Monitoring the FAIRness of geospatial data: Lessons learnt from the European Union

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Abstract

The Findable, Accessible, Interoperable and Reusable (FAIR) principles were introduced to mitigate challenges in discovering, accessing and ultimately reusing data. They still represent the backbone of current, public sector-driven geospatial data infrastructures worldwide, and Key Performance Indicators (KPIs) are used to measure the progress towards their implementation. This work reflects on the experience of the European Union (EU) geospatial data infrastructure, driven by the INSPIRE and the Open Data Directive requirements. Analysing the results of the monitoring process in the last six years, we draw a number of lessons. First and foremost, the way in which KPIs are defined steers the development of an infrastructure against specific directions, and maximising the KPIs used to measure the FAIRness is not enough. A shift would be needed to more user-centric monitoring approaches, which originate from user needs and assess the actual value generated from data reuse. The analysis also demonstrated the importance of employing automated, transparent and reproducible monitoring processes powered by open source tools, as well as the need to define an inclusive governance approach grounded on a continuous involvement, dialogue and trust with the affected stakeholders.

1. Introduction

Over the last decade, the global landscape of data sharing went through profound changes that also applied to the geospatial domain, where traditional geospatial data infrastructures have progressively evolved into multifaceted data sharing ecosystems (Kotsev et al., 2020). These ecosystems embraced fundamentally new elements in terms of: (big) data sources, e.g. from research, Earth Observation, connected Internet of Things devices, crowdsourcing initiatives, synthetic data from Artificial Intelligence (AI) and Machine Learning (ML) algorithms or Digital Twins; technology and infrastructures (e.g. cloud, edge and fog architectures, standards to encode and share data, AI/ML models); actors such as private companies and citizens becoming valuable providers of data and services; legislation (e.g. to open up data, foster data sharing and protect privacy); and business models and governance mechanisms (Coetzee et al., 2021).

At the same time, in a hyperconnected world that only generates more and more information, geospatial data often remain difficult to access and use. This is due to a set of intertwined reasons that are of different nature, including technical (e.g. interoperability, use of proprietary technologies, vendor lock-in), legal (e.g. copyright, licensing, legislatively-driven constraints), and governance (e.g. siloed data infrastructures, exclusive role and access to data of gatekeepers from big commercial actors). The adoption of the FAIR (Findable, Accessible, Interoperable, Reusable) data principles (Wilkinson et al., 2016) can help mitigate these challenges by improving the discoverability, accessibility, and reusability of data. Monitoring the FAIRness of data infrastructures is crucial to ensure their compliance with these principles, thereby promoting a more open and collaborative data ecosystem. Notably, FAIR is being heavily applied for research data, with initiatives such as the European Union's (EU) Horizon Europe programme (`https://europa.eu/!TR3KWQ`), where financed projects have a default clause to make their data available as FAIR, with an opt-out clause in specific cases.

Within this complex context, the public sector remains an important data provider and user despite the growing role of the private sector. In the geospatial domain and beyond, the public sector's role has transformed, with a greater emphasis on delivering high-quality, trustworthy, and authoritative data, and fostering a data ecosystem that supports transparency, accountability, and informed decision making. The importance of ensuring the FAIRness of public geospatial data infrastructures is a long-standing and widely recognized principle among governments worldwide, and ongoing efforts are being made to promote and implement FAIR data practices, standards, and policies that support the effective use and reuse of public data.

To assess progress towards this goal, various Key Performance Indicators (KPIs) have been developed to measure and monitor the FAIRness (considered as the goodness) of public geospatial data infrastructures, which in turn justifies its use by policy and decision makers. Examples of such KPIs, pertaining to geospatial data, can be found in initiatives such as the Canadian Geospatial Data Infrastructure (CGDI) framework (CGDI, 2001), the United States (US) Geospatial Data Act's data quality and accessibility metrics (United States Congress, 2018), and the EU's high-value dataset provisions (European Commission, 2023), and INSPIRE Directive's (European Union, 2007) monitoring and reporting mechanism (European Commission, 2019). Overall, these KPIs aim to capture the extent to which public geospatial data is findable, accessible, interoperable, and reusable, and provide a basis for evaluating the effectiveness of efforts to promote FAIR data practices and improve the overall FAIRness of public geospatial data infrastructures.

This paper focuses on the EU by reflecting on six years of operational experience with monitoring the FAIRness in the EU's public geospatial data infrastructure. It describes the relevant legislation and the context of the monitoring exercise, the approach and the KPIs adopted, and critically distills a number of lessons learned from the monitoring outcomes. Although the specific context of the study is European, the fundamental principles and learnings would be applicable and valuable for stakeholders globally.

The remainder of the paper is structured as follows. In Section 2 we focus on a specific case – the EU geospatial data infra-

structure, which is, at large, also representative to the rest of the cases where a legislative requirement is introduced for the monitoring of data FAIRness. We present the policy context relevant to the provision of datasets in this infrastructure, illustrating the monitoring requirements foreseen by legislation. This is followed by Section 3, where the latest monitoring trends are presented and a number of lessons are derived on how the monitoring process could be potentially improved. The role of open source software components in the process is also discussed. Section 4 closes the paper by reflecting on the needs for improving monitoring initiatives on geospatial data, and by discussing how future research can support this endeavor.

2. Legislatively-driven EU monitoring requirements

The lack of FAIRness in the geospatial data produced by EU public sector data providers was the exact reason behind the conceptualisation and subsequent establishment of the EU public geospatial data infrastructure, at the beginning of the century. This infrastructure was formally triggered by the INSPIRE (*Infrastructure for Spatial Information in the European community*) Directive (European Union, 2007; `https://inspire.ec.europa.eu`). The Directive aimed to unlock public sector geospatial data and facilitate its cross-border sharing and reuse to support environmental decision-making. From the practical point of view, data sharing under INSPIRE is achieved by: i) harmonising the geospatial datasets in scope (`https://europa.eu/!dTy7cG`) according to a set of target data models; ii) making these datasets discoverable through metadata; and iii) accessing them through web-based view and download services. The mechanisms to achieve so were defined through commonly agreed technical guidelines, based on open standards. The EU spatial data infrastructure, which at the time of writing (June 2025) provides access to more than one hundred thousand datasets from all over Europe, has also become a reference implementation for other similar initiatives worldwide (Minghini et al., 2021).

For the reasons mentioned in Section 1, monitoring the FAIRness of the EU public geospatial data infrastructure has been crucial since its inception. First, this process is rooted in the very nature of EU legislation as a measure to certify the compliance from EU Member States and trigger potential infringements or penalties. Second, it is also an opportunity for Member States to strengthen cooperation among national authorities, and enhance their accountability and transparency. The initial rules for monitoring the FAIRness of the EU geospatial data infrastructure (European Commission, 2009) were simplified and streamlined ten years after (European Commission, 2019), in order to both reduce the complexity of the process and support a better comparison between EU Member States implementation.

The analysis presented here focuses on this monitoring procedure, consisting in the automated calculation of 19 KPIs based on the metadata harvested from EU Member States catalogues on 15 December every year. These KPIs are grouped into five categories, measuring: i) the availability of spatial datasets and services (5 KPIs); ii) the conformity of metadata (2 KPIs); iii) the conformity of spatial datasets (4 KPIs); iv) the accessibility of spatial datasets (3 KPIs); and v) the conformity of network services (5 KPIs) (Minghini et al., 2020).

Another legislative milestone shaping the current nature of the EU geospatial data infrastructure is the Open Data Directive (European Union, 2019) and its Implementing Regulation defining the so-called high-value datasets (European Commission, 2023). These are the public sector datasets with the potential to generate the highest socio-economic benefits for the EU thanks to their reuse. As such, the legislation mandates public sector data providers to make these datasets available free of charge, under open licenses, including some basic semantic information, and accessible through Application Programming Interfaces (APIs) and bulk download. High-value datasets are classified in six categories, three of which include geospatial datasets, namely *Geospatial*, *Earth observation and environment* and *Mobility*). In this case the legislation did not define specific KPIs, but EU Member States are still required to report on the FAIRness of their implementation, by providing access to the dataset metadata and the corresponding APIs to access them. The deadline for the first-ever reporting cycle was 9 February 2025.

The list of high-value datasets having a geospatial nature was defined on purpose in full alignment with the scope of the INSPIRE Directive. Leveraging such intersection in scope, at the time of writing (June 2025), a legal revision of the INSPIRE Directive is ongoing (`https://europa.eu/!tGCQ6Q`) to fully align monitoring and reporting obligations to those under the Open Data Directive, with the aim to achieve an integrated, simplified, and user-centric approach to geospatial data management and sharing.

3. Results and lessons learnt

In this section, we distill lessons from the results of the initiatives monitoring the status of the EU public geospatial data infrastructure described in Section 2. The results of the annual INSPIRE monitoring exercise, which covers the six years from 2019 to 2024, are made available online through dedicated dashboards: at `https://inspire-geoportal.ec.europa.eu/mr/mr2019.html` for 2019, at `https://inspire-geoportal.ec.europa.eu/mr/mr2020.html` for 2020, and so on. An example of such a dashboard for one EU Member State, referred to the 2024 monitoring cycle and showing the KPI values scored, is shown in Figure 1. In contrast, the analysis of the FAIRness of high-value datasets at the deadline of 9 February 2025 (European Commission, 2023) is currently (June 2025) still underway, and only partial outcomes are available.

As a general conclusion, the experience with this monitoring activity confirms that policy implementation, especially for public sector-driven initiatives, is not a one-time effort. Instead, it is a continuous process, whose results should be assessed over time frames of at least a couple of years. Accordingly, the analysis of the INSPIRE monitoring KPIs in the last six years revealed a slow but steady improvement, which translated into more datasets constantly being made discoverable and increasingly larger fractions of them being harmonised and made accessible through web services. Along these lines, we assume that the same process (just started in 2025) will happen for the high-value datasets provided under the Open Data Directive. In this case, the analyses of the first monitoring outcomes revealed substantial differences in what was reported by the EU Member States. In some cases, access to some of the datasets in scope is still to be provided, while for other EU Member States that did report, the geospatial high-value datasets (i.e. those belonging to the categories *Geospatial*, *Earth observation and environment* and *Mobility*) there were discrepancies with those made available under INSPIRE (Morrone et al., 2025). This may be

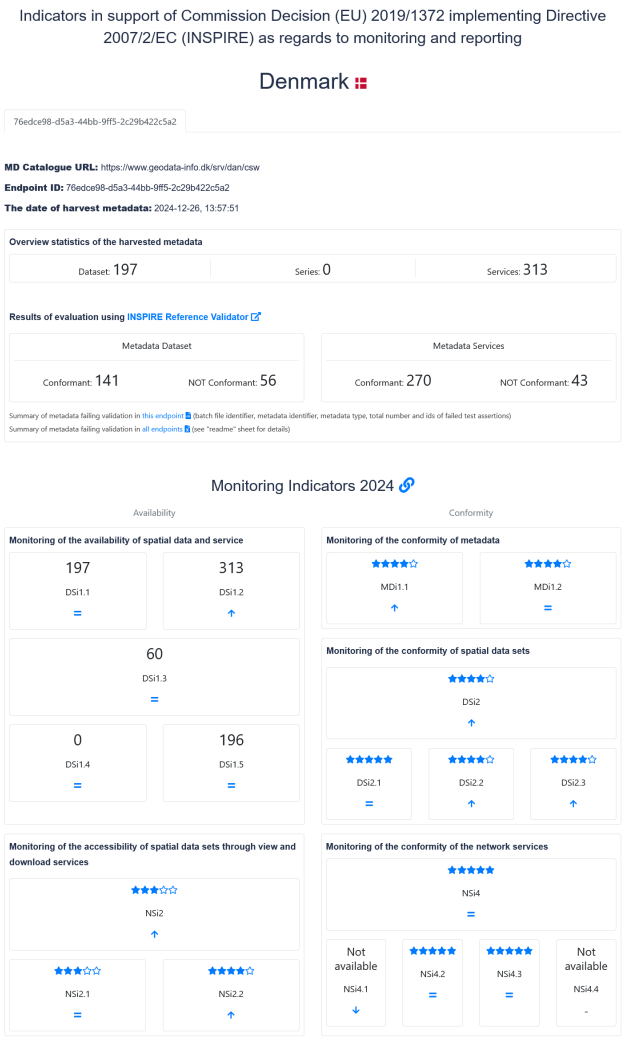

Figure 1. Example of a monitoring dashboard showing the values of the KPIs defined in the INSPIRE legislation, scored by an EU Member State.

attributed to different categories of issues: i) legal, if Member States failed to identify appropriate legal ways to enforce the implementation of the Open Data Directive at the national level; ii) organisational, if Member States did not yet setup the appropriate structures and approaches to make high-value datasets available; and iii) technical, if Member States did not put in place technical workflows to make their high-value datasets discoverable, in particular encoding metadata according to the DCAT/GeoDCAT-AP specifications (World Wide Web Consortium, 2014).

More specific lessons learnt dealing with i) the monitoring approach and measurement, ii) technical and technological aspects, and iii) community and governance processes, are separately described in the following sub-sections. We discuss positives and negatives and, for the latter, we formulate actionable improvement proposals.

3.1 Monitoring strategy

The success of a policy initiative can be highly influenced by the chosen way to monitor its implementation. This is why the strategic choice of KPIs is particularly important, as implementers may end up developing or tuning their infrastructures in order to maximise the values scored. In the case of INSPIRE, most of the KPIs are measured as percentages: examples are the fraction of metadata conformant to the technical specifications, the fraction of datasets harmonised against the target data models, and the fraction of datasets accessible through appropriate network services (Minghini et al., 2020). The counter-effect of these definitions, at least for some EU Member States, was the deliberate choice to decrease the total amount of metadata and datasets exposed, with the aim to increase the percentage values of the KPIs. In other words, instead of e.g. making all/several datasets harmonised, a higher value of the corresponding KPI was achieved by simply removing some/many of the non-harmonised datasets.

The negative effect is that high values of the KPIs (i.e. high levels of FAIRness) are not necessarily a measure of the quality of the infrastructure itself. Indeed, KPIs do not measure the actual 'content' of the geospatial data: for instance, there are no topology or quality checks (beyond the declarations available in the metadata). For these reasons, a fundamental shift would be needed from provider-centric indicators that only measure the offer from data providers, to a user-centric approach where the actual value of the data, reflected by their reuse, is assessed. We therefore point to the need to go beyond the simple measure of data FAIRness. First, different or partial levels of FAIRness may be sufficient depending on the specific dataset (Lowenthal et al., 2025); second, incorporation of the CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) principles – which are people and purpose-oriented – in addition to the FAIR ones, would be extremely valuable (Carroll et al., 2021). The very same approach that in the last two decades has fostered the development of (open data) portals, i.e. publishing as many datasets as possible in the belief that these will be used, should change in favour of publishing high-quality datasets that address the actual user needs and create real values for them.

In addition, the value of several INSPIRE KPIs is calculated based on self-declarations of conformity made by data providers in dataset metadata (Minghini et al., 2020). This approach turned out to be far from ideal, since most self-declarations were demonstrated to be largely unreliable (Escriu et al., 2025).

Finally, as described in Section 2, the legislation requires the monitoring process to happen on an annual basis with a specific target date, both for INSPIRE and the Open Data Directive. Another unintended consequence is that this may stimulate improvement actions at the national level only once a year, in the period immediately preceding the monitoring deadline.

3.2 Technical and technological aspects

From a technical perspective, although confined within legislative boundaries and advancing at a pace lower than mainstream ICT, the opportunities for the provision of geospatial datasets in the EU have significantly evolved, as envisioned by Kotsev et al. (2020). While the technical specifications issued some 15 years ago assumed Geography Markup Language (GML) as the default data encoding, modern encodings such as GeoJSON and GeoPackage have been successfully introduced as valid alternatives to encode data under both the INSPIRE (`https://europa.eu/!v4pdKH`) and the Open Data Directives (European Commission, 2023). Similarly, data provision and monitoring currently benefit from the advantages offered by API-based standards, e.g. OGC APIs, in addition to classic OGC Web Services.

Another positive achievement has consisted in the introduction of a fully automated and transparent monitoring process. This was made possible by a software stack that has evolved over the years and currently includes all open source components: the INSPIRE Geoportal (`https://inspire-geoportal.ec.europa.eu`, see also Figure 2), which is an instance of GeoNetwork (`https://geonetwork-opensource.org`) as a geospatial data catalog; the INSPIRE Reference Validator (`https://inspire.ec.europa.eu/validator`), an instance of the ETF (`https://github.com/etf-validator`), as a validation tool; and the INSPIRE Registry (`https://inspire.ec.europa.eu/registry`), an instance of Re3gistry (`https://github.com/ec-jrc/re3gistry`), to manage identifiers. When such components did not yet offer the desired functionality, custom scripts were produced and published as open source (`https://github.com/INSPIRE-MIF/mr-tools`). The open source nature of the components, with clear documentation and release plans allowing data providers to test their implementations in advance, ensured objectivity, transparency and reproducibility of results. In addition, the use of a reference validation tool brought legal certainty to the monitoring process. Last, Large Language Models (in particular, the family of open-weights models from Mistral, `https://mistral.ai`) proved extremely useful to refine, test, and validate monitoring results – for example by writing a Catalogue Service for the Web (CSW) harvester to test the harvest results returned from the Geoportal.

3.3 Community and governance

The INSPIRE experience has shown that, while monitoring is in itself a technical process, its ultimate success relies on the establishment of a continuous dialogue and a trust relationship with the relevant communities. Setting up a clear governance structure, providing transparent and scientifically sound guidance on indicator calculation, and offering clear explanations of results are key factors in achieving this success. These factors, along with targeted feedback on potential improvement areas, contribute to the regular increase in the FAIRness of INSPIRE datasets, as discussed in Sub-section 3.1. A technical infrastructure is only as good as the social infrastructure underpinning it.

In turn, the presence of an engaged community resulted in the improvement of the same software components used to carry out the monitoring process, and in a way, also in the open source tools they are instances of. As an example, Figure 3 shows the high degree of community interaction in the helpdesk of the INSPIRE Reference Validator.

Despite the legal nature of the initiatives addressed, whose requirements fall on EU Member States public sector organisations, the evolution of the EU public geospatial data infrastructure would highly benefit from broadening the governance to include other key actors such as users (for the reasons already mentioned in Sub-section 3.1), standardisation bodies, and then open source communities themselves.

4. Conclusions

This paper described and analysed the processes associated with the monitoring of data infrastructure requirements. Examples from the EU pertaining to the adherence to FAIR principles of geospatial data shared under legislatively-driven frameworks were provided. Instead of the actual outcome of the monitoring initiatives, focus was mainly placed on the assessment of the

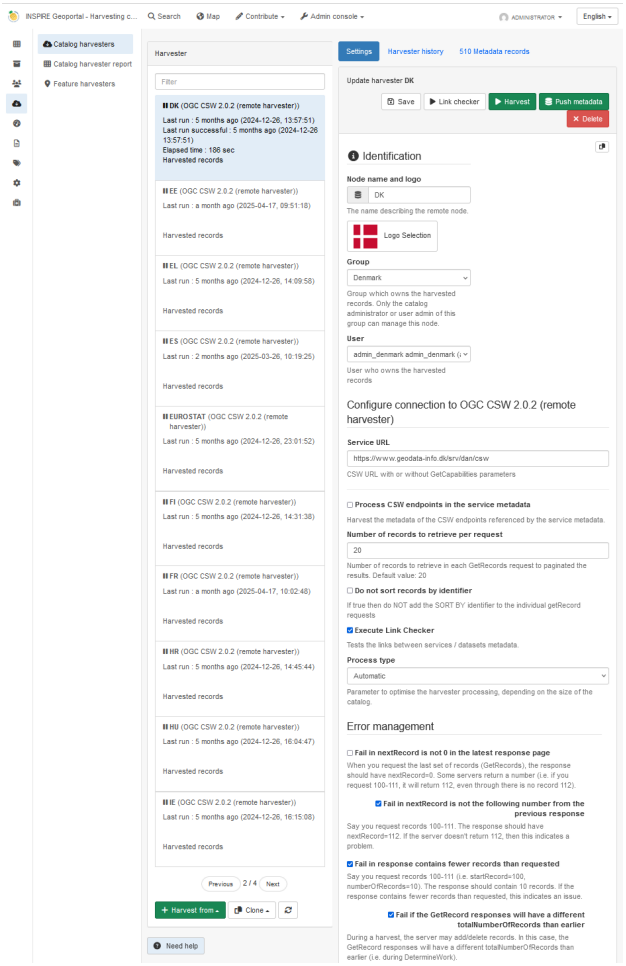

Figure 2. Harvest management console of the INSPIRE Geoportal, based on the open source GeoNetwork software.

positives and negatives of the procedures in place, deriving lessons, do's and don'ts, and formulating actionable proposals to improve the same procedures. We believe these conclusions are largely relevant not only to public sector geospatial data infrastructures, but also to a broader range of data sharing initiatives, including those established outside the EU and/or at different scales (not necessarily continental, but also national, regional or local).

The lessons learnt from the EU highlight well that making data FAIR should not be the goal, but only the means to a an end: establishing a high-quality infrastructure where data are effectively reused to improve decision-making and generate societal and economic value. In a way, despite the obvious differences due to their non-legal nature, the KPIs to monitor the United Nations' Sustainable Development Goals (SDGs) are a good example of indicators associated with the achievement of policy objectives that can (also) be measured through high-quality geospatial data (see e.g. Avtar et al., 2020; Omali, 2022).

As already commented in Section 3, in any monitoring process the choice of KPIs is strategic, as it most likely steers the developments towards a particular vision. In doing so, special attention should be paid on the design of good KPIs in order to 'predetermine' to a certain extent the future outcomes. As shown by the INSPIRE experience, such intended outcomes should go beyond simply making data FAIR, and focus instead on addressing the actual user needs and demands. Within this con-

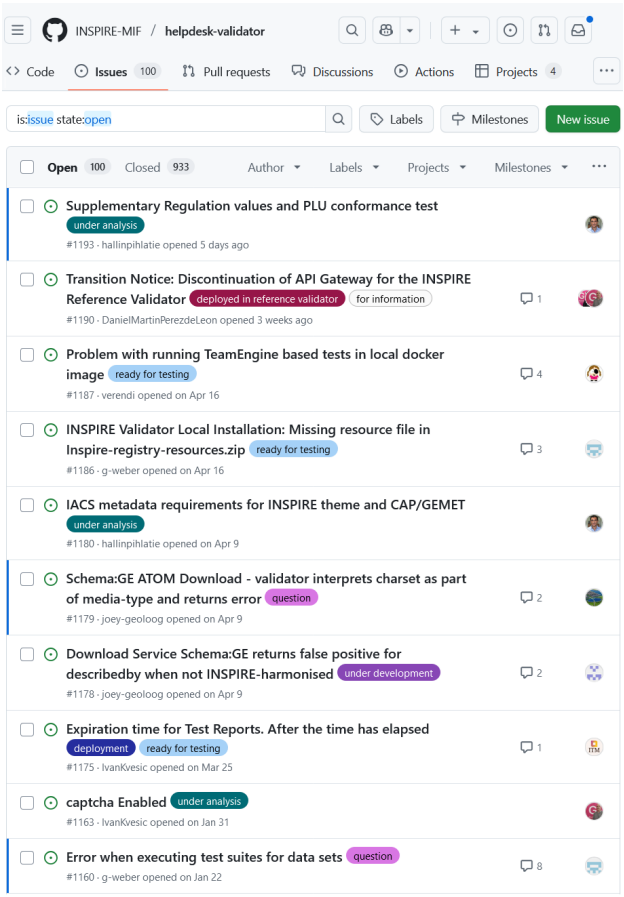

Figure 3. Helpdesk of the INSPIRE Reference Validator (`https://github.com/INSPIRE-MIF/helpdesk-validator/issues`).

text, data quality – in all its dimensions, e.g. positional accuracy, completeness and up-to-dateness (International Organization for Standardization, 2023) – should be ensured by data providers, and reliable information on quality should be included and kept up-to-date in the dataset metadata. In addition, the way data is made FAIR in data infrastructures should aim to maximise user experience. For example, in some cases it may be technically possible to download a dataset, but the experience in doing so could be burdensome. Along the same line of improving the actual data reuse, data 'actionability' should also be improved, e.g. by offering simple data usage operations in addition to the sole possibility to view and/or download the data.

However, even in the ideal case of a fully FAIR-compliant legislatively-driven infrastructure, where data availability and accessibility keep increasing over time, more work is needed in order to capture the actual usage of data and reflect it into new monitoring requirements. Understanding user demands, identifying the concrete use of data and capturing the value generated is all but trivial. It is clear that traditional approaches such as analytics/web server statistics and user surveys are not sufficient, even more so if considered in isolation. For this reason, we believe this challenge can offer a very fertile ground for future research.

A final point concerns the type and frequency of monitoring approaches. In addition to the demonstrated benefits of automating them (including through the use of open source software tools) and establishing a trust relation with the involved stakeholders, available technology holds the potential for a drastic shift from time-bounded activities to real-time, continuous processes. For instance, AI and ML algorithms could be employed for automated monitoring and reporting, while comprehensive APIs could enable real-time compliance and self-compliance checks. All of this would in turn significantly reduce the burden for both data providers and regulatory authorities.

Disclaimer

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