Digitalization and Management Innovation IV
A. Lau and A.J. Tallón-Ballesteros (Eds.)

doi:10.3233/FAIA250723

From Data Silos to FAIR Research: Interoperability and Integration in European CRIS

Danica Zendulková [a,1], Otmane Azeroual [b] and Anna Krivjanská [c]
[a] *Slovak Centre of Scientific and Technical Information, Lamačská 8/a, 840 05 Bratislava, Slovakia*
[b] *German Centre for Higher Education Research and Science Studies (DZHW), 10117, Berlin, Germany & University of Hagen, 58097 Hagen, Germany*
[c] *Slovak Centre of Scientific and Technical Information, Lamačská 8/a, 840 05 Bratislava, Slovakia*
ORCiD ID: Danica Zendulková https://orcid.org/0000-0003-2487-0177
ORCiD ID: Otmane Azeroual https://orcid.org/0000-0002-5225-389X
ORCiD ID: Anna Krivjanská https://orcid.org/0000-0001-7765-0157

Abstract. Current Research Information Systems (CRIS) play a pivotal role in the management, storage, and dissemination of research data, serving as key components within both national and international research infrastructures. Scientific and academic libraries, with their established expertise in resource description, access facilitation, and the long-term stewardship of digital assets, are instrumental in the implementation and operation of CRIS systems. This article examines the integration of the FAIR principles—Findability, Accessibility, Interoperability, and Reusability—within CRIS systems, emphasizing their contribution to supporting Open Science. Through case studies from both Slovakia and Germany, we investigate the implementation of FAIR principles in the national SK CRIS and the German CRIS systems. The article also addresses the critical importance of data source integration, the adoption of Persistent Identifiers (PIDs), and the implementation of robust data management practices as essential elements for advancing Open Science and ensuring the effective application of FAIR principles at the national level. This analysis underscores the crucial role of libraries and CRIS systems in enhancing the accessibility and interoperability of research data, fostering international collaboration, and ensuring the long-term sustainability of scientific outputs.

Keywords. CRIS, FAIR principles, interoperability, open science, data integration, persistent identifiers (PIDs), data management, libraries, national research infrastructures, case study.

1. Introduction

The effective management and dissemination of research data are crucial for scientific progress. A current research information system (CRIS) is a database or other

[1] Corresponding Author: Danica Zendulková, Slovak Centre of Scientific and Technical Information, Lamačská 8/a, 840 05 Bratislava, Slovakia; E-mail: danica.zendulkova@cvtisr.sk.

information system to store, manage and exchange contextual metadata for the research activity funded by a research funder and/or conducted at a research-performing organisation [1]. The CRIS comprise software solutions that merge research information from different sources and databases in order to describe and report on research.

CRIS serve as essential components in research information infrastructures by enabling the systematic collection, organization, and accessibility of research outputs. These systems function as local and national nodes within broader research ecosystems, ensuring structured and interoperable access to scientific information [2,3]. In the context of Open Science, CRIS play a vital role in facilitating transparency, reproducibility, and knowledge exchange [4].

Academic and research libraries have traditionally been responsible for metadata curation, resource description, and long-term digital stewardship [5]. Given this expertise, libraries are instrumental in managing CRIS and ensuring adherence to best practices for research data management. The implementation of the FAIR (Findability, Accessibility, Interoperability, and Reusability) principles [6] within CRIS is fundamental to improving data discoverability, accessibility, and usability on national and international levels. However, achieving FAIR compliance in CRIS requires robust data governance, integration of Persistent Identifiers (PIDs), and the harmonization of metadata standards across institutional and national boundaries [7].

In Europe, several national CRIS initiatives have been developed to align with FAIR principles and support Open Science policies. The Slovak Current Research Information System (SK CRIS) provides a national framework for research data integration, focusing on metadata standardization and persistent identifiers to enhance interoperability. Similarly, Germany has implemented FAIR-aligned infrastructures within the National Research Data Infrastructure (NFDI), particularly in domains such as health and social sciences [8]. These efforts reflect a broader movement toward structured research data management at the national level, supporting both institutional reporting and international collaborations.

This paper aims to examine the role of FAIR principles in CRIS implementation, emphasizing the necessity of data integration, metadata interoperability, and persistent identifiers in supporting Open Science. To achieve this, we employ comparative case studies of CRIS implementations in Slovakia and Germany:

- Case Study: Slovakia – Analyzing the integration of FAIR principles in SK CRIS, particularly in terms of persistent identifiers, metadata alignment, and national Open Science policies.
- Case Study: Germany – Examining FAIR adoption within German CRIS frameworks, focusing on the NFDI initiative, data stewardship practices, and interoperability with European Open Science Cloud (EOSC).
- Comparative Analysis – Identifying best practices, challenges, and lessons learned from both national implementations to provide recommendations for FAIR-compliant CRIS development.

2. Interoperability in CRIS Systems: Foundations, Dimensions, and Strategic Implications

Interoperability is a fundamental requirement for the effectiveness, scalability, and sustainability of CRIS, particularly in the context of Open Science and data-driven research policy. As CRIS platforms serve as integrative nodes within a fragmented research information ecosystem, their ability to interoperate with both internal and external data sources is critical for ensuring consistent, reliable, and reusable research metadata [5,9]. Achieving such interoperability, however, is contingent upon the fulfilment of several interrelated technical, semantic, and organizational conditions, each of which contributes to the broader objective of systemic coherence across heterogeneous infrastructures.

A cornerstone of interoperability in CRIS systems is the implementation and resolution of Persistent Identifiers (PIDs). PIDs such as DOIs (Digital Object Identifiers) for publications and datasets, ORCID iDs for researchers, and RORs (Research Organization Registry) for institutions serve as globally unique identifiers that anchor CRIS metadata in an ecosystem of linked open data [10,11]. The consistent and mandatory use of such identifiers ensures that entities within the CRIS—authors, institutions, outputs—can be unambiguously referenced across systems, thereby enabling findability, data deduplication, and cross-platform data reuse. Without this infrastructural layer of machine-resolvable identifiers, semantic alignment and reliable data federation across CRIS and external services would be significantly impeded.

Another foundational element of CRIS interoperability lies in the creation and maintenance of authoritative records, also referred to as “gold records” or authority files. These are curated, validated, and disambiguated metadata records that serve as canonical representations of key research entities (e.g., individual researchers, organizational units, research outputs). Authority records are essential not only for internal consistency within a CRIS but also for enabling semantic interoperability with external systems [12]. For instance, a disambiguated researcher profile in a national CRIS can be automatically reconciled with records in ORCID or Crossref via standardized metadata fields and PIDs. This reduces data fragmentation and strengthens trust in the provenance and accuracy of research information across platforms.

Beyond identifiers and authority records, interoperability also demands semantic and syntactic alignment with external reference registries and classification schemes. This includes the alignment of CRIS data models with widely accepted ontologies and schemas, such as CERIF (Common European Research Information Format) or schema.org, as well as mappings to domain-specific vocabularies. Such alignment enables CRIS platforms to exchange data with reference registries, particularly in the domains of organizations, projects, and persons, where shared classification systems (e.g., ISCED, NACE) enhance data harmonization across national and disciplinary boundaries [13,14].

A particularly critical layer of interoperability involves content-related systems, notably publication and citation databases (e.g., Scopus, Web of Science), full-text repositories (e.g., institutional repositories, arXiv), and research data repositories (e.g., Zenodo, Figshare). CRIS platforms must be able to both ingest data from and export data to these systems via standard interfaces such as OAI-PMH, RESTful APIs, and Linked Data endpoints. Bidirectional integration enables not only the enrichment of CRIS metadata with citation counts, usage statistics, and full-text access links but also supports the export of curated CRIS data to external aggregators, thus reinforcing Open Access dissemination and research impact monitoring.

A comprehensive approach to interoperability in CRIS systems, therefore, involves more than just technical compatibility. It demands a strategic alignment of infrastructures, standards, and policies to facilitate seamless, sustainable, and trustworthy data exchange. Only through such alignment can CRIS fulfill their role as reliable intermediaries in the global research information landscape and support emerging frameworks such as the European Open Science Cloud (EOSC) or national research assessment exercises.

3. Integration of Data Sources in CRIS

The effective integration of heterogeneous data sources into CRIS is a foundational requirement for achieving both operational efficiency and compliance with the FAIR principles (Findable, Accessible, Interoperable, Reusable). In practice, data integration refers to the systematic collection, harmonization, and continuous updating of research-related information from a diverse range of institutional, national, and international sources. These sources include internal university repositories, project management systems, external bibliographic and citation databases (e.g., Scopus, Web of Science), funding agency databases, and research infrastructure services such as ORCID, ROR, and Crossref [2,15].

A central aim of this integration process is the establishment of authoritative "single points of truth" — high-quality, validated, and de-duplicated information records that minimize inconsistencies and redundancies across systems. This is achieved through the use of authority files, controlled vocabularies, and PIDs, which are essential for the unambiguous identification and linking of research entities such as people, organizations, publications, and datasets. The most widely adopted PIDs include DOIs for publications and datasets (DataCite, Crossref), ORCID iDs for individual researchers, and ROR IDs for research-performing institutions [16].

Figure 1 illustrates how various sources—such as institutional repositories, bibliographic databases, funding agency platforms, and PID services—interface with a central CRIS system using standardized protocols (e.g., OAI-PMH, REST APIs). Persistent identifiers act as connective tissue between distinct entities.

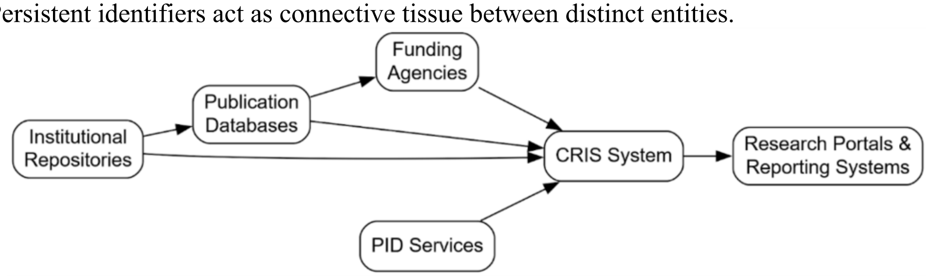

Figure 1. Example of Data Flow into a National CRIS System.

Integrating these data sources into a CRIS not only enables a comprehensive and reliable aggregation of research outputs, but also facilitates advanced functionalities such as automated reporting, Open Science monitoring, and participation in supra-national infrastructures such as the EOSC. Harmonization with external systems through standard data models (e.g., CERIF) and metadata schemas ensures semantic interoperability, which is vital for cross-system data reuse and analytics [17,18].

Despite these clear benefits, the integration of data sources into CRIS environments remains a complex and challenging endeavor. One of the foremost issues is the variability in metadata quality and formatting across data sources. Institutional repositories, bibliographic databases, and national registries often use divergent metadata schemas and terminologies, making semantic alignment and data normalization a nontrivial task. This heterogeneity can significantly hinder interoperability and reduce the overall reliability of aggregated data [19].

A further complication arises from legal and technical restrictions on data sharing, especially in the case of commercial data providers such as Scopus and Web of Science. Licensing agreements may limit the extent to which data can be ingested into CRIS systems or re-used in other contexts, posing a substantial barrier to openness and data sovereignty. Moreover, technical restrictions, such as the absence of standardized APIs or limitations on harvesting frequency, further complicate automated integration workflows.

Another persistent challenge is the inconsistent adoption of persistent identifiers and metadata standards across institutions and regions. While initiatives like ORCID, DataCite, and ROR have made significant strides toward universal adoption, gaps remain—particularly among smaller institutions or in certain disciplinary fields. Without the systematic application of PIDs, linking and deduplicating entities becomes error-prone and inefficient, undermining the promise of data unification across systems [16].

Finally, CRIS systems face high demands for data curation and validation, especially at the point of ingestion. The integration process is rarely automatic or fully error-free; instead, it requires ongoing human intervention to resolve ambiguities, correct metadata errors, and ensure consistency with internal standards. This manual effort is resource-intensive and may be underestimated during CRIS implementation planning [19]. Consequently, institutions must invest in both technical infrastructure and skilled personnel to support high-quality data integration processes.

In light of these challenges, successful CRIS integration strategies often rely on a combination of technological interoperability, institutional collaboration, and policy alignment. National CRIS initiatives, such as SK CRIS in Slovakia or Germany's involvement in the NFDI, demonstrate that overcoming these barriers is possible through coordinated governance frameworks, adoption of shared metadata standards, and investment in long-term sustainability mechanisms.

4. FAIR-by-Design: Integrating FAIR Principles Natively into CRIS Architectures

While the integration of FAIR (Findable, Accessible, Interoperable, Reusable) principles into CRIS has been broadly acknowledged as essential for advancing Open Science [6,20], existing approaches predominantly focus on retrofitting FAIR compliance onto legacy systems and existing data structures. This reactive approach often requires significant human and technical resources for metadata curation, mapping, and validation, and is inherently constrained by legacy formats and system limitations [7]. In contrast, the concept of FAIR-by-Design advocates for a proactive and systemic integration of FAIR principles directly into the architectural and functional foundations of CRIS platforms [21]. Rather than treating FAIRness as an external or evaluative layer, this paradigm proposes embedding FAIR compliance mechanisms into the core workflows and data ingestion pathways of CRIS.

The FAIR-by-Design approach redefines CRIS not as passive aggregators of research metadata, but as active agents in the production of FAIR-compliant research ecosystems. Concretely, this involves the implementation of structured metadata templates that dynamically adapt based on the type of research object (e.g., publication, dataset, project, infrastructure), disciplinary standards, and repository-specific requirements. These templates enforce minimum metadata quality thresholds at the point of entry and promote the use of PIDs such as ORCID iDs, DOIs, and RORs through automated validation and resolution services embedded within the CRIS infrastructure. By making FAIRness a condition of successful data registration, CRIS systems become engines for data quality rather than consumers of external quality assurance tools [7]. A Figure 2 illustrating this FAIR-by-Design architecture is shown below, emphasizing the role of real-time feedback and automated metadata templates in ensuring FAIRness throughout the CRIS system.

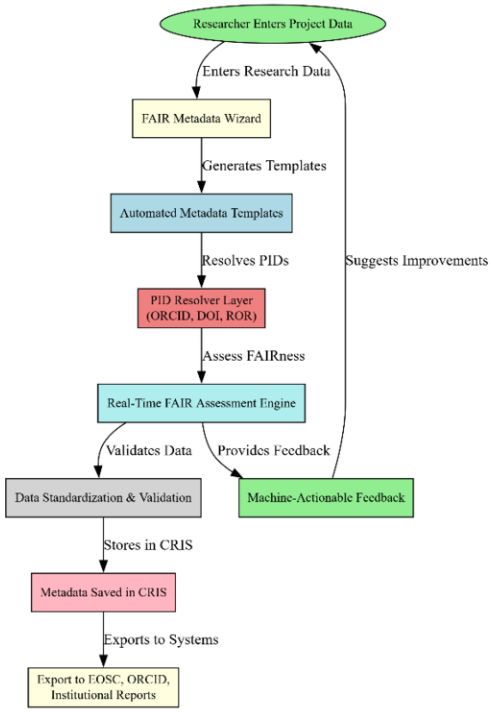

Figure 2. FAIR-by-Design Architecture for CRIS Integration.

Furthermore, a FAIR-by-Design CRIS architecture includes real-time FAIRness assessment mechanisms that offer immediate, machine-actionable feedback to data providers. Such systems may implement visual scoring indicators or automated diagnostics to identify missing metadata elements, incompatible formats, or licensing gaps. This not only supports better metadata practices among researchers but also enables institutions to monitor and benchmark FAIR compliance across departments and disciplines over time. Additionally, machine-actionable metadata facilitates seamless interoperability with transnational infrastructures such as the EOSC and enables CRIS systems to act as certified data providers within wider research data commons.

The implications of this architectural shift are significant. Firstly, it reduces the downstream workload of data curators and CRIS administrators, as compliance is achieved upstream. Secondly, it promotes metadata completeness and standardization at scale, enhancing the discoverability and reusability of research outputs. Lastly, it positions CRIS systems as key enablers of policy-driven Open Science, capable of supporting national and institutional mandates for FAIR data stewardship. While the concept of FAIR-by-Design is still in its infancy and largely absent from current academic discourse, its theoretical promise lies in its ability to operationalize FAIR principles as system logic rather than aspirational goals.

A future research agenda must address the technical and organizational preconditions for implementing FAIR-by-Design CRIS, including the development of discipline-specific metadata ontologies, automated PID resolution layers, and machine-learning models for metadata suggestion and validation. Moreover, ethical considerations surrounding mandatory metadata completeness and researcher autonomy must be critically evaluated. Nevertheless, the transition from FAIR-compliant to FAIR-native CRIS infrastructures may constitute a pivotal step toward sustainable, scalable, and policy-aligned research data ecosystems.

5. Challenges and Opportunities for Open Science

The transition toward Open Science is not merely a technical transformation—it is a systemic shift that requires cultural, institutional, and policy-level realignments. One of the major challenges lies in the fragmentation of accountability and responsibility across stakeholders in the research ecosystem. While PIDs have become standard for individuals, publications, and institutions, the granular and consistent linkage of research projects to their respective outputs and contributors remains incomplete in many systems. Without reliable attribution at the project level, assessing societal impact or calculating "value for money" becomes difficult. This gap presents an opportunity: by embedding project-level PIDs and metadata into national and institutional workflows, a more complete and transparent view of the research lifecycle can be achieved.

Another systemic challenge is the lack of harmonized workflows across institutions when it comes to data curation and metadata management. Even where technical interoperability exists, divergent practices regarding metadata quality, completeness, and validation impede effective data reuse and policy monitoring. Instead of focusing solely on unifying standards, incentivizing local practices that align with shared reference models—and making tools for metadata generation more usable—could accelerate convergence organically. Particularly underexplored is the potential of automated metadata enrichment, driven by AI tools, to bridge local variations and improve standard compliance without increasing researcher workload.

At the institutional level, a further opportunity lies in embedding Open Science goals into research evaluation and funding mechanisms. Too often, open data practices are treated as optional or auxiliary to traditional publication outputs. By integrating Open Science criteria into grant assessments, promotion criteria, and institutional audits, compliance can evolve into commitment. This, however, requires not just policy reform but also capacity-building—especially in smaller institutions that may lack the resources to develop advanced CRIS or data stewardship teams.

Lastly, Open Science efforts are often constrained by asymmetric access to infrastructure. Countries and institutions with limited digital infrastructure face disproportionate challenges in implementing FAIR principles or maintaining interoperable CRIS systems. A coordinated European effort—similar to existing models in the EOSC—could focus on shared service centers that provide technical back-ends, training, and certification services to under-resourced institutions, thereby reducing the digital divide in research information management.

In sum, while the conceptual framework for Open Science is well articulated, its operationalization depends on overcoming structural, social, and economic barriers. The integration of PIDs, better metadata workflows, and equitable access to infrastructure are not just technical enhancements—they are foundational to achieving the inclusive, transparent, and reproducible research ecosystem that Open Science envisions.

6. Case Studies from Slovakia and Germany: SK CRIS and German CRIS Systems

In Slovakia, we are aware that the concept of the CRIS system is to provide comprehensive information about science and research at the national, departmental, and institutional levels. As part of the research, we sought answers to several questions:

- Why is a scientific/academic library a suitable operator of science support systems, including the CRIS system?
- What conditions have to be met to integrate information systems for science support?
- How do we address the issue of science support in Slovakia, with an emphasis on the integration of resources (science support systems) and the implementation of FAIR principles?

Research information comprises data on a research institution's (scientific) staff and structure, projects, third-party funding, publications, patents, etc. The efficient processing of institutional research information in higher education and research institutions is a complex task, which involves the implementation and use of the CRIS system [22]. High-quality data about research activities and processes (research information) are of strategic relevance for both science communication and for research governance and policy.

The CRIS system is often operated by scientific and academic libraries. The role of libraries in this area is based on the fact that libraries have a strong tradition in describing resources, providing access and building collections, and providing support for the long-term stewardship of digital resources [23].

The Slovak Centre of Scientific and Technical Information (SCSTI) is a subsidiary organization (public body) of the Ministry of Education, Research, Development, and Youth of the Slovak Republic. SCSTI is the national information center for science, technology, innovation, and education, and a specialized scientific library of the Slovak Republic. It coordinates activities and ensures the operation of interdisciplinary R&D centers and national infrastructures for research, development, innovation, and education.

The SCSTI's main roles and activities are as follows:

- National information center and specialized scientific library of the Slovak Republic
- Operation of specialized portals and systems for research and higher education
- Promotion of technology transfer and innovation
- Popularization of science and technology
- Support of Slovakia in international research cooperation
- Implementation of national and international projects in research, development, and education

Comprehensive experience in supporting science and education with an emphasis on operating information systems at the national level, including data curation, predetermines SCSTI to play the role of an implementer of the FAIR and open science principles in the processing of research information.

In Slovakia, we focus on the implementation of unique identifiers, data management, and metadata quality control, as well as the integration of various data sources into larger infrastructures with the character of research infrastructures. The goal is to use the collected data not only at the national level but also to provide it for international comparison as part of research infrastructures.

Several significant milestones in this area have been achieved in the recent past:

(1) Deployment of the new Information System for Research and Development SK CRIS
(2) Deployment of a Comprehensive Information System for Acquiring, Processing, Storing, and Making Available Scientific and Bibliometric Data and Publications and Ensuring Access to Tools and Applications for Supporting Science and Research (KOMIS)
(3) Joining the EOSC network as a national EOSC Node

6.1. SK CRIS Information System

The information system SK CRIS, which has been in operation since 2013, is updated annually with data on research activities, entities, results, and infrastructures at the national level. The system has recently undergone a significant functional and design upgrade, especially a technological one, and has been operating in a new version since the summer of 2024.

It was built in accordance with the standards and best practices of research information in the EU. In addition to the CERIF relational data format, which allowed us to record links between basic objects, we also implemented open science and FAIR principles for the collected data. It is also important to follow standards for PIDs with an emphasis on EOSC compatibility [24].

In addition to the new design, the SK CRIS information system has the following new features after the upgrade:

(1) Implementation of the ID federation for researchers: The offer includes internationally used PIDs, namely ORCID, ResearcherID, and SCOPUS ID, as well as the national identifier of university teachers (ID from the University employee register). These IDs are currently entered manually by users.

Figure 3 ID federation in the record of a researcher.

(2) Integration with the Register of Legal Entities (RPO): The integration uses PID for an organization at the national level, namely the Organization Identification Number - IČO. The RPO is a reference register. This integration allows obtaining data on organizations into SK CRIS based on the IČO check. The "once is enough" principle is applied, meaning users do not have to enter data that already exists in the RPO.

(3) Expansion of registered data for research results with DOI and URL of the full text of the publication.

(4) Extended user interface options for searching, including multi-criteria search, allowing simultaneous selection of multiple code list items and adding combined search of basic objects (projects by organization and researcher).

6.2. KOMIS – The National Research Infrastructure

The created national research infrastructure KOMIS aggregates science support systems operated by SCSTI and makes available the services of the Data Centre for Research and Development (DC VaV). This includes the use of storage capacity, data processing, and the use of various installed software (Software as a Service - SaaS), mainly from the fields of mathematics, statistics, and bioinformatics. The solution includes analytical tools for data processing and a module for searching available data and information sources.

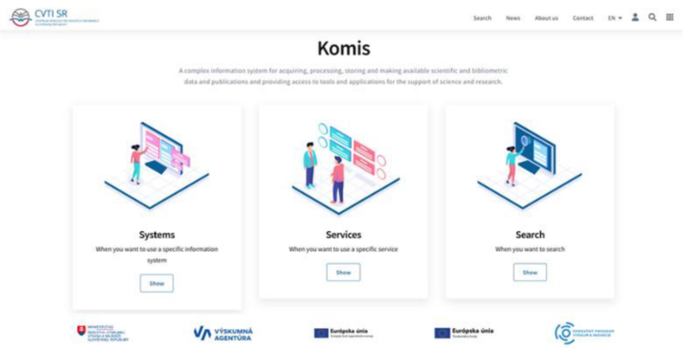

Figure 4 The KOMIS system – main webpage.

The KOMIS integrates several systems:

- **The Slovak Current Research Information System (SK CRIS)** and **The Central Information Portal for Research, Development, and Innovation (CIPVVI):** The CIPVVI website represents one of the basic information, management, and control tools of the state scientific and technical policy. It provides information on science, research, and innovations supported by public resources.
- **The Central Registry of Publications of Universities in the Slovak Republic (CREPC):** This database records and evaluates the publication activity of higher education institutions in Slovakia.
- **The Central Registry of Artistic Activity of Universities in the Slovak Republic (CREUC).**
- **The Central Registry of Theses and Dissertations** with the anti-plagiarism system (CRZP): This repository holds electronic versions of final and qualification theses from higher education institutions in Slovakia.
- **The Slovak Central Database of Electronic Information Resources for Research and Development (SCIDAP):** This database stores and provides access to information resources produced by Slovak scientific and research institutions.
- **Research Data Management (SVD):** This repository stores and makes available research datasets produced by Slovak scientific and research institutions.

KOMIS will also contain an Analytical Module for Science Assessment, Open Access Publishing Platform, Integrated System of Services of the SCSTI, and a Discovery System for Electronic Information Resources. Not all of the last-mentioned modules are in production yet, as KOMIS is currently in its pilot operation, with its beta version not yet enabling the full operation of all functionalities.

6.3. SCSTI and EOSC

SCSTI, as the national EOSC coordinator for Slovakia, became part of the pilot consortium of European organizations that will participate in building the EOSC Federation's network of nodes. In a six-month selection process at the European level, SCSTI was selected from 121 applications to be part of a group of thirteen established institutions that will participate in building the initial form of the EOSC Federation. The nomination of SCSTI to the position of national EOSC node will allow SCSTI to rank among the leading European scientific and research institutions supporting the principles of open science and FAIR data.

The technical solution for joining the EOSC assumes the involvement of the KOMIS system, including SK CRIS.

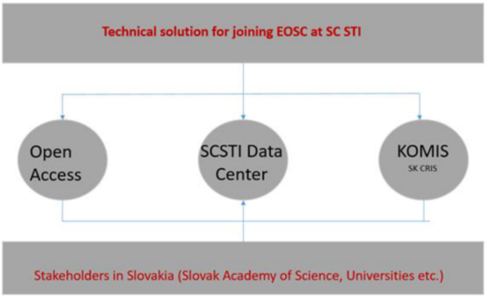

Figure 5 Technical solution for joining EOSC.

All major KOMIS components will meet EOSC compliance standards: the central KOMIS framework, SVD (research data objects repository), SCIDAP (scientific publications repository), SK CRIS (Current Research Information System tracking projects, organizations, and researchers), and discovery service layer. Technical enhancements will include implementing IDM integration with the EOSC AAI, developing standardized API gateways for all subsystems, establishing automated metadata harvesting pipelines, and altering a robust PID management system supporting multiple identifier schemas.

6.4. Comparison with Germany: CRIS Systems in a Decentralized Landscape

Unlike Slovakia, where the Slovak Centre of Scientific and Technical Information (SCSTI) coordinates a centralized and state-supported approach to research information systems, Germany operates in a more decentralized and federated model.

In Germany, no single national CRIS system exists. Instead, research information systems are implemented locally at the level of universities, research institutions, and research funding organizations. Many of these institutions use commercial CRIS solutions (such as PURE or CONVERIS) or self-developed systems to manage and integrate research data.

To support interoperability and standardization across this fragmented landscape, the German Research Foundation (DFG) and organizations such as DINI (German Initiative for Network Information) and the Research Core Dataset (Kerndatensatz Forschung, KDSF) initiative have established guidelines and minimum standards for research reporting. The KDSF model is widely used as a basis for harmonizing the collection and exchange of research information.

Table 1. Key Differences and Similarities.

Aspect	Slovakia (SK CRIS & KOMIS)	Germany (Local CRIS Systems)
Governance	Centralized, coordinated by SCSTI under the Ministry	Decentralized, institutional autonomy
System Coverage	National-level integration (SK CRIS, KOMIS)	Institutional-level implementation
Standards	CERIF, FAIR principles, EOSC integration	KDSF, CERIF-compatible in some systems
PID Integration	Centralized (ORCID, IČO, DOI)	Institution-specific, growing ORCID adoption
EOSC Participation	National EOSC node via SCSTI	Participation through individual institutions and consortia (e.g. NFDI)
Open Science Support	Centralized infrastructure (KOMIS)	Diverse initiatives, e.g., via NFDI consortia and OpenAIRE nodes

While Slovakia benefits from central coordination and rapid implementation, Germany emphasizes institutional freedom and diversity, which fosters innovation but can lead to inconsistencies in data structures and interoperability.

Both countries are moving toward greater integration with the European Open Science Cloud (EOSC) and are actively promoting FAIR data principles, albeit through different organizational structures.

7. Conclusion

The transition from fragmented research information landscapes to integrated, FAIR-aligned CRIS infrastructures is not merely a technical evolution—it is a strategic imperative for Open Science and international research collaboration. This paper has demonstrated that persistent identifiers, harmonized metadata standards, and FAIR-by-Design architectures are not optional features but essential enablers of sustainable, transparent, and interoperable research ecosystems. The case studies from Slovakia and Germany underscore that national efforts, when aligned with European initiatives such as the EOSC, can successfully overcome legacy system limitations and institutional fragmentation.

Libraries, due to their expertise in metadata curation and stewardship, are uniquely positioned to lead this transformation by operating CRIS systems and shaping best practices. Yet, the realization of truly FAIR-compliant infrastructures depends on continuous investment—in both technical capabilities and human expertise—as well as policy support that embeds FAIR and Open Science goals into evaluation, funding, and governance frameworks.

To fully unlock the potential of CRIS in the digital age, stakeholders must embrace interoperability not just as a technical challenge, but as a collaborative responsibility. Only through such alignment can Europe build a resilient and inclusive research infrastructure where data is not only stored but actively shared, reused, and trusted across borders and disciplines.

References

[1] Jakobs K. Shaping the Future Through Standardization. IGI Global, 2019. ISBN: 9781799821816. doi:10.4018/978-1-7998-2181-6.
[2] Jeffery KG. Research information management: The CERIF approach. International Journal of Metadata, Semantics and Ontologies, 2015; 10(1): 15–28.
[3] De Castro P. The role of Current Research Information Systems (CRIS) in supporting open science implementation: the case of Strathclyde. Informačné technológie a knižnice (ITLib), 2018.
[4] Ayris P, López de San Román A, Maes K, Labastida I. Open Science and its role in universities: A roadmap for cultural change. League of European Research Universities (LERU), 2018.
[5] Schöpfel J, Azeroual O, Jungbauer-Gans M. Research ethics, open science and CRIS. Publications, 2020; 8(4): 51.
[6] Wilkinson MD, Dumontier M, Aalbersberg IJ, et al. The FAIR guiding principles for scientific data management and stewardship. Scientific Data, 2016; 3: 160018.
[7] Azeroual O, Schöpfel J, Pölönen J, Nikiforova A. Putting FAIR principles in the context of research information: FAIRness for CRIS and CRIS for FAIRness. In: 14th Int. Conf. on Knowledge Management and Information Systems (KMIS2022). SCITEPRESS, 2022; 63–71.
[8] Pampel H, Vierkant P, Scholze F, et al. Making research data repositories visible: the re3data.org registry. PLOS ONE, 2013; 8(11): e78080.
[9] Suominen T. FAIRCORE4EOSC: Developing EOSC Core components to enable a FAIR EOSC ecosystem, 2022.
[10] Haak LL, Fenner M, Paglione L, Pentz E, Ratner H. ORCID: a system to uniquely identify researchers. Learned Publishing, 2012; 25(4): 259–264.
[11] Cousijn H, Braukmann R, Fenner M, et al. Connected research: The potential of the PID graph. Patterns, 2021; 2(1).
[12] Schöpfel J, Azeroual O. Current research information systems and institutional repositories: From data ingestion to convergence and merger. In: Future Directions in Digital Information. Chandos Publishing, 2021; 19–37.
[13] Vancauwenbergh S. Governance of research information and classifications, key assets to interoperability of CRIS systems in inter-organizational contexts. Procedia Computer Science, 2017; 106: 335–342.
[14] Leiva-Mederos A, Senso JA, Hidalgo-Delgado Y, Hipola P. Working framework of semantic interoperability for CRIS with heterogeneous data sources. Journal of Documentation, 2017; 73(3): 481–499.
[15] Sivertsen G. Developing Current Research Information Systems (CRIS) as data sources for studies of research. In: Springer Handbook of Science and Technology Indicators, 2019; 667–683.
[16] Fenner M, Crosas M, Grethe JS, et al. A data citation roadmap for scholarly data repositories. Scientific Data, 2019; 6(1): 28.
[17] Jeffery KG, Asserson A, Houssos N, Brasse V, Jörg B. From open data to data-intensive science through CERIF. Procedia Computer Science, 2014; 33: 191–198.
[18] Azeroual O, Herbig N. Mapping and semantic interoperability of the German RCD data model with the Europe-wide accepted CERIF. Information Services & Use, 2020; 40(1–2): 87–113.
[19] Azeroual O, Saake G, Abuosba M. Data Quality Measures and Data Cleansing for Research Information Systems. Journal of Digital Information Management, 2018; 16(1): 12–21.
[20] Ayris P, Ignat T. Defining the role of libraries in the Open Science landscape: a reflection on current European practice. Open Information Science, 2018; 2(1): 1–22.
[21] Azeroual O, Schöpfel J, Pölönen J, Nikiforova A. FAIRification of CRIS: A review. In: International Joint Conference on Knowledge Discovery, Knowledge Engineering, and Knowledge Management. Springer, Cham, 2023; 280–298.
[22] Biesenbender S, Petersohn S, Thiedig C. Using Current Research Information Systems (CRIS) to showcase national and institutional research (potential): research information systems in the context of Open Science. Procedia Computer Science, 2019; 146: 142–155.
[23] LIBER Europe. Implementing FAIR Data Principles: The Role of Libraries. 2017. Available at: https://libereurope.eu/blog/2017/12/08/implementing-fair-data-principles-role-libraries.
[24] Valle M, Heughebaert A, Kotarski R, et al. A persistent identifier (PID) policy for the European Open Science Cloud (EOSC). 2020.