation Group (MIG)**[17] was set up, consisting of representatives of the INSPIRE national contact points of EU Member States. The MIG coordinates the joint activities between the European Commission, the EEA and

17 *https://inspire.ec.europa.eu/inspire-maintenance-and-implementation/46*

the EU Member States to support the maintenance and implementation of the INSPIRE Directive. The tasks of the MIG are:

- To prepare and regularly update the rolling **INSPIRE Maintenance and Implementation Work Programme** (MIWP) to be agreed by the **INSPIRE Committee** (composed of representatives of the Member States and chaired by a representative of the Commission) and the Commission.
- To bring about an exchange of experience and good practice related to the implementation of the INSPIRE Directive and the Implementing Rules;
- To identify and give advice about the priority issues to be addressed in the maintenance of the INSPIRE Directive, Implementing Rules and/or TG documents;
- To identify issues related to INSPIRE implementation (including, but not limited to, technologies, standards, methods, coherence across INSPIRE chapters and communication measures to be adopted) and advise the Commission on how to address them.

The MIG has a permanent **sub-group of experts focusing on technical aspects (MIG-T)** and can set up temporary sub-groups focusing on specific, time-bounded actions defined in the Maintenance and Implementation Work Programme. After the end of the MIWP 2016-2020[18], the new **MIWP 2021-2024**[19] was recently started. It is based on the emerging policy landscape under the new European Commission (see ***Section 5***) and the status of the implementation and impact of INSPIRE. It is focused on the following key strategic objectives without neglecting existing legal obligations:

1. Develop a future vision for the role of INSPIRE in the Green Deal Data space in particular, and the EU Common Data space in general.

2. Define the INSPIRE "crown jewels" – those datasets/themes, for which tangible benefits for environmental policy, the implementation of the European Green Deal or other policy priorities can be expected.

3. Develop an implementation plan to focus implementation efforts to maximise availability, ensure interoperability and reach pan-European spatial coverage for a well-defined set of priority data.

4. Continue work on simplifying and mainstreaming the technical requirements of the INSPIRE Directive, considering emerging standards and technologies to fulfil concrete user expectations.

5. Define the transition from the current legal framework to a digital ecosystem for environment and sustainability which addresses clearly defined EU-wide needs, is based on proven standards and technologies, can be implemented in a foreseeable time with limited effort, allows to quantify an added value for environment and sustainability and has a built-in review cycle.

These key objectives are grouped into the following main areas of work:

- **Area of work 1:** A digital ecosystem for the environment and sustainability (objective 1);
- **Area of work 2:** Towards a common implementation landing zone (objectives 2-4);
- **Area of work 3:** GreenData4All (objective 5).

The MIWP 2021-2024 is designed to continue the successful work under the Maintenance and Implementation Framework (MIF) in the past. The MIWP clearly identifies the concrete core actions in more detail for the period 2021-2022, taking the implementation of the INSPIRE Directive to a common landing zone supporting tangible Europe-

18 *https://wikis.ec.europa.eu/display/InspireMIG/MIWP+2016-2020*

19 *https://wikis.ec.europa.eu/display/InspireMIG/INSPIRE+work+programme+2021-24*

an use cases. The planning is less detailed beyond 2022 in anticipation of the evaluation and possible review of the INSPIRE Directive. Hence, a regular review of the MIWP will be undertaken by the MIG with input from the MIG-T.

The MIG is also complemented by a pool of experts drawn from the INSPIRE stakeholder community. The experts in this pool are called upon when MIG sub-groups are formed to address specific implementation or maintenance issues. This also provides the opportunity to reach out to experts involved or interested in particular aspects of INSPIRE implementation or maintenance.

3.2.1 Good practices

In order to promote good implementation practices to the INSPIRE community, e.g. resulting from new standards or emerging technologies, a light-weight procedure is defined for proposing, documenting, reviewing and publishing such good practices[20]. The procedure also defines how to further develop, where appropriate, a good practice into TG documents. This procedure does not replace, but rather builds on existing resources to support the INSPIRE community while providing documented evidence and a defined link between current implementation practices and needs and the MIG. The good practice procedure consists of **six consecutive steps**.

1 Initiation

The proposers compile and share a "good practice fiche", describing the nature of the solution, the benefits it has or would provide and a reference to a detailed description of the solution, as well as a number of other "metadata".

2 Submission as good practice candidate

The implementation solution is submitted to the MIG-T as a good practice candidate. For this step, implementation evidence and community support can still be limited.

3 Outreach

The proposers host a webinar to explain the main features and expected benefits of the good practice solution and reflect any pertinent feedback from stakeholders in the good practice fiche.

4 Submission

The implementation solution is submitted to the MIG for endorsement as a good practice. For endorsement at this stage, it is crucial to demonstrate evidence that the solution: (i) has been put into practice, ideally in more than one context (either more than one domain or more than one country); (ii) is already supported by multiple software implementations; and (iii) has received broad community support.

5 Legal scrutiny

Following endorsement by the MIG, a rapid assessment of the good practice is performed by the European Commission in order to ensure the alignment of the technical provisions with the legal framework. Feedback is provided to the MIG and the proposers, which confirms the proposed approach or suggests modifications.

6 Feedback

The good practice is sustained in time, and there is a mechanism for ensuring that bugs are fixed, and requests from the community are accommodated.

3.3 Technological stack

From a technical perspective, INSPIRE is grounded on existing standards (see ***Section 2***) but to minimise the risks of introducing dependencies, is neutral from any particular technologies. There are multiple ways of implementing the different components of an INSPIRE data flow, which are both multi-purpose and single use. In terms of licensing, both proprietary and open-source solutions are within INSPIRE's scope. Without having the ambition of being exhaustive, ***Subsection 3.3.1*** presents the most frequently used tools for both the provision and consumption of INSPIRE data.

20 *https://inspire.ec.europa.eu/portfolio/good-practice-library*

These tools are linked to the role of the central software components of the INSPIRE ecosystem, which are operated by the European Commission (JRC), already described in *Section 2.2*.

3.3.1 Software tools for data provision and consumption

Figure 11 provides a graphical representation of the traditional components of an INSPIRE data flow, divided into two categories: on the left, those pertaining to the **provision of INSPIRE data** and relevant to data providers; on the right, those pertaining to the **consumption of INSPIRE data** and relevant to data users are shown. For each component, the logos of the most used software tools covering that specific functionality are included. Given the specificity of the INSPIRE requirements, all such tools have featured ad hoc developments usually as extensions of already existing geospatial software solutions.

At the bottom of the figure, the INSPIRE central infrastructure components (already described in *Section 2.2*) relevant to data provision and data consumption are shown.

Regarding data provision, the first type of tools covers those offering **Extract-Transform-Load (ETL)** functionality to produce harmonised INSPIRE datasets starting from raw geospatial data. These include e.g., the open-source HALE studio[21] and GeoKettle[22] (although the development of the latter has been discontinued since some years but the tool is nonetheless widely used), and the proprietary Feature Manipulation Engine (FME)[23]. The implementation of **discovery services**, used by EU Member States organisations to make their INSPIRE data discoverable, is performed using tools

21 *https://www.wetransform.to/products/halestudio*
22 *https://sourceforge.net/projects/geokettle*
23 *https://www.safe.com/fme*

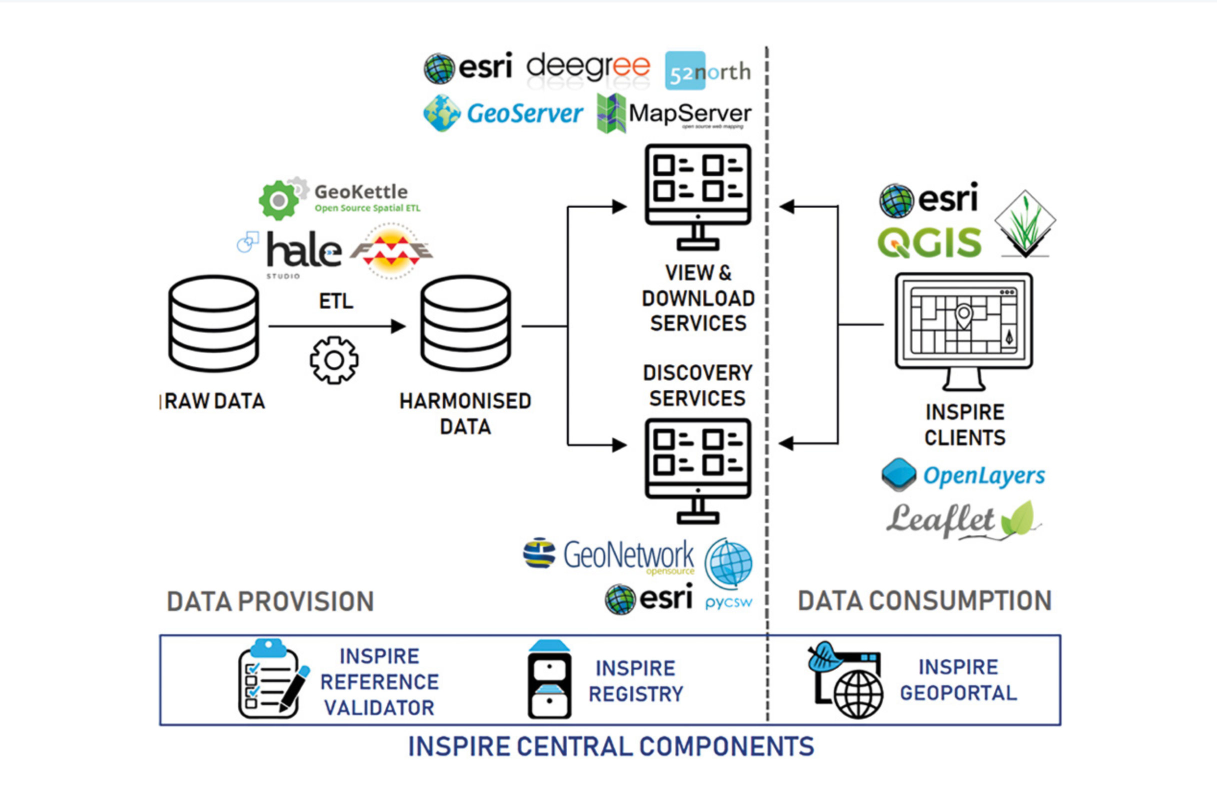


Figure 11. Overview of frequently used software tools for the provision (left) and the consumption (right) of INSPIRE data

Source: JRC, 2021.

Box 3

OSGeo's mission is to foster global adoption of open geospatial technology by being an inclusive software foundation devoted to an open philosophy and participatory community driven development. OSGeo actively supports interoperability with open formats, international and community standards. The Open Source Geospatial community is actively participating in the development of Open Standards through partnerships with OGC and ISO/TC 211. Specifically in Europe, the INSPIRE Directive has been widely supported and implemented using Open Source Software for over a decade. INSPIRE has provided OSGeo the opportunity to showcase the maturity and effectiveness of implementing open source solutions across the EU. OSGeo is a strong supporter and contributor of the evolution of the Open Geospatial Standards towards facilitating a more straightforward adoption, more developer friendly and modern approach, as demonstrated in the last couple of years with the evolution of the OGC API efforts. Members of JRC are valuable partners and members of the OSGeo Community and we look forward to continuing collaboration in the future.

The European Members of the OSGeo board.

such as GeoNetwork opensource[24], pycsw[25] and ESRI Geoportal Server[26]. They implement similar functionality consisting in editing, managing and publishing geospatial (including INSPIRE-compliant) metadata. According to the results of a survey made during the INSPIRE Geoportal workshop held at the JRC on January 23-24, 2019 with the Geoportal National Contact Points from Member States, two thirds of EU Member States discovery services are implemented using GeoNetwork opensource (JRC INSPIRE Team, 2019a). Like discovery services, INSPIRE **view and download services** can be also implemented using a variety of open-source and proprietary solutions. MapServer[27], deegree[28] and GeoServer[29] are traditional open-source tools to serve data through view and download services (although they are sometimes also used to implement discovery services), while ArcGIS for INSPIRE[30] is the proprietary counterpart provided by ESRI. 52° North SOS[31] provides a notable open-source implementation of an INSPIRE download service to serve sensor observation data. INSPIRE-compliant datasets and metadata make substantial use of the INSPIRE Registry (see ***Subsection 2.2.3***). It is a central component, which ensures consistency of the reference codes (e.g., code lists) used in the data resources. Metadata offered by discovery services, datasets served by download services, and the discovery, view and download services themselves can be checked for compliance using the INSPIRE Reference Validator (see ***Subsection 2.2.2***). Consumption of INSPIRE data can happen through a wide spectrum of tools. Desktop tools (depicted at the top right of ***Figure 11***) include for instance ArcGIS Desktop[32] and ArcGIS Pro[33], ESRI's proprietary desktop GIS solutions, and open-source alternatives such as GRASS GIS[34] and QGIS[35]. These software tools are able, either natively or through specific add-ons or plugins (e.g., the QGIS GML Application Schema Toolbox plugin[36] for QGIS, specifically developed for INSPIRE-related purposes) to read and consume INSPIRE datasets derived from view and download services or directly uploaded as GML files. Although the GML encoding is not ideal for data consumption on the web, INSPIRE view and download services can be also accessed through web clients (depicted at the bottom right of ***Figure 11***) such as OpenLayers[37] and Leaflet[38], the two most popular open-source libraries to develop Web maps. The reference client application to discover, access and download all the datasets published under INSPIRE is the INSPIRE Geoportal (see ***Subsection 2.2.1***).

3.4 Standardisation

While agnostic from the perspective of a particular technology, INSPIRE is strongly influenced by international standards such as the ones developed by the **Open Geospatial Consortium (OGC)** (see ***Section 2.1***), the **ISO Technical Committee 211 - Geographic Information (ISO TC/211) and the World Wide Web Consortium (W3C)**. For example, at the time of writing (August 2021) about one third of the MIG-T members are also members of the OGC. Multiple domain-specific standards such as e.g., the Darwin Core Archive (DwC-A) for species distribution, are reused by the

24 *https://geonetwork-opensource.org*
25 *https://pycsw.org*
26 *https://www.esri.com/en-us/arcgis/products/geoportal-server*
27 *https://mapserver.org*
28 *http://www.deegree.org*
29 *http://geoserver.org*
30 *https://www.esri.com/en-us/arcgis/products/arcgis-for-inspire*
31 *https://sensorweb.demo.52north.org/sensorwebtestbed*
32 *https://desktop.arcgis.com*
33 *https://pro.arcgis.com*
34 *https://grass.osgeo.org*
35 *https://qgis.org*
36 *https://plugins.qgis.org/plugins/gml_application_schema_toolbox*
37 *https://openlayers.org*
38 *https://leafletjs.com*

different data specifications. Standards are considered in INSPIRE as building blocks (see ***Figure 12***), minimising the need to develop own specifications. In addition to the obvious benefits for INSPIRE from the uptake of international standards, this approach has also benefitted standardisation organisations themselves, through the participation in technical committees, feedback from the implementation, and additional argumentation for public sectors to embrace standard-based approaches for data sharing. ***Figure 12*** shows how the approach undertaken for conceptualising the approaches in INSPIRE leverages on strategic partnerships and standards. In addition, multiple institutions that are represented within the INSPIRE governance structure, already described in ***Section 3.2***, are also members of standardisation organisations.

Some of the most prominent standards in use in INSPIRE are listed in ***Table 1***. The newly adopted process for introduction of new standards and approaches defined in ***Subsection 3.2.1*** provides a simple step-wise approach for accommodation of new standards that can help modernise the technical framework of INSPIRE. Examples of recently adopted good practices cover download services: (SensorThingsAPI and OGC API - Features, see also ***Section 6.2***), data encoding (Statistical Data and Metadata Exchange - SDMX[39]), and metadata (GeoDCAT-AP[40], an extension of the DCAT application profile for European data portals – DCAT-AP).

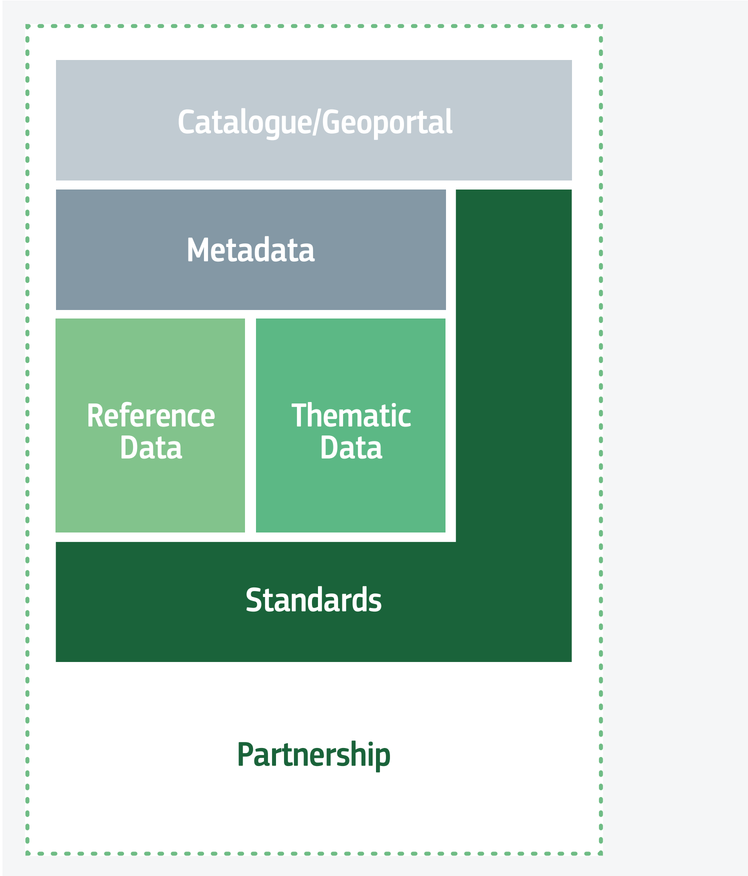


Figure 12. Key role of standardisation in the INSPIRE framework

39 *https://sdmx.org*
40 *https://semiceu.github.io/GeoDCAT-AP/drafts/latest*

Table 1. Most prominent standards used in INSPIRE

Standard	Description	Application
ISO 19115/19119 - Geographic information — Metadata	Schema for describing geographic information and services	metadata
ISO 19139	XML Schema implementation derived from ISO 19115	metadata
ISO 19103 – Geographic information – Conceptual schema language	Specification of data types used for describing geographic information	Data specifications
ISO 19131 – Geographic information – Data product specifications	Elements of data specifications	Data specification
GeoDCAT-AP	Extension to the DCAT application profile for European data portals for the representation of geographic metadata	metadata
OGC Geography Markup Language (GML)	XML-based encoding for geographical features	Data encoding
GeoJSON	JSON-based encoding for geographical features	Data encoding
ISO 19156 Observations and Measurements (O&M)	Conceptual schema encoding for spatio-temporal observations	Data encoding
OGC Catalogue Service for the Web (CSW)	Web interface for discovery, browsing, and query of metadata	Discovery service
OGC Web Map Service (WMS)	Web service for requesting spatially-referenced images	View service
OGC Web Map Tile Service (WMTS)	Web service for spatially-referenced map tiles	View service
Atom Syndication Format	XML-based data and metadata syndication format	Download service
OGC Web Feature Service (WFS)	Download service for access to feature data	Download service
OGC Web Coverage Service (WCS)	Download service for access to coverage data	Download service
OGC API – Features	Multi-part API-based standard for sharing geospatial features	Download service
OGC SensorThings API	API-based standard for sharing of spatially-enabled IoT data	Download service

3.5 Community

Built around consensus (Cetl et al., 2017), the technical stack of INSPIRE is meant to accommodate the perspectives and preferences of the different stakeholders with an interest in location data. By design, the governance of INSPIRE through the established Maintenance and Implementation Group (MIG) and its permanent technical sub-group (MIG-T) ensure the smooth coordination across the different levels. Considering the substantial number of stakeholders involved on a voluntary basis, the development of the infrastructure and the **engagement of stakeholders** can be considered as a leading practice in policy and technical development. From a community perspective, a lesson learned in the INSPIRE implementation process is that a technical infrastructure is only as good as the social infrastructure that underpins it (see ***Figure 13***).

Box 4

*In the Netherlands the INSPIRE Directive has led to the creation of **www.pdok.nl**, a national data platform for open spatial data. With a steady growth (2013: 500 million hits; 2020: 30 billion hits), it now fuels data-driven solutions for a wide variety of societal challenges (e.g., it serves over 15.000 websites).*

Geonovum

Figure 13. Attendees of the INSPIRE Helsinki 2019 conference

Source: National Land Survey of Finland, 2019.

A European **INSPIRE conference** has been held for 13 consecutive years, from 2007 to 2019 (see *Figure 14*) – although the 2019 event[41], organised in Helsinki, was not an official INSPIRE conference. Due to the COVID-19 restrictions, virtual events were held in 2020[42] and 2021[43]. The INSPIRE conference provides a forum for stakeholders from government, academia, and industry to hear about and discuss the latest developments related to data-driven innovation and the INSPIRE Directive. This conference provides an excellent opportunity to present Europe's data landscape to the community and relevant developments in national SDIs. The conferences are organised through a series of plenary sessions addressing common policy issues, which are complemented by parallel sessions and workshops focusing on applications and implementations of SDIs, research issues and new and evolving technologies and applications. The next INSPIRE conference, COVID-19 permitting, will be held in Dubrovnik, Croatia in the spring of 2022.

41 *https://www.inspire-helsinki-2019.fi*

42 *https://inspire.ec.europa.eu/conference2020*

43 *https://inspire.ec.europa.eu/conference2021*

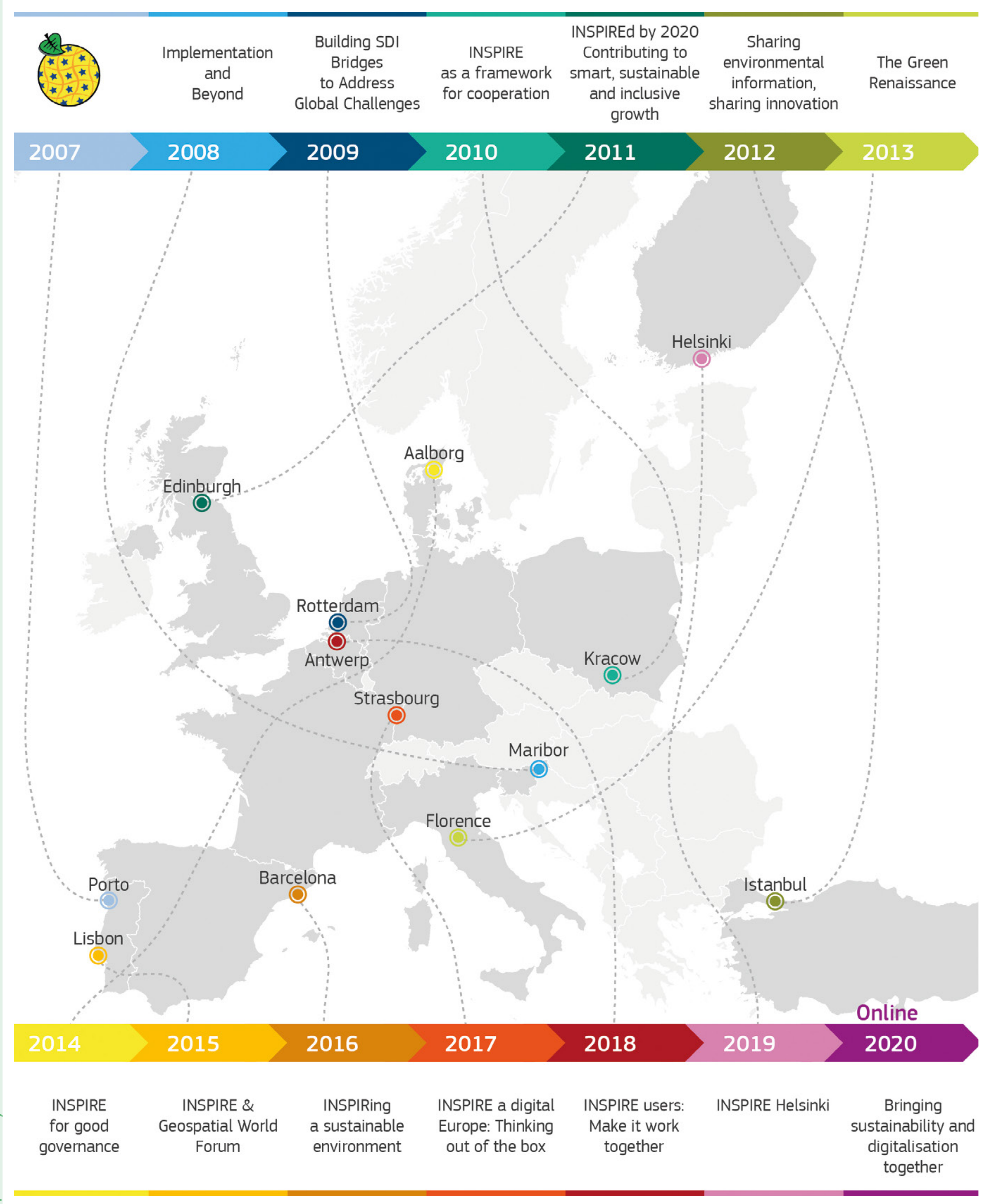


Figure 14. Years, locations and mottos of the INSPIRE conferences from 2007 to 2020

4

Lessons learned

In this section, we present selected lessons learnt from the implementation of INSPIRE. Emphasis is put on the technological and organisational lessons. The legal dimension is out of the scope of this report, so we do not cover here issues such as the Directive transposition and subordination with national legislation.

4.1 Improved data discoverability and availability

The number of INSPIRE datasets described by metadata and made available through national discovery services has been gradually growing (see ***Figure 15***). This development has brought multiple benefits. Firstly, through the metadata, it became clearer what environmental geospatial data was available across Europe.

Secondly, the improved transparency and availability of metadata has also shown many cases of inefficiencies, gaps and overlaps in the production of datasets. Some countries have seized the opportunity and have improved their national structures, including the roles and responsibilities of the different data providers.

Thirdly, the availability of the discovery services provided an opportunity to reuse the geospatial catalogues in different open data portals at the national and European levels – an example of the latter case is the recent *data.europa.eu*[44] portal (see ***Figure 16***). We have witnessed multiple examples of such reuse in different contexts (e.g., the establishment of domain-specific portals), or on the international level.

4.2 Parallel implementations

Despite the explicit requirements of the Directive, many EU Member States share only a limited number of datasets within the INSPIRE infrastructure because they would like to avoid setting up network services for all existing datasets and harmonise them according to the Implementing Rules on data interoperability. In several countries, there is a policy to share and harmonise only datasets aggregated at national or regional level (often one dataset per INSPIRE theme or application schema), despite the fact that also the source data is in scope of the Directive. This causes the problem at the European level: **the data** (themes, spatial object types, but also scale and data quality) that are shared through services and in compliance with the Implementing Rules on interoperability **are different across EU Member States**. This results in a patchwork of data available in the INSPIRE infrastructure and makes it difficult to achieve pan-European coverage for specific themes. In addition to that, **most EU Member States provide INSPIRE datasets and services as a standalone activity** that is only marginally linked – instead of being built upon – the national infrastructure (see ***Figure 17***). Often this is done as a one-off activity, and the national SDI is used only in a limited way, often supplying access to (a subset of) the metadata available in the national catalogue. This is because INSPIRE requirements are different, more limited or go beyond the requirements adopted at the national level. For example, the INSPIRE data models may be simpler than the national models, the INSPIRE-recommended formats (such as GML) may not be considered relevant by national users or INSPIRE may require additional service metadata that are not included in common standards and hence are not provided by the (off-the-shelf) software used at national level.

44 ***https://data.europa.eu***

Furthermore, when EU Member States are providing separate INSPIRE datasets and services, they usually pay little attention to their usability. For example, INSPIRE services may be set up to serve huge amounts of datasets or layers, or the services may not be actively quality-controlled or monitored and hence might be often down or poorly performant. This makes them difficult to use in any practical application.

4.3 Technological innovation

Multiple technologies are involved in the implementation of INSPIRE both on the client, but also on the provider end. The most prominent tools in use were already described in ***Section 3.3***. Responding to the legal obligations, INSPIRE stakeholders have supported the **evolution and development of many open-source geospatial tools**. Looking for example into the software projects governed by the Open Source Geospatial Foundation (OSGeo)[45], there is hardly any product that has not considered implementing certain functionality that somehow relates to INSPIRE. From that perspective, the entry into force of the legal framework has acted as a catalyst for innovation in the open-source world (see e.g. ***Figure 18***).

In addition, central INSPIRE components (see ***Section 2.2***) that were developed to satisfy concrete needs of the infrastructure have also been released under open-source licenses and have been reused by different EU Member States. For instance, in addition to the INSPIRE implementation, the Re3gistry software (see ***Subsection 2.2.3***) has been reused so far in different contexts[46] (see ***Figure 19***), including:

- National-level deployments: Austria[47], Finland[48], France[49], Italy[50], Slovakia[51], Spain[52], the Netherlands[53] and North Macedonia[54]
- EU-funded projects: ELISE Energy pilot[55], GO-PEG[56]
- Private sector: Minerva Intelligence[57]

4.4 Custom extensions are problematic

In the conceptualisation of INSPIRE, it was assumed in multiple cases that requirements which were during the scoping stage not supported by software tools and libraries would be implemented once proposed and endorsed by INSPIRE. Unfortunately, this rarely happened. Typical examples in this respect are (1) support for complex GML and XML attributes in desktop GIS clients, and (2) extended capabilities of INSPIRE network services. In both cases, those requirements have been to a large extent difficult to implement, but also not very well supported by clients and servers. That is why, it would be important to **align technical requirements as much as possible to functionalities that are already supported (out-of-the-box) by existing tools**. In addition, requirements that satisfy the needs of a particular 'niche' (e.g., exposing the same dataset in more than one natural language) often create an implementation overhead with little value added for most users and should ideally be avoided whenever possible.

4.5 Flexible governance approaches

45 *https://www.osgeo.org*
46 *https://ec.europa.eu/isa2/solutions/re3gistry_en*
47 *https://registry.inspire.gv.at/registry*
48 *http://luettelopalvelu.fi/registry*
49 *https://data.geoscience.fr/ncl/*
50 *https://registry.geodati.gov.it/registry*
51 *http://registre.enviroportal.sk/geo*
52 *https://registro.idee.es/registry*
53 *http://inspireregister.nl/codelijst*
54 *https://nipp2.katastar.gov.mk:5003/nipp3/registry*
55 *https://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/registry*
56 *http://locationintelligence.epsilon-italia.it/registry/GO-PEG*
57 *http://minerva.codes/registry*

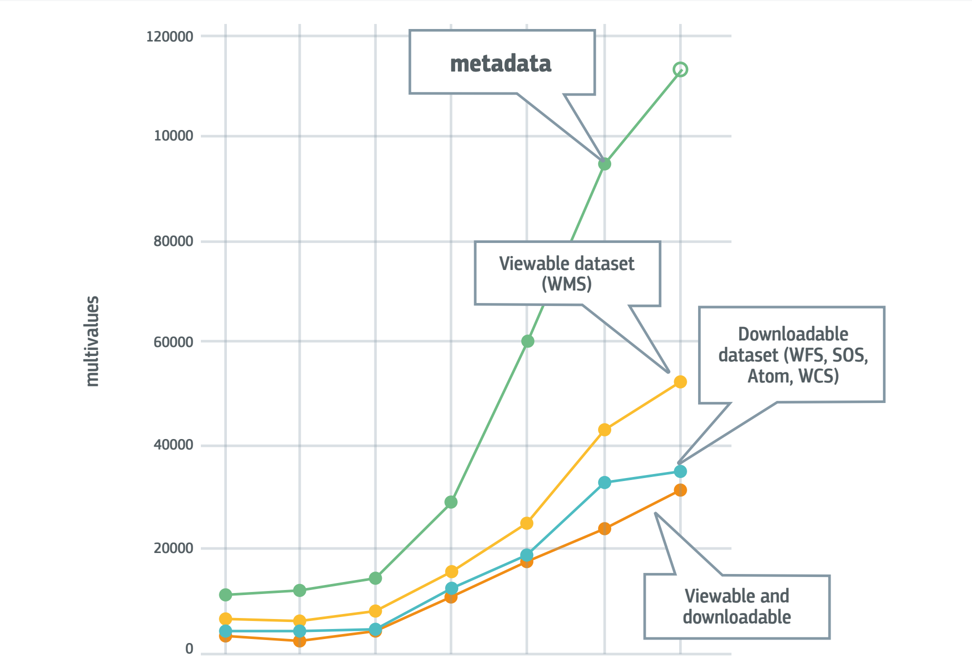


Figure 15. Improved data availability in the INSPIRE infrastructure (2007-2018)

Source: European Environment Agency, 2018.

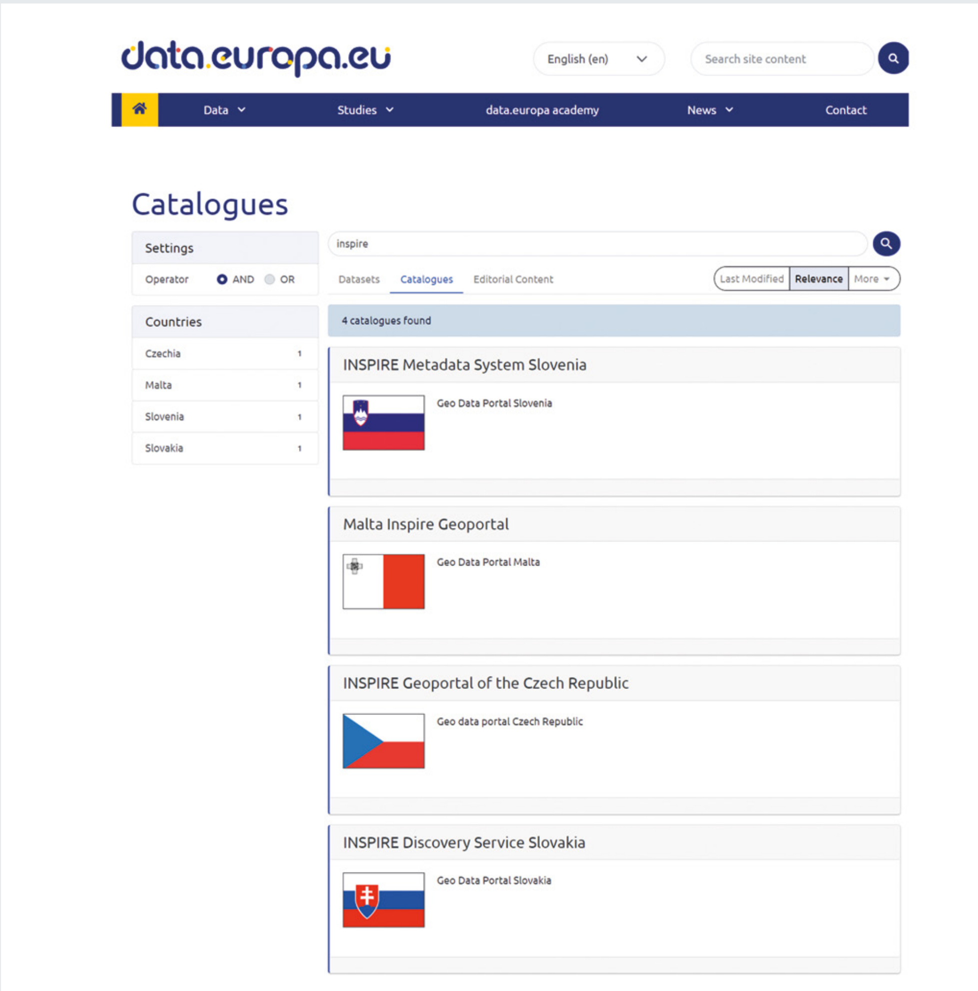


Figure 16. INSPIRE catalogues reused in the data.europa.eu portal

Source: data.europa.eu portal, 2021.

Box 5

The INSPIRE Directive represented the guiding regulatory framework for spatial data sharing in Italy within the wider policies on digital government. Policy and technical documents issued by (or with the contribution of) the Agency for Digital Italy (AgID), such as the Three-Year Plan for ICT in Public Administration and the new national strategy for data, deeply anchored in the INSPIRE principles. In this context, important investments were made to improve the discoverability, accessibility and interoperability of public information resources including spatial data, e.g. by creating a national data catalogue; reusing and extending INSPIRE data models and metadata encoding rules; making spatial datasets discoverable through both general data portals and web search engines; and creating a national registry (included in the INSPIRE register federation) through the reuse of the Re3gistry software.

Antonio Rotundo, AgID – Servizio Banche Dati e Open Data

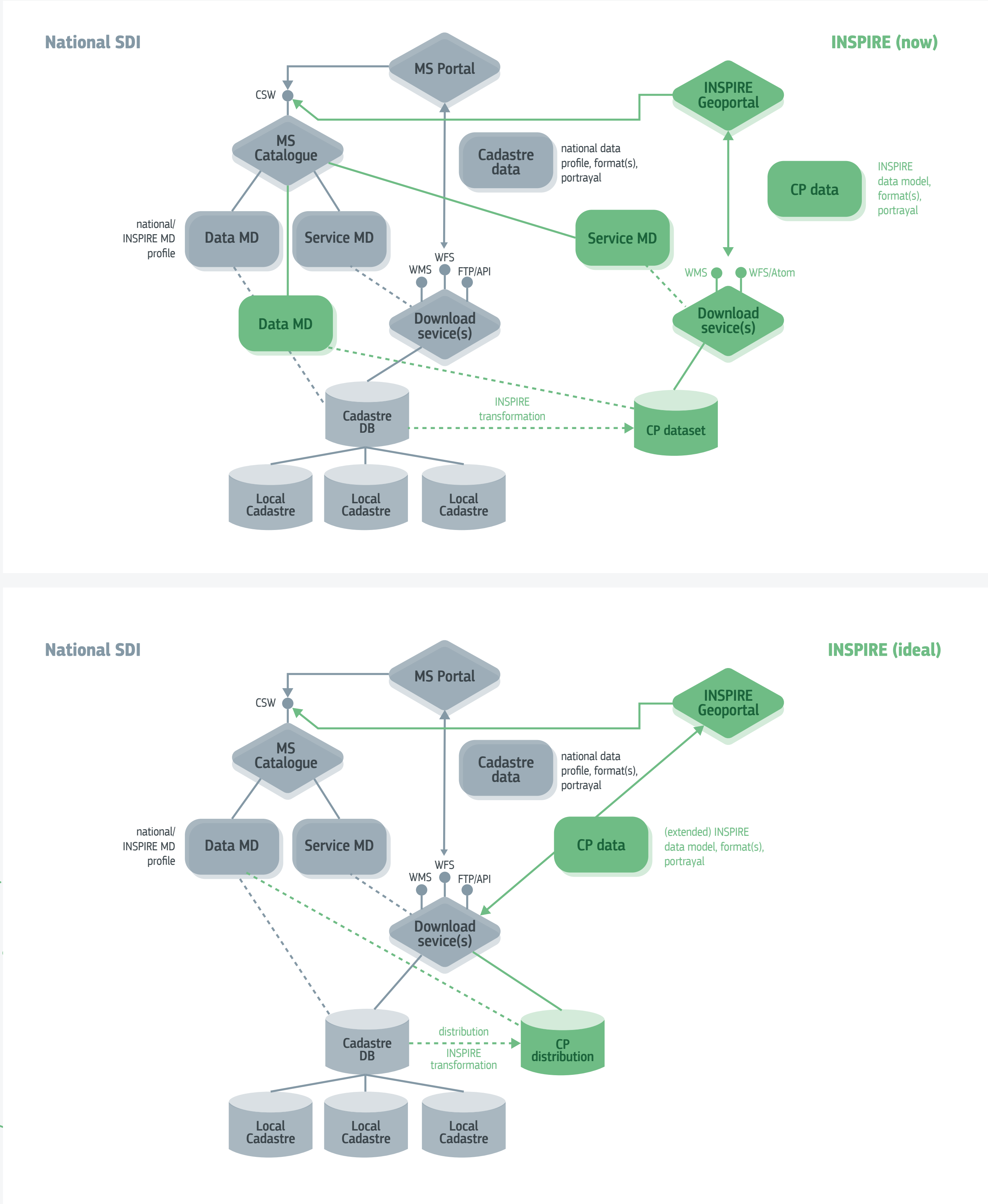


Figure 17. INSPIRE implementation resulting in a parallel infrastructure (top) vs. ideal INSPIRE implementation building on the national infrastructure (bottom) (example with Cadastral Parcels data)

Source: JRC, 2019.

Figure 18. Frequency and occurrence of INSPIRE-related topics on the OSGeo wiki page[58] and related sub-pages.

INSPIRE was conceptualised with an inclusive and open approach in mind. In fact, collaboration on multiple levels between a broad spectrum of users is critical to the overall success of the implementation. The existing governance structure with the technical and policy arms of the INSPIRE MIG ensures that the different organisational, legal and technical questions are being addressed by the right fora. However, the multi-level structure of the MIG, represented exclusively by data providers, has not always been flexible and fast in accommodating novelties. The endorsement of more **agile approaches, supported by the increased use of online collaborative platforms for co-creation of content** (e.g., technical guidelines, software solutions, good practices) would help modernise the way in which the infrastructure is governed.

58 *https://wiki.osgeo.org/wiki/Main_Page*

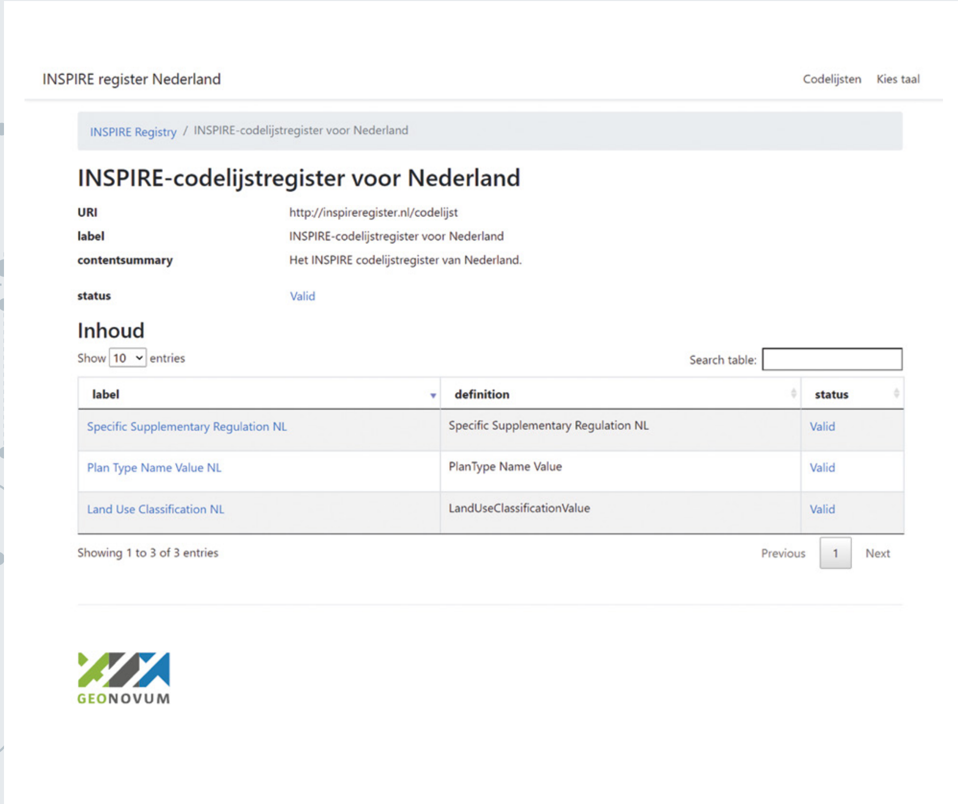
4.6 Impact of standardisation

As outlined in *Section 2.1*, INSPIRE is not a standalone activity but is based on several cross-cutting and domain-specific standards (e.g. from ISO and OGC). In particular, the implementation of the Directive has led to probably the **largest uptake of the OGC standards worldwide**. That approach has benefited both the standardisation organisations themselves (through the uptake and improvement of their standards), as well as the data users and providers (through the streamlined processes of encoding, sharing and use of the data). However, at the same time **the strong utilisation of particular standards has sometimes created problems**, particularly related to slowing down the processes of implementation because of inherited dependencies, but also due to the mismatch between the standards and their software implementations. From that perspective, it is critically important to ensure that mature and well supported standards are considered for the technical provisions related to the evolution of INSPIRE. Considering the high level of availability and maturity of different software tools for extracting, transforming and loading data (ETL), having more than one standardisation approach for implementing the same functionality seems an increasingly feasible option. Finally, standards that are supported should ideally not only be capable of satisfying the legal requirements, but also add value to the technological stack of data providers, and ultimately to make it easier for users to utilise the data.

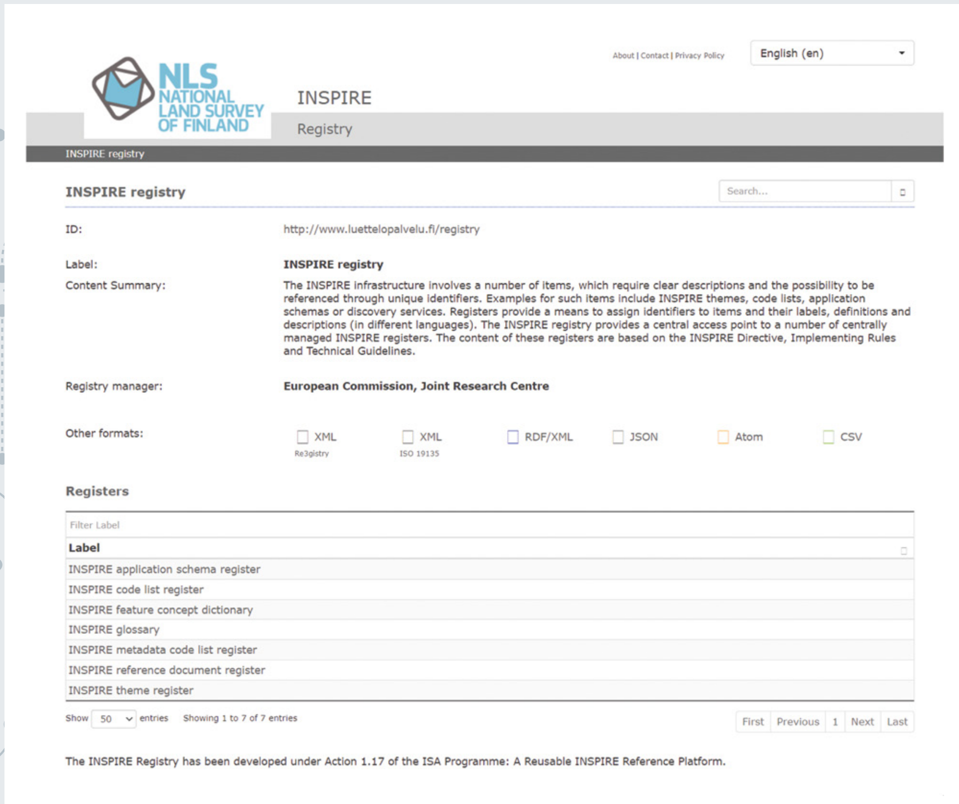
4.7 Heterogeneous approaches to licensing exist

A quick analysis of the licensing approaches from the INSPIRE Geoportal, i.e., based on the metadata made available by EU Member States shows that countries, but also individual data providers apply quite heterogeneous approaches. Even more substantially, in a vast majority of cases, licensing information is not available at all (JRC INSPIRE Team, 2019b). This lack of consistency and **the absence of harmonisation poses a serious obstacle to the uptake and reusability of the data**. Overcoming this would require the establishment of a coordinated common European approach/framework for the licensing of the data. The envisaged high-value datasets as defined in the Open Data Directive (see ***Section 5.3***) can provide a model which can then be scaled across the whole infrastructure. Ideally, those datasets should be made available free of charge, in a machine-readable format and through the metadata, but also through the services that are exposing the data.

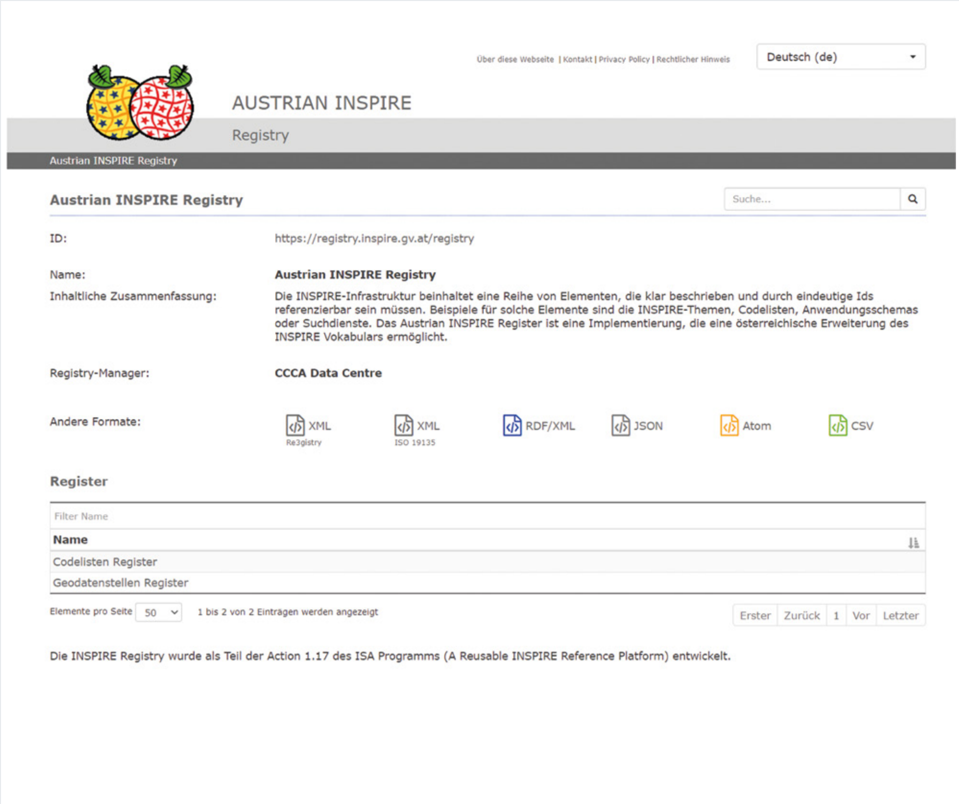
Instances (a)



Instances (c)



Instances (b)



Instances (d)

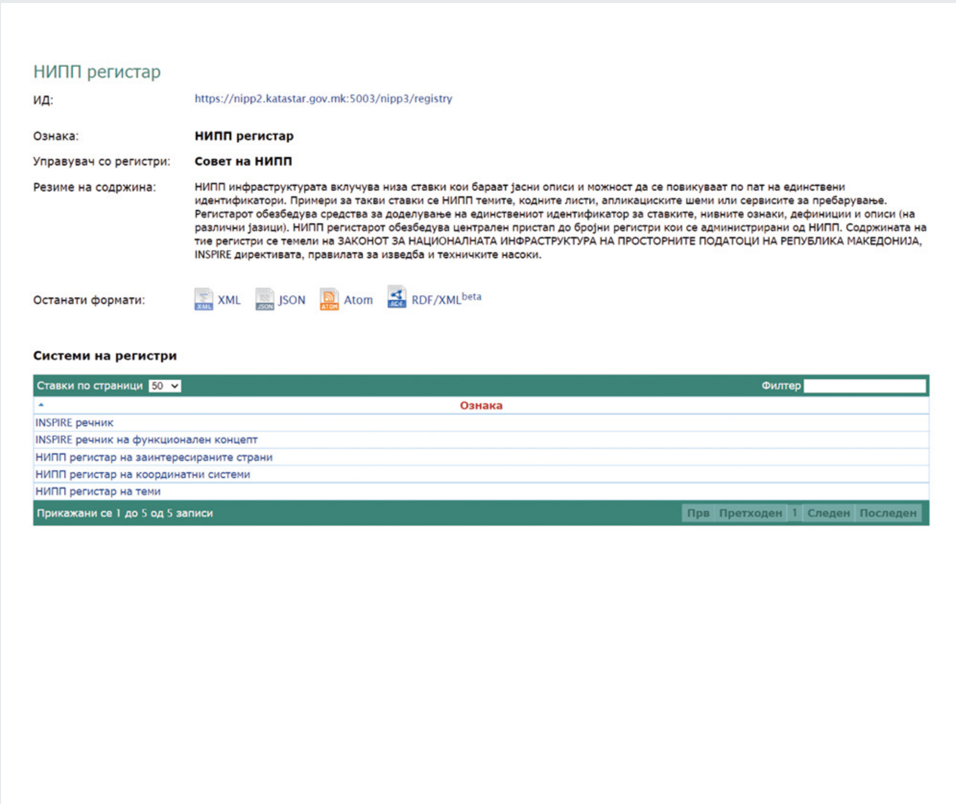


Figure 19. Instances of the Re3gistry software deployed in: the Netherlands (a), Austria (b), Finland (c), North Macedonia (d)

Source: JRC, 2021.

5

Policy context

The EU has recently embarked on a **green and digital transition**. The two dimensions are closely interrelated, and the Commission has taken the lead to drive these transitions and to focus investments on recovery and resilience efforts in these areas. The 2019 **European Green Deal**[59] recognises the potential of digitalisation to achieve the environment and climate aims and the necessity to explore sustainable digital technologies as essential enablers for a just green transition. In February 2020, the Commission adopted its new digital strategy titled 'Shaping Europe's Digital Future' (European Commission, 2020b) along with its first two pillars: the European Strategy for Data (European Commission, 2020a) and a White Paper on Artificial Intelligence (European Commission, 2020c). The European Strategy for Data (European Commission, 2020a) sets a vision for a transition to a healthy planet and a new digital world. It emphasises the need for the twin challenge of a green and digital transformation, and points to the digital component as a key in reaching the ambitions of the European Green Deal. It also recognises that digitalisation contributes to environmental degradation e.g., through high energy and resource use and that these impacts need to be reduced. The Strategy also recognises the need to make data available for the public good. Among other uses, the Data Strategy indicates that data can serve to address societal challenges, combat environmental emergencies and tackle environmental degradation and climate change. It sets an objective to capture the benefits of better use of data. Ensuring the availability of data and improving data usage are essential for tackling these societal, climate and environmental challenges.

59 *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en*

The **White Paper on Artificial Intelligence** (European Commission, 2020c) acknowledges the potential of Artificial Intelligence (AI) to find solutions to societal challenges such as environmental degradation. However, AI technology also has a significant environmental footprint. The environmental impacts of AI systems throughout the whole AI lifecycle are addressed in the **Coordinated Plan on Artificial Intelligence** (European Commission, 2018a). Finally, the recent update to the **2020 New Industrial Strategy** (European Commission, 2021a) points to the twin ecological and digital transitions and the role of innovative technologies in supporting a sustainable transition. The Industrial Strategy also indicates the need for investment and innovation to deliver these innovative technologies. It also illustrates the significant business opportunities in these areas.

Reacting to the Commission's initiatives, the **2020 Environment Council conclusions** on *digitalisation for the benefit of the environment*[60] recognises the enormous potential digitalisation offers in reaching the goals of the European Green Deal. In its conclusions, the Council concurs with the Commission on the potential of the twin green and digital transition and emphasises it is a necessary approach to economic recovery after the COVID-19 pandemic. The conclusions stress an inclusive digital transition which limits the negative impacts of digitalisation while fully exploiting the opportunities that digitalisation brings. The conclusions also point to topics where the EU needs to act to best achieve the twin transition, giving the Commission policy guidance on areas in need of specific attention. The conclusions also highlight

60 *https://www.consilium.europa.eu/en/press/press-releases/2020/12/17/digitalisation-for-the-benefit-of-the-environment-council-approves-conclusions*

that reliable, accessible, comparable, high quality and up-to-date data is required for:

- fact-based EU environmental policy;
- data-driven solutions for environmental protection;
- low-bureaucracy and user-friendly implementation of EU environmental law; and
- effective monitoring of its progress and results.

Moreover, the Council conclusions encourage the Commission to set up a dedicated technical forum between Member States and the Commission to facilitate the use of digital technologies and innovative methods for monitoring biodiversity, ecosystems and general environmental monitoring and reporting. At the same time, they propose to adjust the legal monitoring requirements to embrace modern technologies and promote active dissemination of environmental information at European and national levels that facilitates access to the right information in the right form at the right time.

We are on a turning point in the digital transition where the way we work with data is changing rapidly. The old practices of preparing dedicated packages of information for dedicated processes is increasingly being replaced by more active data sharing through data services, as envisaged and promoted through data sharing and interoperability frameworks such as:

- the **INSPIRE Directive** (European Union, 2007), which is currently under evaluation with a possible revision in 2022;
- the **Directive on public access to environmental information** (European Union, 2003b), which can be reviewed together with the INSPIRE Directive in 2022;
- the **Open Data Directive** (European Union, 2019) and its upcoming implementing act on high-value datasets, which maximally reuses the INSPIRE Directive (see *Section 5.3*);
- the abovementioned **European Strategy for Data** (European Commission, 2020a) and its common European data spaces as overarching data sharing framework, including data from public administrations, businesses, research, and citizens (see *Sectiion 5.1*);
- the **European Interoperability Framework (EIF)** (European Commission, 2017) that is under revision; and
- the **Copernicus programme** (see *Subsection 6.1.3*).

Technologies such as geospatial intelligence (exploitation and analysis of geospatial data), Internet of Things (sensors) and Artificial Intelligence (simulation of human intelligence in machines) are being explored to assess the possibility of using alternative sources of data to reduce administrative reporting burden and get access to more exhaustive and timely if not real-time data to build our evidence bases.

5.1 European Strategy for Data

The European Strategy for Data (European Commission, 2020a) provides a high-level vision for the establishment of a single market for data in Europe through the definition and elaboration of large, sector-specific though interconnected data spaces (see *Figure 20*). Such an approach will ensure Europe's global competitiveness and data sovereignty.

The aim of the European Strategy for Data is to create **a common European data space** – a genuine single market for data, open to data from across the world – where personal as well as non-personal data, including sensitive business data, are secure and businesses also have easy access to an almost infinite amount of high-quality industrial data, boosting growth and creating value, while minimising the human carbon and environmental footprint. To get there, the strategy announced the development of nine **common European data spaces in strategic economic**

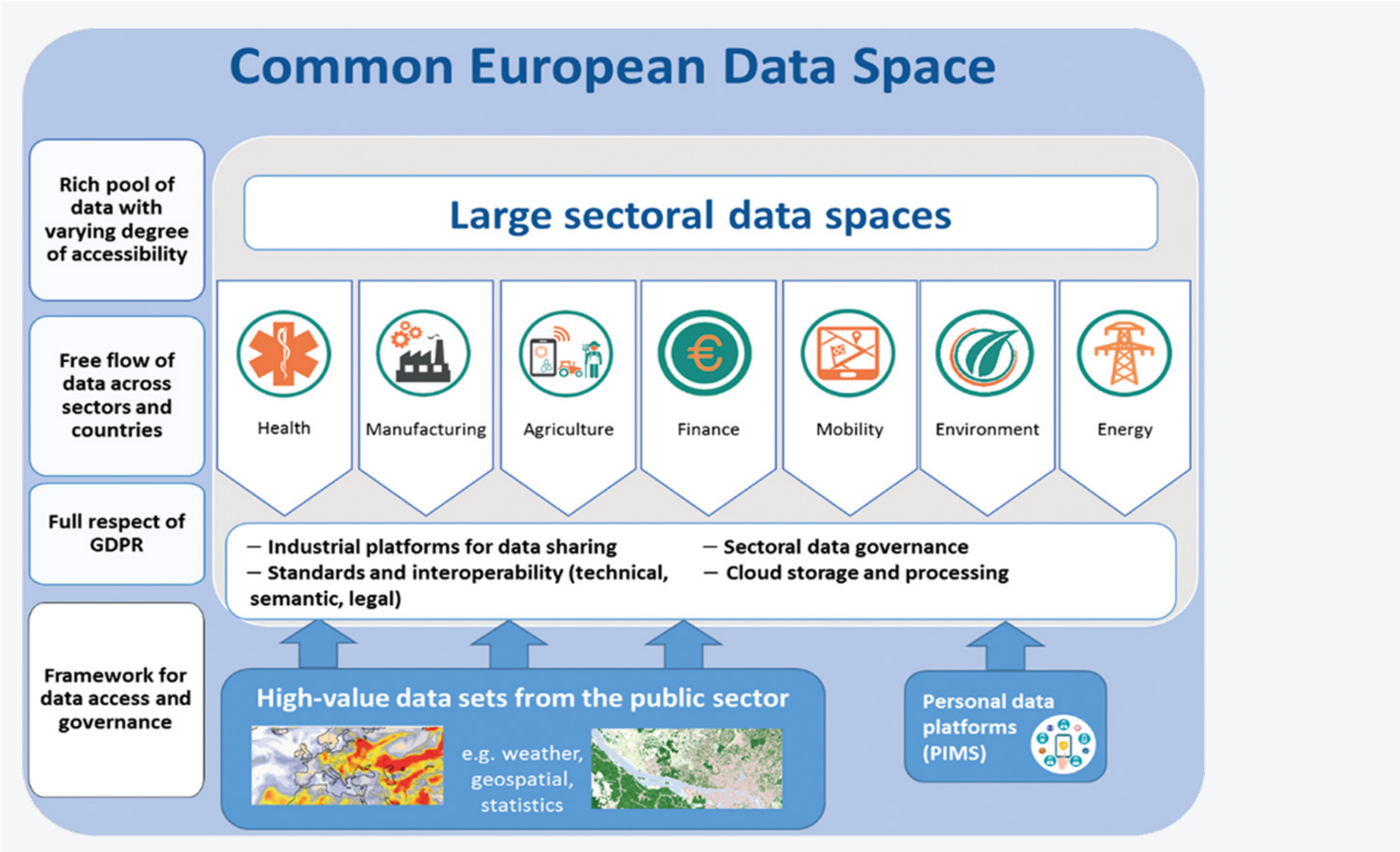


Figure 20. High-level architecture of the envisioned common European data space

Source: European Commission, 2019.

sectors and domains of public interest, where the use of data will have systemic impact on the entire ecosystem and on citizens. Considering the prominent role of the environment among the top policy priorities of the European Commission, a significant role in the European Strategy for Data is dedicated to the Green Deal Data space.

The concept of a data space includes a horizontal framework for data governance (i.e. a legal component, covering, for example data access and usage rights). It has a certain **data infrastructure** (i.e. a technical component, including, tools for data pooling and sharing, IT capacity for (cloud) storage and processing, and technical standards ensuring interoperability). Such a data space contains a rich pool of data with varying degrees of accessibility and allows for the free flow of data across sectors and countries, in full compliance with the General Data Protection Regulation (GDPR) rules (European Union, 2016). There is no "one-size-fits-all" format for the common European data spaces. They will each need to follow an approach that is well suited to their specific sector/domain and its characteristics.

The new **Digital Europe Programme (DIGITAL)**[61] will provide the necessary support to the development of sectoral data spaces. An important horizontal support action of the first DIGITAL Work Programme (WP) 2021-2022 is setting up and operating a **Data Spaces Support Centre**. Its objective is to coordinate all relevant actions on sectoral data spaces and make available technologies, processes, standards, and tools that will allow reuse of data across sectors by the public sector and businesses. The DIGITAL will also invest

61 *https://digital-strategy.ec.europa.eu/en/activities/digital-programme*

in a cloud-to-edge infrastructure, which is very important for the development of the data spaces. A **Common Services Platform (CSP)** will be also introduced with the aim of boosting the uptake and ensuring the sustainability of interoperable and reusable digital components. The open source tools underlying the INSPIRE central infrastructure components (see *Section 2.2*) are among the candidate technologies to be included in the CSP.

Two main initiatives have been selected under the DIGITAL for the first two years (2021-2022): Destination Earth and the local data ecosystem for climate-neutral and smart communities. To complement the work during the first two years, a Coordination Action on Digital Product Passport will prepare the ground for a future common European data space for smart circular applications.

The legislative instruments put forward within the context of the European Strategy for Data are already being conceptualised and are on a different stage of development. *Figure 21* summarises the different legal acts, alongside the problem that they are tackling, who holds the data, and what is the envisioned policy intervention.

5.1.1 The European Green Deal data space

As mentioned above, the European Strategy for Data specifically supports the Green Deal ambitions through the development of a **common European Green Deal data space**. The development of this data space will be supported by two pilots on circular economy (product passport) and zero pollution, GreenData4All (evaluation and review of the INSPIRE Directive and to some extent Directive 2003/4/EC on public access to environmental information) and Destination Earth[62], i.e. a digital twin

62 *https://ec.europa.eu/digital-single-market/en/destination-earth-destine*

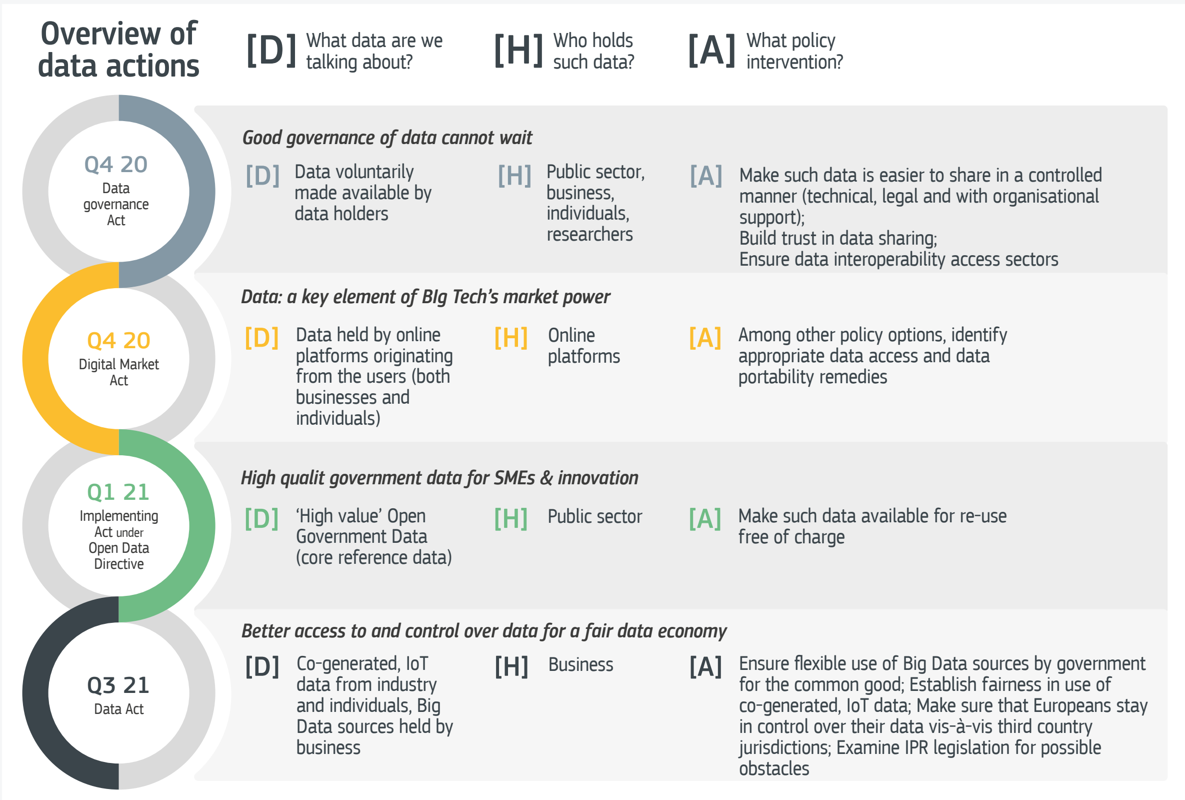


Figure 21. Legislative framework for the implementation of the European Strategy for Data

Source: European Commission, 2020.

of the Earth to support prediction of behaviour of ecosystems. This common data space should make environmental data from the public, private and academic sectors and from citizens accessible for reuse by others to boost the data economy and improve policy implementation and development. To safeguard the rights of the data providers, this data space should be governed by a principle of EU-wide **data sovereignty**. It means that users only get access to the data in line with the ruling reuse conditions and for the use as intended. Some of these reuse mechanisms have been articulated in the **Data Governance Act** that was proposed in 2020 (European Commission, 2020d).

5.2 GreenData4All

The main pillar for bringing data from public administrations into the Green Deal data space is the INSPIRE Directive (European Union, 2007) together with the Directive on public access to environmental information (European Union, 2003b). The importance of this existing environmental data sharing framework was recognised by the European Strategy for Data and articulated in the **GreenData4All initiative.** This will be the centrepiece action to evaluate and possibly review the INSPIRE Directive and selected articles of the Directive on public access to environmental information to bring the legal framework into the 21st century and up to speed with contemporary and cutting-edge technology (see ***Section 6***). This ambition is strengthened by the excellent collaboration between the Commission Services working on the implementation of the INSPIRE Directive and on the development of new data legislation. The collaboration already resulted in a converging strategy as part of the implementing act on the high-value datasets to make data in scope of INSPIRE available as open data for public reuse (see ***Section 5.3***). This will form the basis for the implementation of the public data part of the Green Deal data space.

Through the GreenData4All initiative, the Commission also aims to provide support to the **EU Strategy on Adaptation to Climate Change** (European Commission, 2021b) by extending the scope of environmental data sharing to also include climate-related data as was already intended by the Art. 191(1) of the Lisbon Treaty (Treaty on the functioning of the European Union) (European Union, 2012). It will be explored if the legal framework can be amended to include specific spatial data in support of combating climate change.

Another strand of work under GreenData4All is the collaboration with the agricultural domain on sharing data managed by the **Common Agricultural Policy (CAP)** paying agencies in the EU Member States as part of the mandatory Integrated Administration and Control System (IACS). It will be explored how the INSPIRE Directive can be used as an enabling instrument to effectively organise and implement data sharing across different domains. IACS data sharing will provide the **common European agriculture data space** with essential public agricultural data that will support policy development and the implementation of the Farm to Fork strategy[63]. Moreover, the availability of this data will be essential for monitoring and reaching environmental (Green Deal) objectives set out in biodiversity, food security, farm to fork and even zero pollution strategies. The work will provide guidelines on optimising the discoverability and the reuse of agricultural data, building on the experience with INSPIRE implementation and existing IACS data sharing practices in the EU Member States. The INSPIRE central infrastructure components (see ***Section 2.2***) will incorporate new features to reflect this extended scope, in particular new codelists and related values will be included in the INSPIRE Registry to make agricultural datasets discoverable, and new filters based on those keywords will be introduced in the INSPIRE Geoportal to provide access to those data.

63 ***https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en***

5.3 Open Data Directive and high-value datasets

The push towards more open data, active dissemination and reuse is embodied in the **Open Data Directive** (European Union, 2019), which was a recast of the former Public Sector Information Directive (European Union, 2003a). The Open Data Directive introduces the notion of **high-value datasets**, i.e. datasets whose reuse is associated with important benefits for economy and society. To facilitate the reuse of such datasets and maximise their impact, the Directive requires Member States public authorities to make high-value datasets available free of charge, in machine-readable formats, under standardised open access licenses that allow generous reuse conditions (including e.g. for commercial purposes). Such datasets are to be made accessible through both Application Programming Interfaces (APIs) and bulk download. The Open Data Directive does not yet provide the full list of high-value datasets, but only the 6 thematic categories they belong to (included in Annex I of the Directive), i.e. *Geospatial, Earth observation and environment, Meteorological, Statistics, Companies and company ownership, and Mobility*.

At the time of finalising this report (August 2021), the Commission is working on an implementing act on high-value datasets (with adoption expected between the end of 2021 and beginning of 2022) that will lay down the full list of high-value datasets. The implementing act will rely heavily on the INSPIRE Directive, both in terms of the actual datasets and their modes of provision (data formats, metadata information, licensing, etc.) for the definition of high-value datasets in the thematic categories *Geospatial, Earth observation and environment and Mobility.* Some datasets already made available by Member States data providers under several INSPIRE data themes (from all INSPIRE Annexes) falling under the three abovementioned categories will be also part of the high-value datasets. Overall, the key impact of the Open Data Directive on INSPIRE will be the **publication of (many) INSPIRE datasets under open data licenses**, which would in turn increase the exploitation of the overall infrastructure.

6

Technology trends

In this section, we provide a short overview of relevant emerging technology trends that, when combined, to a large extent define the bounding conditions for the evolution of SDIs. In describing those we consequently focus on (1) new data sources that can complement and even in some cases substitute data that is traditionally provided by the public sector, (2) modern means for exposure of the data in a developer-friendly manner, (3) the impact of platforms on the architectures of data infrastructures, and finally (4) the role of analytics and location intelligence built on top of existing data. Failing to consider those would lead to SDIs becoming a big silo, and even being considered obsolete in the long term.

6.1 New data sources

6.1.1 Internet of Things

An ever-increasing number of heterogeneous devices are connected to the Internet and are capable of producing increasing volumes of different data (Swan, 2012). This development has profound implications on all actors in the data economy, including the public sector. With the rise of 5G networks and a low cost of hardware components, the number of sensors and the data they produce are only expected to grow. This provides unprecedented opportunities for densifying existing monitoring networks and collecting data with a precision and spatial resolution that were unthinkable only several years ago. That is why, the rise of the Internet of Things (IoT) has a direct influence on the data ecosystem dynamics, architectures, tools and standards, and ultimately poses new challenges and opportunities for the use of the data. A debate on the advantages and issues related with the uptake of the IoT concretely within the context of geospatial applications is provided by Granell et al. (2020).

6.1.2 Citizen-generated geospatial data

The major technological changes occurred in the geospatial domain during the first decade of the 2000s, mainly the spread of GPS-enabled mobile devices and the availability of high-resolution satellite imagery at low cost, have seen a new player – the crowd – become a major producer of geospatial information, thus challenging the traditional role of the public sector. Citizen-generated geospatial data is nowadays referred to through multiple terms. The first one to be coined was Volunteered Geographic Information (VGI) (Goodchild, 2007), followed by a plethora of other terms which are overall summarised by the umbrella expression *crowdsourced geographic information* (See et al., 2016).

The most popular VGI project to date is certainly **OpenStreetMap (OSM)**[64]. Started in 2004, it consists of a crowdsourced database of vector data (points, lines and polygons) covering the whole world and available under the open access Open Database License (ODbL). To date more than 1.6 million contributors have performed at least one change to the database, with about 50 thousand active contributors performing approximately 120 million edits every month[65]. The simplicity of the OSM data model, based on only three different object types complemented by a flat list of attributes, named tags (Ramm et al., 2010) and the

64 *https://www.openstreetmap.org*

65 *https://wiki.openstreetmap.org/wiki/Stats*

availability of multiple APIs to access the data[66] make it extremely easy to download and consume OSM data in mainstream GIS software or via third-party applications. This is – together with the open license – the reason why OSM is currently used by an increasing number of actors (Mooney and Minghini, 2017), including, among others: humanitarian organisations, coordinating collection of new OSM data when natural disasters or humanitarian crises unfold[67]; private companies, including tech giants such as Facebook, Apple and Amazon, exploiting (but also contributing to) OSM for their business purposes (Anderson et al., 2019); and even **governments, using OSM to integrate, complement or update authoritative data**[68]. The latter case represents one of the most fascinating examples of adaptation of the public sector to the current data landscape, although examples of integration of authoritative and citizen-generated data are still isolated and developed on a case-by-case basis, with common business models and approaches yet to be investigated (Minghini et al., 2019; Sarretta and Minghini, 2021). The main factor which is still limiting the use of OSM, particularly from the public sector, is the concern about its quality, deriving from the typically non-professional nature of contributors and the absence of metadata. However, a huge body of literature exists – for a comprehensive review, see Senaratne et al. (2016) – showing that OSM quality may have biases (e.g. data completeness and spatial accuracy are typically higher in urban than rural areas) but may also equal, if not even outperform, the quality of the corresponding authoritative datasets.

A significant portion of citizen-generated geospatial data also derives from **Citizen Science** (CS) initiatives. CS is a more general and historically older term pertaining to the involvement of non-professionals in scientific activities, mainly data collection but also quality assurance, data analysis and dissemination of results (Irwin, 1995). In contrast to OSM where contributors can add any type of geospatial data, the objectives of CS projects usually target a specific thematic area, for example biodiversity (Schade et al., 2016). CS was demonstrated to be a viable way to **engage and empower the public in EU policy-making**, particularly to support the European Commission objectives connected to the Green Deal (European Commission, 2020e).

6.1.3 Satellite data

In addition to allowing citizens to produce new data, remotely-sensed observations are themselves a valuable data source for many geospatial applications. The domain of satellite remote sensing is currently characterised by the presence of **big industry players** such as Planet[69] and Maxar[70], which directly control hundreds of satellites and offer an impressive number of products ranging from high-resolution imagery to derived datasets and services.

However, some recent developments are revolutionising the way in which the Earth can be observed. Those include e.g. **affordable small satellites** (Sweeting, 2018), which provide opportunities for mass deployment and establishment of dense Earth Observation constellations at the fraction of the price of traditional (military, government and private) systems. Low-cost **unmanned aerial vehicles (UAV)** have also become mature and reliable systems to generate valuable data for several disciplines and applications (Nex and Remondino, 2014), with collections of openly-licensed UAV imagery, such as OpenAerialMap[71], becoming increasingly available.

66 *https://wiki.openstreetmap.org/wiki/API*

67 *https://wiki.openstreetmap.org/wiki/Humanitarian_OSM_Team*

68 *https://wiki.openstreetmap.org/wiki/Import*

69 *https://www.planet.com*

70 *https://www.maxar.com*

71 *https://openaerialmap.org*

A prominent role is also played by **Copernicus**[72], the EU's Earth Observation programme managed by the European Commission in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan. Though still under development, through the family of Sentinel satellites Copernicus already delivers an immense amount of data, all provided free of charge and under an open access license to maximise the reuse. Copernicus services target six key areas (atmosphere, marine, land, climate change, security and emergency) with direct impacts on several EU policies, e.g. the Common Agricultural Policy that will benefit from an unprecedented opportunity to streamline and optimise the monitoring of agricultural subsidies. When fully operational, Copernicus will generate more than 25 PB of data per year, thus becoming the largest satellite system in history (Bai et. al, 2017).

6.1.4 Open research data

In parallel to the legislative framework and the related initiatives aimed to open up and reuse public sector data discussed in ***Section 5***, an increased attention has been placed on making research digital objects – including not only 'data' in the conventional sense but also the associated algorithms, tools and workflows – aligned with the **FAIR (Findability, Accessibility, Interoperability, Reusability) guiding principles** (Wilkinson et al., 2016). The need for FAIR research data at the EU level has been also directly recognised by the European Commission with the setup in 2016 of an Expert Group to investigate how the FAIR paradigm can be turned into reality. The Report and Action Plan released by the Group highlighted the needs of a proper research culture and technological infrastructure to ensure that all digital outputs of research are made FAIR (European Commission, 2018b). To concretely allow researchers to make their data FAIR several specialised repositories were created, including some specific to certain disciplines or institutions and some global and general-purpose. While an example of the former is the JRC Data Catalogue[73], among the latter, FigShare[74], Dataverse[75], Zenodo[76] and DataHub[77] welcome a huge variety of object types (including code, datasets and papers) and do not impose strict restrictions on their metadata. In turn, the FAIR data principles and their underlying values of openness, transparency, reliability and collaboration represent enablers for the so-called open science approach and its key principle of **research reproducibility** (Goodman et al., 2016). A number of scientific communities are already strictly adopting such an approach, with the notable example of the AGILE's (Association of Geographic Information Laboratories in Europe) Reproducible Paper Guidelines (Nüst et al., 2019) requiring the presence of a section on data and software availability in all papers submitted to the AGILE conferences. At the European level, a dedicated platform[78] is made available for accommodating the findings of EU research projects, which in turn are by default following the FAIR principles. Similarly, several research journals were recently created, or fine-tuned their scope, in order not only to offer open access publication options but also to make research data and/or software directly discoverable, accessible and citable. Examples are MDPI's Data[79], Elsevier's Data in Brief[80] and, in the geospatial domain, Springer's Open Geospatial Data, Software and Standards[81].

72 *https://www.copernicus.eu*

73 *https://data.jrc.ec.europa.eu*

74 *https://figshare.com*

75 *https://dataverse.org*

76 *https://zenodo.org*

77 *https://datahub.io*

78 *https://open-research-europe.ec.europa.eu*

79 *https://www.mdpi.com/journal/data*

80 *https://www.journals.elsevier.com/data-in-brief*

81 *https://opengeospatialdata.springeropen.com*

6.1.5 Private data

Private entities in many application domains and of varied sizes ranging from small and medium enterprises to hyperscalers now hold increasing amounts of data. Being collected, stored, and used often without the awareness or explicit consent of those who contributed it, private sector data are of critical importance for the success of a growing number of commercial endeavours as well as an important strategic asset. The role of **private data for public good** is not fully harnessed. One of many examples, illustrating the potential for privately-owned geospatial data are those collected by mobile network operators (Iacus et al., 2020). Such data can act as a proxy for population data of relatively high spatial resolution. More importantly, the temporal resolution of such data can be remarkably high. However, when considering commercial data as a source of information for public good, the emerging issues relating to privacy and ethics are to be accounted for (Keßler and McKenzie, 2018).

The reuse of private-sector data is at present difficult, as companies are in most cases contributing them on a voluntary basis. Considering that data are an important asset of companies, they are very often not willing to share them with the rest of the world. In the absence of a clear regulatory framework requiring the private sector across multiple domains to share their data, societal benefits from their possible reuse unfortunately remain limited. The envisioned **Data Act** described in ***Figure 21*** will address those shortcomings and lead to a fairer business data sharing. Additionally, if personal data are to be shared, specific measures for their anonymisation shall be put in place, while ensuring that companies which contribute them retain their competitiveness. In this complex setting we still have to understand how to reuse private sector data to be beneficial for all stakeholders. Indication on how to overcome those outstanding challenges and leverage on the use of such data are provided by Craglia et al. (2021) and Martin et al. (2021).

6.2 From data collection to data connection (APIs)

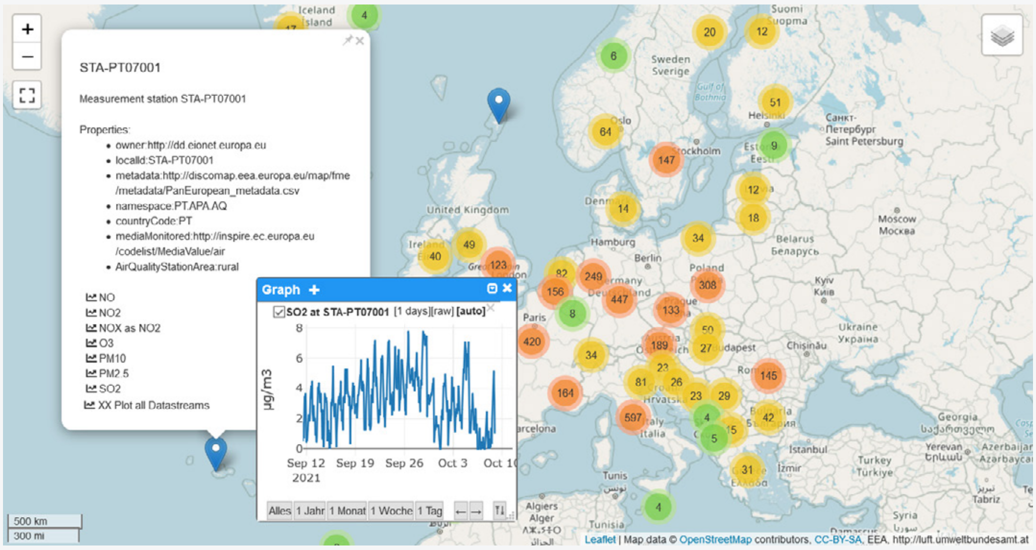
The Web has since the early conceptualisation of INSPIRE been used as the means for exposing geospatial data. However, this was done using technical approaches that required specific knowledge to interact with the data. The service interfaces in traditional SDIs, including INSPIRE (e.g., WMS, WFS, WCS and SOS) are well known and supported by client applications, but they use the Web as a ‘tunnel’ and are difficult to interact with in the absence of up-front knowledge of the query logic. In contrast, modern web-based **Application Programming Interfaces (APIs) provide a means for developers to easily create value-added products** with limited preliminary knowledge (Vaccari et al., 2021). In addition, APIs can hide the complexity of upstream infrastructures and offer a set of well-defined and documented web methods (e.g., HTTP GET, POST, PUT, etc.) for data utilisation and processing across various components. Modern web-based APIs support modern SDIs by going one step further as they (1) provide a simple approach to data processing and management functionalities, (2) possibly offer different encodings of the payload, (3) can easily be integrated into different tools, and (4) can facilitate the discovery of data through mainstream search engines such as Google and Bing (Kotsev et al., 2020).

The recently developed standards of the OGC have a strong focus on establishing APIs for sharing geospatial data. For instance, the **OGC API - Features**[82] and the **OGC SensorThings API**[83] standards provide standardised APIs for ensuring modern access to spatial and observation data. However, multiple questions arise on possible approaches on the implementation of APIs alone, or on top of existing services, i.e., implementing APIs that leverage on investments already made in service interfaces such as WFS and WMS.

82 *https://ogcapi.ogc.org/features*

83 *https://www.ogc.org/standards/sensorthings*

Box 6



*In recent years, new modalities of data provision have been emerging, foremost Representational State Transfer (REST) APIs. Under this new RESTful paradigm, various issues with the existing OGC web services have been alleviated, allowing for far more intuitive data provision and use. Funded by ELISE, the API4INSPIRE project (**datacoveeu.github.io/API4INSPIRE**) evaluated new, API-based open standards like the OGC API - Features and SensorThings API for inclusion within INSPIRE. For the provision of SensorThings API the Fraunhofer Open Source SensorThings Server (FROST) is already available as a free solution and allowed for a much faster implementation of real-world applications. In one of the use cases, data from both the German and French sides of the Rhine River, integrating datasets from the German State of Baden-Württemberg (LUBW) with those stemming from the French Geological Survey (BRGM) and the French Office for Biodiversity (OFB) provided alternative perspectives on the Rhine. In this example, more than 300 million spatio-temporal, pan-European air quality observations are made available through the FROST implementation of the OGC SensorThings API.*

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In addition to that, the frequently used OpenAPI specification[84] allows to document APIs in a vendor independent, portable and open manner. In addition, a testing client is fully integrated within the API documentation, which allows users to easily and quickly start interacting with the API.

6.3 Novel architectures

Traditionally, the exchange of data in an SDI follows a request-response pattern which extracts requested data from a database and delivers them to the users. With the rise of the IoT as a major source of information, the **streaming of data** is playing an increasingly important role. A stream provides a sequence of digitally encoded signals with a certain frequency and payload that are transmitted and/or received. Often, there is no need to store the streamed data, e.g., in cases where data is useful only in certain circumstances and within the right context.

In addition, the polling of data which is inherent to the service-oriented architecture of SDIs as we know them might lead to the generation of excessive traffic. This is not necessarily well-suited for data intensive use-cases, or when data is needed only as result of the occurrence of a particular event, for example when a threshold value is reached, or when new data is made available. Standards such as the Message Queue Telemetry Transport (MQTT)[85] are well established and fit for such purposes. That is why Rieke et al. (2018) recommend the establishment of "Event-driven SDI's". This might be achieved in an evolutionary manner that complements, and does not substitute existing approaches. Such an approach would provide users with a choice of a solution which is tailored to their needs. This possibility becomes feasible from a technological point of view, as the emergence of cloud-based solutions can address the user demand in a flexible and scalable manner (Kotsev et al., 2020).

84 *https://swagger.io/specification*
85 *https://mqtt.org*

The increased **diversity of architectural approaches** that we are facing is inevitably impacting SDIs. Whereas in the past data was processed and made available on some sort of centralised server, now this only comprises one of several frequently used architectural approaches, described in detail in Granell et al. (2020). Depending on the concrete use case, computing can also take place in 1 the **network edge** (e.g., on sensors devices), 2 **fog** (e.g., on network gateways), or 3 **cloud**. This novelty has led to the emergence of data spaces with various complexity that also occur at multiple levels such as the local or the regional. If most data today are being processed in the cloud - 80% in accordance with a recent study of the International Data Corporation (2018), it is expected that the rapid growth of the IoT will revert that, and most processing would therefore take place close to the network edge. Today, network latency, leading to a slow transfer of data, poses a limitation for the uptake of edge and fog computing, which will be overcome by the fifth-generation wireless technology for digital cellular networks (5G). Despite the different architectural setting of edge, fog and cloud computing, a shared characteristic of the three approaches is the coupling of data and algorithms.

6.4 Agile standards

In addition to all the technological trends described above, a new kind of standardisation initiatives are emerging. Historically formal standardisation bodies often approached studied phenomena through a comprehensive approach in their attempt to represent multiple, sometimes complex phenomena. This approach slowed down standardisation, resulted into the adoption of highly excessive standards which in turn sometimes lead to very few implementations, and posed a burden on both users and data providers. Standardisation for the needs of SDIs inherited such complexity from their multiple standardisation building blocks. INSPIRE is no exception, and that is why it is considered by some as too complex. Recently, understanding the limitations introduced by this top-down approach, but also taking advantage of the emergence of platforms that leverage on tools for co-creation of content such as wiki and git, a new breed of *de facto* standards is rapidly being established. In contrast to the above-mentioned approach, those **standards are co-created online by multiple actors**, including the future users of those standards, in an agile and iterative manner. Capturing all possible use cases is no longer the primary objective of the standardisation activity. On the contrary, tweaking the developments to the needs of users, thinking of simplicity, and lowering the entry level are the primary objectives. Good examples of such a lightweight approach are the abovementioned OGC API - Features and SensorThings API standards (and more in general the new **OGC API family of standards**[86] that is being produced by the OGC). Both have huge potential for modernising SDIs and have been already recognised as INSPIRE good practices (see ***Subsection 3.2.1***).

As far as **data encoding** is concerned, several new standards with excellent client support should be mentioned. Those include (1) the GeoPackage standard[87], which is fast, efficient and provides multiple advantages over text-based formats, in particular relating to the sharing of complex geometries and big volumes of data, (2) the Cloud Optimized GeoTIFF (COG)[88] format, which is a modern and effective solution to make satellite imagery, and in general big raster data, easily consumable through the web, (3) GeoJSON[89], which is the de facto standard for sharing geospatial data on the web through modern APIs, and (4) the SpatioTemporal Asset Catalogs (STAC)[90], which is not yet a full OGC standard but provides a powerful way to expose collections of spatio-temporal data (including satellite imagery, data cubes and point clouds).

6.5 Mature tools

From our perspective, the increased availability and diversity of data sources goes hand in hand with a growing **versatility of software tools** (e.g., open source, proprietary, mixed, standalone, bundled). This in turn is leading to an increased number of different approaches for processing, analysing and visualising data. Having more options at disposal empowers data users and is a precondition for the reuse of existing data. However, from a European perspective aligned with the FAIR principles and centred around the concepts defined in the European Strategy for Data (European Commission, 2020a) as well as the European Commission's Open Source Software Strategy 2020-2023 (European Commission, 2020f), we assume that open source software would be very well fit for best utilising the different data sources described in ***Section 6.1***.

86 ***https://ogcapi.ogc.org***

87 ***https://github.com/INSPIRE-MIF/gp-geopackage-encodings***

88 ***https://www.cogeo.org***

89 ***https://github.com/INSPIRE-MIF/2017.2/blob/master/GeoJSON/geojson-encoding-rule.md***

90 ***https://stacspec.org***

7

VISION

Spatial data sharing is not a goal in itself, but **a means to an end** – and INSPIRE is no exception.

To remain fit for purpose, INSPIRE should support **data-driven decision-making** and **innovation** to help tackle our societal and environmental challenges, while also contributing to the data economy. To ensure compatibility and long-term sustainability, INSPIRE should ideally **'blend in' with the broader ecosystem** of spatial and non-spatial data, infrastructures, technologies and policies.

This will also mean opening up to a **broader community of implementers and users** and to a **broader range of applications and use cases**. Making the INSPIRE **legal and technical framework more flexible and agile** will significantly lower the entry level to the sharing and utilisation of data.

To achieve this, the technical approaches need to be simplified by re-using **well-adopted standards and technologies**.

After having clarified the bounding conditions for (geo)data-driven innovation from both a technological and policy perspective, here we provide our vision for the future of European SDIs, and of INSPIRE in particular. In doing so, we put particular emphasis on the guiding principles, but also on the key components and barriers to be overcome. Acknowledging the fact that technology is developing at a rapid pace, we also propose a high-level architecture of INSPIRE which, from our perspective, would be valid within a horizon of five to ten years from now.

To illustrate the practical implications of this vision, here we provide a hypothetical example (use case) exemplifying what will happen if our vision becomes a reality. Our use case is presented from the perspective of a user who needs heterogeneous data for the creation and scaling up of a data-driven product.

Box 7

In 2025, a European SME is working on an analytical service for supporting citizens and real estate agencies in finding the areas of cities that are most suitable for renting housing. In accordance with their business plan, such an approach is only economically feasible if the service can be scaled to a pan-European level.

The team of developers engaged with this task has thorough experience in data science but little or no prior knowledge of geospatial technologies and standards.

They approach the problem in the following manner:

1 DISCOVERY

The team searches through a search engine for relevant datasets (that include, but are not limited to INSPIRE)**, and through a code repository for processing tools and relevant discussions.**

2 DATA EVALUATION

The team discovers well-documented data and different APIs with examples that help them to immediately start experimenting.

Data encodings and models are self-explanatory, and easy to combine through multiple tools, even if not fully harmonised. The metadata that is bundled together with the datasets and exposed by the APIs is clear and follows a recognised standard. Some of the data is open, and some is proprietary, but everything is clearly described and gives certainty for the usage conditions.

3 DATA PREPARATION

For data that is not harmonised, the team uses powerful, yet simple Extract-Transform-Load (ETL) tools to combine the various sources of data into a single derivative product.

Where data from the public domain is not available, the team complements the sources with citizen-generated information from OpenStreetMap. For some of the data that is needed, out-of-the-box products are already available in a European federated cloud environment for immediate reuse.

4 APP PROTOTYPING AND DEPLOYMENT

As a result, the team produces a working prototype that scales to the pan-European market.

The prototype together with all data sources is directly processed and stored in a European federated cloud environment which is aligned with the principles of EU legislation and offers out of the box functionalities such as authentication, AI algorithms for quality checks of the data, multiple standard-based APIs for exposing the data. The developed product combines personal information of users in the cloud and ensures the privacy and compliance with European data protection legislation.

5 USAGE AND FEEDBACK LOOP

Feedback from the usage of the data is evaluated and incorporated into the different data sources to help the corresponding data providers improve their quality, but also the relevant technologies and standards.

7.1 Making the vision a reality

Here, we propose a list of actionable legal, organisational and technological items to help achieve the vision presented in ***Section 7***. Deliberately, we emphasise on the period until 2024 in order to align the work with the already endorsed INSPIRE MIWP 2021-2024 (see ***Section 3.2***). The activities contributing to the implementation of the vision are complex, and for instance the legislative decisions will have implications on the organisational and technological ones and vice versa. That is why, it only makes sense to address them by considering the legal, organisational and technological dimensions altogether. However, for simplicity reasons, those are kept separate below.

7.1.1 Legal actions

Avoid overspecification in legislation

As also highlighted on multiple occasions in this report, there is a significant difference in the speed at which technology and legislation develop. If technology is evolving in an ever-growing speed, legislation alongside with all the necessary supplemental processes, e.g., public consultation ex ante and ex post evaluation is a slow process. It is therefore essential that the **provisions in legislation are scoped with sustainability in mind and do not overspecify the technical requirements while remaining fit for purpose** but also avoiding the need for frequent changes in the legal framework. A possible approach for addressing this challenge is to (1) refer in the legal acts to persistent identifiers in publicly accessible repositories, where the actual technical provisions are to be maintained and updated, and (2) define the governance approach for the repositories and technical provisions. Regarding the former, the approach already used for sharing and governing registers, used by the INSPIRE Registry (see ***Subsection 3.2.1***) can be further developed.

Streamlining and simplifying the legal framework, combined with a reduction of the overspecification of technical provisions, can be achieved within the context of the evaluation of the INSPIRE Directive[91], and the follow-up actions under the European Strategy for Data (European Commission, 2020a) and its function as a digital enabler for the European Green Deal initiative (European Commission, 2019a). The evaluation of the Directive (due by 1 January 2022) provides an excellent opportunity to simplify the technical specifications. A possible approach to be followed would be to reduce the technical provisions in the legal base and govern them outside by exploiting the full potential of the INSPIRE good practices procedure (see ***Subsection 3.2.1***), and existing online collaborative platforms like the INSPIRE MIF GitHub repository[92].

An additional legal boost for the implementation of INSPIRE would be the forthcoming implementing act on the high-value datasets defined under the Open Data Directive (see ***Section 5.3***). Closely aligned with INSPIRE, the provisions on high-value datasets would catalyse geospatial data sharing through the requirements relating to the use of standard-based APIs, commonly agreed licensing, open data formats and metadata.

Use a simple licensing framework

Licensing information is an essential requirement for making sure that the data are used in a proper manner. What we have observed in INSPIRE is that the approach towards licensing is very different from country to country, and even more so between data providers (see ***Section 4.7***). Furthermore, quite often the license for a given dataset is not available at all which creates a significant barrier for the reuse. That is why, (1) **ensuring that the approach is harmonised through an existing licensing framework** such as Creative Commons[93],

91 *https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12427-Sharing-geospatial-data-on-the-environment-evaluation-INSPIRE-Directive-en*

92 *https://github.com/INSPIRE-MIF*

93 *https://creativecommons.org/licenses/*

and 2 **exposing the license in a machine-readable manner together with the datasets** would significantly increase the reusability potential of the data. Once again, the new developments under the Open Data Directive, and in particular the forthcoming implementing act on the high-value datasets (as described in ***Section 5.3***) provide the legal foundation for sharing the data under open standardised licenses. An additional aspect, considering the rapid rise and disruptive role of AI, is to ensure that licensing information is exposed in a machine-readable manner close to the datasets.

7.1.2 Organisational actions

Embrace co-design by default

The development of Europe's SDIs, and the INSPIRE infrastructure in particular, pioneered mechanisms for co-creation and co-design of consensus-based technical arrangements. However, this approach 1 represented at large the perspective of those who participated in the drafting, that is, data providers, 2 took too long for the arrangements to be endorsed and adopted, and 3 followed a linear approach for making data available where the interaction with users only came in the last stages of the implementation. Consequently, other stakeholders such as software vendors, data integrators and end users were not fully included in the process. Nowadays, mainstream online collaborative tools such as GitHub and BitBucket provide excellent opportunities for building on top of the already established partnerships, but also in speeding up the process of co-creation and endorsement of technical specifications. In this context, **the overall approach to SDIs should ideally be neither top-down, nor bottom-up, but shared across multiple levels**.

In addition, the conceptualisation of approaches should embrace in advance the fact that technologies are, and will continue to rapidly change, that is, there will be new disruptive technologies soon, while others will quickly become obsolete. That is why, a rigid linear process which roots all developments into a particular standard or technology makes little sense. Instead, **an agile approach based on extensive experimentation (sandboxing) is desirable, which** would respect the overall principles and concepts but **can easily and inclusively be tailored to the needs of different stakeholders**, with no predominance of data providers. This would ensure flexibility and create sustainable conditions for leveraging on already existing technologies and approaches in a collaborative and transparent manner.

The **established procedure for INSPIRE good practices** (see ***Subsection 3.2.1***) provides a feasible way forward for introducing and agreeing on new technologies and approaches through extensive collaboration between providers, early adopters of standards and users. The final step of the good practice procedure dedicated to the legal scrutiny, in turn, ensures that the technical provisions are aligned with the legal framework. Similarly, in line with the overall vision, it is crucial to **elaborate a sustainability strategy for the central INSPIRE infrastructure components** (see ***Section 2.2***) by 1 relying, whenever possible, on mature and well-established open source software tools in order to limit the development effort to the INSPIRE-specific parts, 2 harmonising the approaches for the helpdesks, and 3 establishing governance structures based on strategic partnerships with relevant communities, including EU Member States, stakeholder organisations and open source communities. Such a sustainability strategy has been recently planned and started to be implemented within the INSPIRE MIWP 2021-2024. In addition, the new Digital Europe (DIGITAL) Programme[61] would provide important instruments to achieve this objective. Actions already undertaken include the migration of all the helpdesks to the INSPIRE MIF GitHub repository and the ongoing development of a re-engineered backend of the INSPIRE Geoportal (see ***Subsection 2.2.1***), which is currently a highly customised, home-developed system, based on the open source GeoNetwork[94] project.

Finally, an agile approach is also required to **ensure the governance and sustainable evolution of the INSPIRE artefacts**, which are key assets of the whole infrastructure and include application schemas, TG documents and UML models. The established approach has been recently operationalised on specific GitHub repositories[95,96] and defines a structured procedure involving multiple actors in the proposal, discussion and endorsement of changes according to a specific timeline. This would ensure the evolution of the INSPIRE infrastructure in an agile, collaborative and consensus-based manner.

Rethink the existing INSPIRE governance structures

In light of the new context and priorities (see *Section 5*), rethinking the currently existing MIG governance structures is an important step towards ensuring that INSPIRE can 'blend in' within a broader data ecosystem. The recent work with the Open and Agile Smart Cities (OASC) international network on feeding the technological approaches developed by INSPIRE into the smart city Minimal Interoperability Mechanisms (MIMs)[97] is an example in this respect. Including other stakeholders, in particular cities and regions, but also giving intermediaries, such as marketplaces (for example the Dutch PDOK distribution platform[98] or the API-AGRO initiative[99]) a prominent role would guarantee that INSPIRE remains open and inclusive. An ideal governance structure would be more balanced, i.e. represented by less providers, and with more users, open source projects and standardisation initiatives.

Adopt an ecosystem approach

We envisage that by 2030 there will be no specific governance centrally-managed structure for INSPIRE such as the currently existing MIG. **The role for governing the infrastructure should ideally blend into the broader data ecosystems**, defined as an environment where a number of actors interact with each other for a specific purpose, generating value from the network by producing, exchanging and consuming data in a collectively governed and operated way[100]. Concretely, approaches for the evolution of SDIs into self-sustainable ecosystems, derived from the study of existing data ecosystems, are discussed by Martin et al. (2021) as well as Coetzee et al. (in press). Within the envisioned governance approach data intermediaries, and even more so the communities of data users would become an integral part of the governance. Within the data ecosystem, it would be essential to understand the role of the different actors, alongside their interplay, incentives, barriers to data sharing and enablers that can help overcome the bottlenecks which act as an obstacle to the sharing of data.

Figure 22 provides a simplified perspective of a data ecosystem with different actors (based on the quadruple helix model), alongside their incentives (provided for each of the segments), and the enablers that would facilitate the exchange of data. The enablers shown in the figure are structured in accordance with the European Interoperability Framework (EIF) into legal, organisational and technical. In interpreting this perspective on data ecosystems, it is important to emphasise that the distinction between the providers and users of data is almost impossible, as e.g. public sector authorities are often also the users of the data.

94 *https://geonetwork-opensource.org*
95 *https://github.com/INSPIRE-MIF/application-schemas*
96 *https://github.com/INSPIRE-MIF/technical-guidelines*
97 *https://mims.oascities.org/interaction/oasc-mim7-places*
98 *https://www.pdok.nl*
99 *https://api-agro.eu*
100 *https://joinup.ec.europa.eu/collection/elise-european-location-interoperability-solutions-e-government/document/report-european-union-location-framework-blueprint*

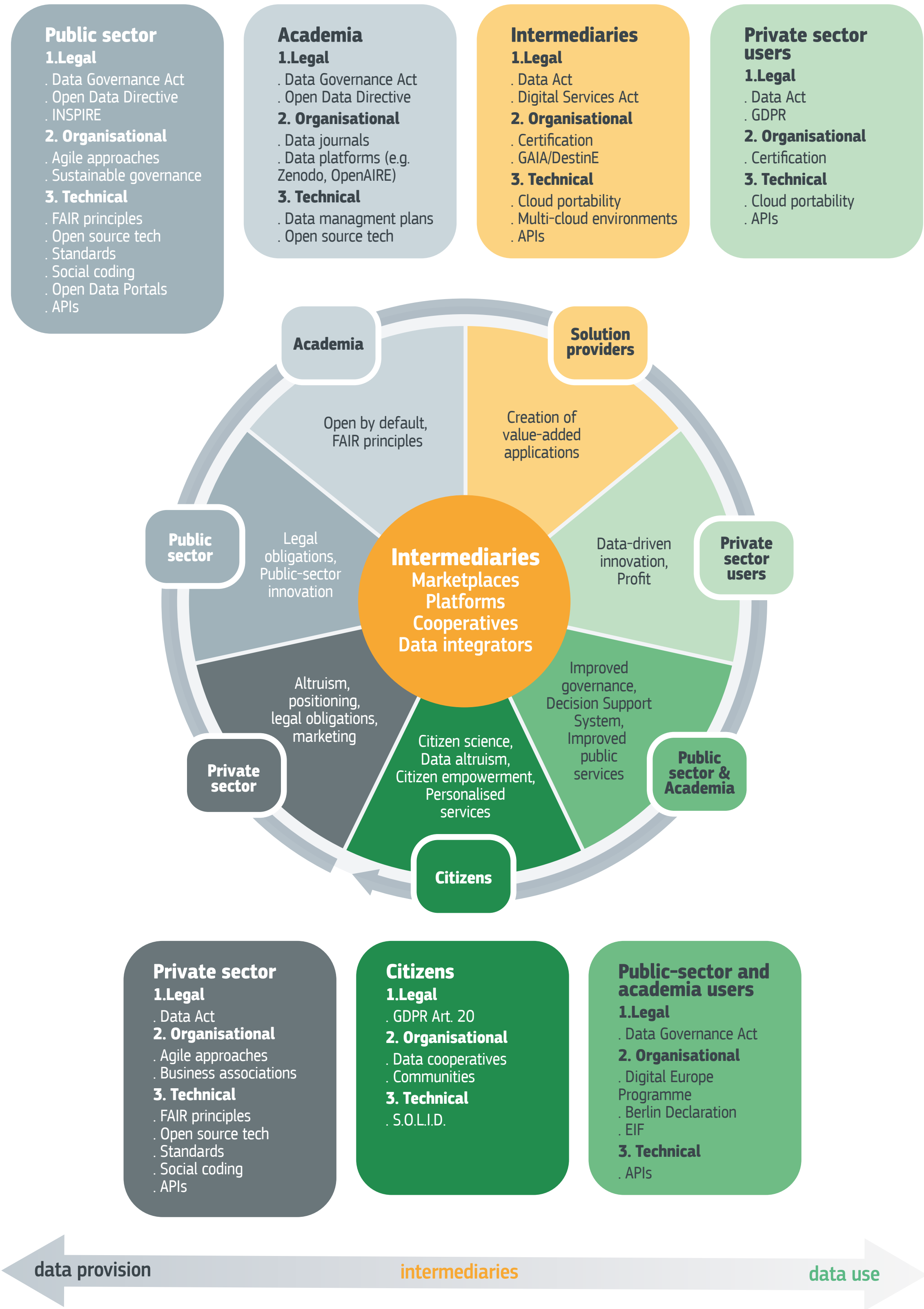

Figure 22. Data ecosystem actors, incentives and enablers

Source: JRC; authors' own elaboration.

7.1.3 Technological actions

Continue to improve the discoverability and accessibility of data

As already argued on multiple occasions in this report, INSPIRE has proven to be a particularly useful framework for improving the discoverability of existing data through the compilation and exposure of metadata, as well as the accessibility through the implementation of download services. These initiatives should be continued and further streamlined through a transparent, well documented monitoring process, and generic open source software tools.

Ensure neutrality and embrace well-adopted standards and technologies

The thematic scope of INSPIRE is by definition very broad, and it has therefore been difficult to narrow down the technological options. Clearly, making data available that complies with certain requirements but is difficult to use through mainstream tools is of little use. That is why, **client support is a top priority for the technological stack of INSPIRE**, for general purpose libraries such as the Geospatial Data Abstraction Library (GDAL)[101] that are reused by multiple end user applications. A minimum baseline of functionality to at least visualise the spatial and non-spatial components of the data within web clients, and, in addition, allow their analysis and processing in desktop clients, should be ensured by the most broadly desired tools. During the years, we have observed a growing number of possible solutions that are backed up by technical guidelines. At the same time, with the rapid development of technologies, there are an increasing number of different pathways for handling data. Considering all of this, **it makes very little sense to restrict data to a vendor-specific or immature standard or technology**. While such an approach would have the benefit of ensuring high degree of interoperability, it would only be fit for the needs of some users while limiting the opportunities for a broader uptake of the data. In contrast, having a technological stack of more solutions would decrease interoperability, but would ensure a more inclusive approach. In terms of data encoding, multiple distributions of the same dataset, or data exposure through multiple APIs are both feasible options. Adopting such an approach would increase the need to do mapping between different standards and further reinforce the role of mature ETL tools. It is important to also highlight that **the adoption of a given technology or standard should remain a community-driven exercise** where all stakeholders play a prominent role in all stages of the process. Accordingly, a procedure to propose and endorse good practices (already described in *Section 3.2.1*) ensures the establishment of a community-driven approach for modernising the technological stack of INSPIRE.

Avoid custom extensions

It is essential that the technical solutions put forward by INSPIRE are easy to implement and not only comply with the legal requirements, but also add value to the stack of technologies of data providers and are useful to the users of the infrastructure. From that perspective, as outlined in *Section 4.4*, **custom extensions of existing standards and their implementations and/or of concrete tools and libraries are both difficult to implement and useful only to some particular use cases**. Leveraging on out-of-the-box solutions and standards for both clients and servers should therefore be the default approach for all technical developments. Going beyond those might only be considered if critically important and after a scrutiny of stakeholders for the usefulness and implementability.

101 *https://gdal.org/*

Embrace well-documented, standard-based APIs

APIs are the new norm for exchange of data through standard web requests. **By applying the well-known interaction patterns of APIs to the exchange of spatial data, the power of spatial data** and spatial analysis will no longer be restricted to a relatively small group of spatial data specialists (that understand the specific interaction patterns of the geospatial community) but **will become available to all web and software developers**, regardless their level of geospatial experience. Embracing well documented standard-based APIs enhances the Developer Experience (DX) and minimises the Time to First Successful Call (TTFSC). This eliminates some of the most important thresholds for the application of spatial data by non-expert users.

The broad uptake of APIs for INSPIRE would also ensure that the artificial divide between discovery, view and download services can be overcome. Ensuring such an approach would require additional technical guidelines, as well as possibly an update of the corresponding INSPIRE legal framework. In addition, APIs can expose different distributions of the dataset alongside its metadata in machine-readable format.

Optimise data for search engines

Making data findable/discoverable through search engines, which are nowadays the common starting point for almost all web users, is an essential step in reaching out to a wider target audience (beyond the traditional expert users). **By making spatial data indexable by search engines, discovery of data is no longer limited to those who are aware of the existence of web-based catalogues**. According to Best Practice 2 of the Spatial Data on the Web Best Practices (World Wide Web Consortium, 2017) this can be achieved by publishing an HTML webpage for a spatial dataset and each spatial thing that it describes and by ensuring that these pages are crawlable.

Leverage on the developments of federated European cloud infrastructures

The opportunities for exploiting the emerging trend of European technological sovereignty and the federated infrastructure provided by initiatives such as **GAIA-X**[102] have to be further investigated, as they have the potential to not only provide a scalable environment, but also to provide out-of-the-box technological enablers such as authentication mechanisms and certification. A first pilot to test the use of GAIA-X for INSPIRE-related purposes is starting by the end of 2021.

Deprecate obsolete technologies and standards

While the good practice procedure (see ***Subsection 3.2.1***), reinforced by the release plan and governance approach for the INSPIRE artefacts, provides the means for adoption of new prominent approaches and standards, the **way in which obsolete technologies are to be phased out** is still to be developed. An approach might be elaborated that would be similar to the collaborative way in which good practices are adopted. It would be acting in the opposite direction and be used for agreeing how to remove technological options that are not needed any more.

102 ***https://gaia-x.eu***


8

Conclusions

14 years have passed since the entry into force of the INSPIRE Directive, which has been the first worldwide effort trying to setup such an ambitious, legally-driven SDI at a continental level. Despite the obvious issues and difficulties triggered by the process, this is also the main reason why **INSPIRE has been, and is still today, seen as a reference example by many countries and organisations all over the world** that intend to establish SDIs from the local to the national and international level. During these 14 years, the context around geospatial data sharing across Europe has radically changed, as a consequence of both a non-stop, disruptive technological innovation in standards and technical approaches, and a new European political framework. The new policies put data and data sharing at the centre of the digital transformation to address urgent societal and environmental challenges. All of this creates very favourable conditions for taking a close view on the INSPIRE development so far, for critically assessing achievements and failures, and, building on these, for defining a vision and the actions to achieve it. This way, the benefits for the future European data economy and society that INSPIRE can bring are maximised. This was in essence the overall objective of this report, which was written in parallel with the process of evaluation of the INSPIRE Directive (due by 1 January 2022). The evaluation will reveal if a revision of the Directive itself will be deemed necessary.

The key message of this report is that **SDIs** conceived in the traditional sense, and INSPIRE is no exception, **shall evolve from complex and highly specialised geospatial data frameworks**, where legal obligations are enforced by strict technical specifications, **to flexible, agile, sustainable and data-driven ecosystems** lowering the entry point to maximise data sharing and consumption by communities as diverse as possible. We live in an era where more and more data coming from an increasingly huge number of sources become available on a real-time basis, thus not only making 'spatial' data not 'special' anymore, but also challenging the traditional role of the public sector as the main actor in data production, management and sharing. This shows how much **we need INSPIRE to blend in with a larger European data space** enabling everyone to seamlessly discover, access and use data for whatever final purpose, being it a research study, a policy intervention or a business application in any geospatially-related domain.

To achieve this challenging goal, the report has demonstrated the **need for a simplification and a modernisation of the INSPIRE technological framework**. Keeping in mind that technology evolves, and will continue to evolve, at a very fast pace, concrete actions should ideally be taken not only at the purely technical level, by e.g. welcoming new standards and approaches for data encoding and sharing, but also at the legal and organisational (governance) levels. No intervention at any single level would suffice if planned in isolation from the others. Although a huge and continuous process is needed to achieve this vision, such a process is luckily not starting from scratch. First, what INSPIRE has achieved so far – from its collection of available data to its mature software components and vibrant community – represents a key ingredient to 'cook' its future development. Second, the recently established INSPIRE Maintenance and Implementation Work Programme (MIWP) 2021-2024 has already defined concrete actions for the next years – built on the lessons learnt from the past – to **make INSPIRE evolve into a sustainable data ecosystem for the environment** to closely support the European

Commission priorities around the green and digital transformation, and more specifically for the forthcoming European data spaces.

To conclude the report by complementing the whole information provided so far, we offer our initial proposal for a concrete **INSPIRE reference architecture to be adopted in the years to come**. Such an architecture does not have the ambition to be encompassing all possible technical details, since we are aware that the emergence of the next technological trends would quickly make the details obsolete. On the contrary, it attempts to condense at a high level the various aspects covered in this report and illustrate the interplay between different interconnected actors within an increasingly rich ecosystem of technologies and approaches. Ultimately it is expected to trigger a debate with the community on what future technological evolution INSPIRE shall undertake. In ***Figure 23***, we deliberately represent this hypothetical architecture next to the original INSPIRE architecture, already shown in ***Figure 4*** and also explained by Cetl et al. (2019). The new architecture captures most of the technological trends covered in ***Figure 6***. The existence of innovative data sources to complement public sector information will make it increasingly necessary to include a data validation layer. APIs will become the de facto interface for the majority of users to enter the INSPIRE data ecosystem, including accessing, analysing and processing data, with ultimate possible applications – favoured by the emergence of digital twins – addressing a range of domains much broader than the environmental one and a set of use cases with a geographical scope no longer limited to Europe. The whole ecosystem will be accessible in a cloud infrastructure, being in turn only a piece of a much larger European federated data infrastructure ensuring data openness, transparency and sovereignty.

There is no doubt that **the vision for the technological evolution of INSPIRE elaborated in this report is very ambitious**. Due to the challenges of various nature (from the legal to the organisational ones) is unlikely to become a reality in a short period of time, especially considering that the public sector does not typically evolve at a fast pace. It is therefore crucial that incentives are available to facilitate innovators, demonstrators and early adopters in the community to pave the way for the new data sharing approaches mentioned in this report (as well as those becoming available in the future). The good news is that – as shown by the text boxes available throughout the report – the vision can indeed be achieved as there is already a promising implementation evidence across many dimensions and geographical scales.

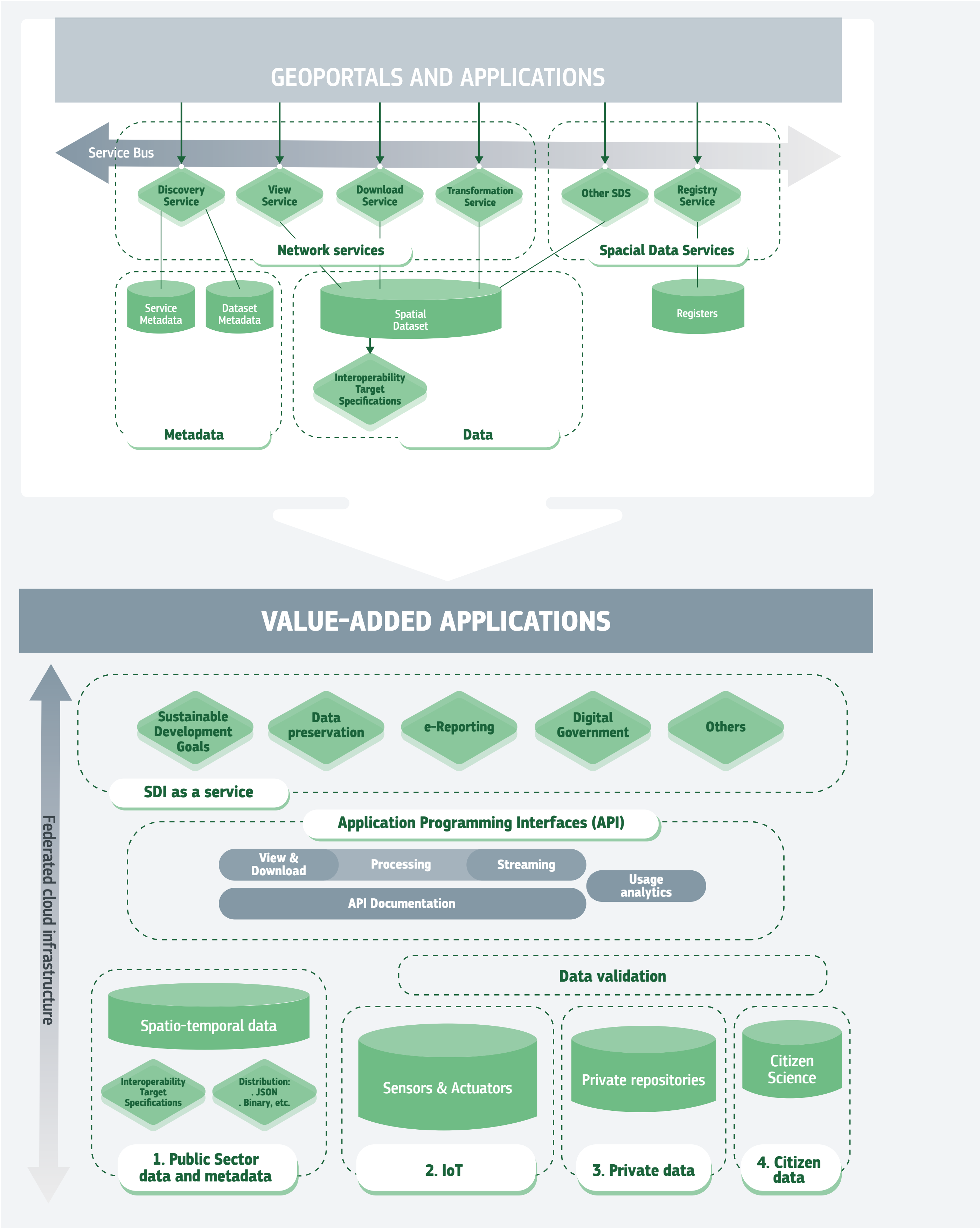

Figure 23. Updated reference architecture of INSPIRE

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List of abbreviations and definitions

AGILE	Association of Geographic Information Laboratories in Europe
AI	Artificial Intelligence
API	Application Programming Interface
ATOM	Atom Syndication Format
ATS	Abstract Test Suite
CAP	Common Agricultural Policy
COG	Cloud Optimized GeoTIFF
CSP	Common Services Platform
CSV	Comma-Separated Values
CSW	Catalogue Service for the Web
DCAT-AP	DCAT application profile for European data portals
DG	Directorate-General
DG AGRI	Directorate-General for Agriculture and Rural Development
DG ENV	Directorate-General for Environment
DG ESTAT	Directorate-General for European statistics
DX	Developer Experience
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
EFTA	European Free Trade Association
EIF	European Interoperability Framework
ELISE	European Location Interoperability Solutions for e-Government
ESA	European Space Agency

EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ETS	Executable Test Suite
EU	European Union
EUPL	European Union Public License
EIF	European Interoperability Framework
FAIR	Findability, Accessibility, Interoperability, Reusability
FROST	Fraunhofer Open Source SensorThings Server
GDAL	Geospatial Data Abstraction Library
GDPR	General Data Protection Regulation
GIS	Geographic Information Systems
GML	Geography Markup Language
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
IACS	Integrated Administration and Control System
IKB	INSPIRE Knowledge Base
INSPIRE	Infrastructure for Spatial Information in the European Community
INSPIRE CT	INSPIRE Coordination Team
IoT	Internet of Things
ISA2	Interoperability solutions for public administrations, businesses and citizens
ISO	International Organization for Standardization
IT	Information Technology
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data
MIF	Maintenance and Implementation Framework
MIG	Maintenance and Implementation Group

MIM	Minimal Interoperability Mechanism
MIWP	Maintenance and Implementation Work Programme
MQTT	Message Queue Telemetry Transport
OASC	Open and Agile Smart Cities
ODbL	Open Database License
OGC	Open Geospatial Consortium
OSGeo	Open Source Geospatial Foundation
OSM	OpenStreetMap
RDF	Resource Description Framework
SDG	Sustainable Development Goal
SDI	Spatial Data Infrastructure
SDMX	Statistical Data and Metadata Exchange
SOA	Service-Oriented Architecture
SOS	Sensor Observation Service
STAC	SpatioTemporal Asset Catalogs
TG	Technical Guidance
TTFSC	Time to First Successful Call
UAV	unmanned aerial vehicles
VGI	Volunteered Geographic Information
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WMTS	Web Map Tile Service
XML	Extensible Markup Language

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