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D4.2 - FAIR semantic artefact lifecycle from engineering, to sharing

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D4.2 - FAIR semantic artefact lifecycle from engineering, to sharing

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Acronyms

Acronym	Description
10-SR	Ten Simple Rules for FAIR vocabularies
API	Application Programming Interface
DCAT	Data Catalogue Vocabulary
EOSC	European Open Science Cloud
EOSC-IF	EOSC Interoperability Framework
FAIR	Findable, Accessible, Interoperable, Reusable principles
IF	Interoperability Framework
KOS	Knowledge Organization System
LOT	Linked Open Terms methodology
LOV	Linked Open Vocabulary
FOOPS	Ontology Pitfall Scanner for FAIR
FsF	H2020 FAIRsFAIR project
FvF	Feature of a FAIR vocabulary
MOD	Metadata for Ontology Description and Publication
O'FAIRe	Ontology FAIRness Evaluator
OWL	Web Ontology Language
RDF	Resource Description Framework
RDF-S	Resource Description Framework Schema
SA	Semantic Artefact
SAC	Semantic Artefact Catalogue
SKOS	Simple Knowledge Organisation System
SKOSMOS	Open source web-based SKOS vocabulary
URI	Uniform Resource Identifier
VSSIG	RDA Vocabulary and Semantic Services Interest Group

Executive Summary

Semantic Artefacts (SAs) is a broad term to designate different knowledge organization systems or semantic resources, including ontologies, terminologies, taxonomies, thesauri, vocabularies and, metadata schemas. SAs are essential for standardising data representation and annotation, encapsulating the highest level of meaningful knowledge within interoperability frameworks. These artefacts are fundamental to sustainable, quality-assured data description practices and they are crucial to follow the FAIR Principles, particularly Interoperability (Principle I.2). Experts, including those involved in the EOSC Interoperability Framework (EOSC-IF), agree that this framework should adopt a bottom-up approach, to take in account insights from different real-world domains.

This deliverable (D4.2) presents several aspects of SAs lifecycle that are scanned to guide and inspire stakeholders in producing and distributing FAIR semantic artefacts. D4.2 is one of the main deliverables of FAIR-IMPACT's task T4.2 which aims to establish guidelines and practices related to the FAIR SA's lifecycle from creation (*Subtask 4.2.1 - Semantic artefact engineering, adoption and description*) to sharing and reuse via Semantic Artefact Catalogues (SACs) or repositories (*Subtask 4.2.2 - Interoperable Semantic Artefact Catalogues*). The task also worked to standardise the mechanisms to describe and serve semantic artefacts (*Subtask 4.2.3 - Standardised semantic artefact metadata and their catalogue APIs*) respectively with MOD (Metadata Ontology Description and Publication) and the MOD-API specification. This document shows the work of T4.2 in embedding the FAIR principles throughout the lifecycle of SAs (Section 2), from their engineering (Section 2.1) to the sharing process (Section 2.2), with a particular focus on SACs. It highlights the interoperability strategies concerning SACs and the actions taken to federate and sustain them (Section 3).

1 Introduction

1.1 Topic presentation

1.1.1 Semantic Artefacts and their catalogues

Semantic Artefacts (SAs) as defined in FAIRsFAIR¹ and the EOSC Interoperability Framework is a broad term that includes ontologies, terminologies, taxonomies, thesauri, vocabularies, metadata schemas and standards— were defined by the FAIRsFAIR project as: “*machine-actionable and readable formalisation of a conceptualisation that enables the sharing and reuse by humans and machines*. These artefacts may have a broad range of formalisation, from loose set of terms, taxonomies, thesauri to higher-order logics. Moreover, SAs are serialised using a variety of digital representation formats, e.g., RDF Turtle, OWL-RDF, XML, JSON-LD”. Acting as shared knowledge, they can harmonise heterogeneous datasets, facilitate data integration, enable meaningful analysis, and

¹ <https://doi.org/10.5281/zenodo.3707985>

interoperability. SAs are critical for advancing scientific research, fostering data interoperability, facilitating the reuse of data across disciplines.

Collecting and centralising SAs in the same platform represents another step to facilitate data interoperability by enhancing their organisation, discoverability and accessibility. We call these centralised systems/platforms: **Semantic Artefact Catalogues (SACs)** and they include, among others, ontology repositories, knowledge organization systems registries, vocabulary/terminology services and metadata standards/schemas catalogues and registries. SACs are essential tools for the identification, description, evaluation, and exchange of semantic artefacts, enhancing their reuse and alignment. SACs represent a cornerstone of a successful and effective process for sharing SAs and have to be considered as key elements in the SA lifecycle and for making SAs FAIR.^{2,3}

To enhance the data discovery, access and reuse in scientific research performance, a set of principles have been proposed, called **FAIR Data Principles**,⁴ for Findable, Accessible, Interoperable and Reusable. Those principles have been embraced by different research funding organisations, government bodies or alike, such as the European Commission⁵ as a requirement and good practice to be adopted by the scientific community for an intelligible characterisation and harmonised (re)use of research data. The FAIR principles outline guidelines for scientific communities to produce quality-assured data sustainably. However, they are not formal standards and should not be treated as a universal set of rules applicable to every research outcome, in every discipline or scientific community. FAIR-IMPACT's mission is to support the interpretation and implementation of the FAIR principles across diverse types of outcomes and different scientific domains.

To develop a 'web of FAIR Data and Services' for science in Europe, the **European Open Science Cloud (EOOSC)** strategy aims to promote open science, enhance research outcomes as (re) usable digital assets by machine and humans, and make them available for interdisciplinarity research. SAs and their Catalogues are explicitly highlighted in the **EOOSC Strategic Research & Innovation Agenda and Multi-Annual Roadmap**.⁶ The **EOOSC Interoperability Framework (EOOSC-IF)**⁷ further support this vision by providing a set of guidelines on technical and semantic interoperability, enabling communities to overcome silos and foster collaboration and reuse. Among the key components identified by the EOOSC-IF are SAs and their catalogues.

1.1.2 Challenges to overcome

In the context of FAIR principles for research outcomes' potential value, SAs themselves need to be FAIR. Widely used across scientific disciplines to standardise data representation and annotation, these artefacts play a pivotal role in implementing the FAIR principles,

² <https://doi.org/10.5281/zenodo.6675295>

³ <https://theses.hal.science/tel-02133335v1>

⁴ <https://doi.org/10.1038/sdata.2016.18>

⁵ <http://data.europa.eu/doi/10.2777/986252>

⁶ <https://eosc.eu/sria-mar/>

⁷ <https://data.europa.eu/doi/10.2777/620649>

particularly the I2 principle). However it has become increasingly clear that these artefacts themselves must also comply with these principles. The growing proliferation of SAs brings new challenges, including their description, selection, evaluation, trustworthiness and interconnection. The **landscape remains fragmented, with SAs distributed across various registries, collections, indexes, etc., presented in different formats, varying in size and structure**, and often overlapping their domain coverage. Each level of SA has a preferential language representation and/or syntax relying on standards such as SKOS or OWL. However, the compartmentalisation of the SA formalisation poses significant barriers to achieve full interoperability. Overcoming these challenges requires the development of common platforms to catalog, align, and facilitate the sharing of FAIR SAs. In response, **SAs catalogues (SACs) are essential to support scientific communities and their diverse use cases**. However, SACs often emerge asynchronously, with little or no coordination among stakeholders, leading to the creation of multiple platforms that are not necessarily interoperable. This frequently lacks alignment in terms of technologies, metadata models and API protocols used. Such lack of standardisation and alignment jeopardize not only the interoperability and the reusability of SACs but also the FAIRness of the SAs.

Below, we connect the challenges for SAs and SACs to those identified by the **EOSC-IF**. The key concerns of the EOSC-IF include the quality and completeness of SA metadata, harmonisation across disciplinary communities, sustainability through a well-defined governance framework, and their FAIRness.

*There is a **lack or over-abundance of metadata models** that allow the description, functional preservation and ultimately re-use of the data stored.*

*The need to have (...) **shared semantic artefacts (ontologies, thesauri) inside and across the communities**, which allow homogenising the interpretation and treatment of the exchanged data and all of its associated resources.*

*Not only term definitions are usually lacking, but also common semantic artefacts across communities (e.g., general ontologies that can be shared). And in case that they exist, **these artefacts may not be sufficiently well documented** (...) Every semantic artefact that is being maintained in EOSC must have sufficient associated documentation, with clear examples of usage and conceptual diagrams.*

*Need for principled approaches and tools for ontology and metadata schema creation, maintenance, governance and use (...) furthermore, **any semantic artefact should also be FAIR**.*

*Repositories of semantic artefacts, rules with a **clear governance framework** (...) Clear protocols and building blocks for the **federation/harvesting of semantic artefacts catalogues**.*

*...The functional content can be summarised as different types of knowledge bases/**repositories provisioning metadata, semantic artefacts and crosswalks/mappings** that enable translation between different metadata standards and semantic artefacts to enable an effective exchange.*

Box 1. Extracts from the EOSC Interoperability Framework⁸ related to SA and SACs.

⁸ <https://data.europa.eu/doi/10.2777/62064>

1.2 Objectives of T4.2. Deliverable (D4.2)


1.2.1 FAIR-IMPACT project and WP4 scope

The FAIR-IMPACT project aims to **support the implementation of FAIR-enabling practices, tools and services across scientific communities within the EOSC ecosystem**. FAIR-IMPACT works to connect knowledge across scientific domains on five main topics: Persistent identifiers (WP3), Metadata and ontologies (WP4), Metrics, certification and guidelines (WP5) and Interoperability (WP6) aspects via a community-led approach.


FAIR-IMPACT's WP4⁹ plays a key role in advancing several components necessary for the implementation of the "Semantic Interoperability" of EOSC-IF by addressing **diverse research objects such as SA, SAC but also mappings and research software**. WP4's goal is to foster community consensus on adopting the FAIR Principles, thereby preventing the compartmentalisation of practices that might hinder the interoperability and reusability. Fig1. summarises the work undertaken on SAs and SACs to support FAIR principles and EOSC-IF recommendations.

Our work on Semantic Artefacts and their Catalogues


- Existing catalogues being consolidated in communities
- New catalogues being deployed in other communities/projects
- Semantic Artefact « FAIR-by-design » methodology
- FAIR-enabling tools and methods being transferred
- Exhaustive review of current and retired catalogues and FAIR-enabling criteria
- Catalogues being exploited in data repositories (9 use cases)
- A metadata standard for semantic artefacts (MOD)
- A standard API for semantic artefact catalogues (MOD-API)
- Early work on federation of 4 catalogues
- 3 possible models for semantic artefact governance
- Toward specifications for FAIR mappings



Semantic Artefact Catalogues



Semantic Artefact



Mappings

Figure 1. Summary of main FAIR-IMPACT's WP4 results related to SAs.

1.2.2 Community-driven approach

As previously mentioned FAIR-IMPACT is a **multi-level community-driven project** that integrates use cases¹⁰ along the project, and beyond. This approach allows us to address real-world challenges and provide practical and concrete solutions. Initially, we work with **multiple communities as use case** to consolidate, deploy or experiment SACs tailored, for their specific disciplines or contexts (e.g. AgroPortal¹¹ (INRAE) for agri-food, EcoPortal¹²

⁹ <https://fair-impact.eu/wp4-metadata-and-ontologies>

¹⁰ <https://fair-impact.eu/use-cases>

¹¹ <https://agroportal.lirmm.fr/>

¹² <https://ecoportal.lifewatch.eu/>

(LifeWatch) for ecology, EarthPortal¹³ (CNRS/Data Terra) for earth sciences and the recent OntoPortal-Astro prototype (OBS-PARIS) for astronomy. We are now also working on moving the Linked Open Vocabulary¹⁴ (LOV) platform to an OntoPortal-based instance.

Furthermore, we extend our reach by engaging with **communities beyond FAIR-IMPACT within the EOSC ecosystem**. With the participation of the OntoPortal Alliance WP4's team has also collaborated with communities outside the scope of FAIR-IMPACT and its partners, (e.g., NFDI4Biodiversity in Germany, technological sciences and wind energy in Switzerland, or Consortium of European Social Science Data Archive (CESSDA). These adoptions are examples of FAIR-IMPACT's success in its mission to consolidate and harmonise the use of FAIR SAs across multiple EOSC communities. Finally, **in partnership with WP2 on engagement, adoption and implementation, WP4 extends its outreach to different tiers** including external parties across domain and disciplines, geographic areas and stakeholder groups, through WP2 support program.¹⁵ For the 3rd FAIR-IMPACT Open call, WP4 supported the implementation of a standardised Application Programming Interface (API) for SACs based on MOD, a recommendation for the description of SA previously existing and adopted/enhanced by FAIR-IMPACT.¹⁶ Supporting this API specification is one of the means identified to enable SAC interoperability and provide unified access to their content, as will be detailed ed later.

This deliverable highlights the work done in T4.2 and describes FAIR-IMPACT's contribution to the lifecycle of FAIR SAs, from engineering (Section 2.1) to sharing (Section 2.2) and SAC interoperability (Section 3). A table summarizing FAIR-IMPACT related SACs is presented in Section 4 before the Conclusion (Section 4).

2 FAIR Semantic Artefacts: From Engineering to Sharing

FAIR-IMPACT highlighted the uneven maturity of **SA engineering practices** across disciplines, ranging from the advanced workflows and formalised vocabularies in biomedicine to the limited accessibility of semantic artefacts in fields like astronomy, social sciences, cultural heritage or earth sciences. Creating or engineering FAIR SAs is a complex and demanding process that requires expertise in knowledge representation, ontology engineering, semantic web technologies and standards (e.g., OWL, SKOS), including versioning, adapting, importing, and reusing other SAs. Additionally, the FAIR principles must be considered at every step of the SA reuse. By being well-documented, machine-readable, and governed by clear licensing terms, FAIR SAs enhance data discoverability, accessibility, and reusability, reducing duplication of effort and accelerating collaboration. They underpin the FAIRness of data by providing standardised terms and structures for consistent annotation and representation, which are essential for automation, AI-driven workflows, and advanced applications such as knowledge graphs. Ensuring their FAIRness supports long-term sustainability, preserving their relevance as technologies evolve and aligning with global

¹³ <https://earthportal.eu/>

¹⁴ <https://lov.linkeddata.es/dataset/lov/>

¹⁵ <https://fair-impact.eu/fair-impact-open-calls-support>

¹⁶ <https://fair-impact.eu/implementing-shared-api-for-semantic-catalogues>

open science commons and infrastructures like EOSC. FAIR SAs are strategic assets for creating a more efficient, collaborative, and impactful research ecosystem.

Beyond the creation and engineering steps, the **sharing process** is a pivotal phase/step in the SA lifecycle. The methods for sharing and publishing SAs vary depending on the context. As data, the dissemination of SA can be fostered by being associated with a scientific publication, or in relation with a specific project. Ideally like any other digital objects, SAs should be catalogued to synchronise and harmonise the sharing process across disciplines and communities. SACs play a critical role in fostering the compliance of SAs within the context of EOSC. For instance, catalogues of SAs provide platforms not only for hosting and serving SA but also enable their alignment with other SAs facilitating their reuse across diverse communities and disciplines.

2.1 FAIR Semantic Artefacts Engineering

This section explores various aspects of the SA creation, engineering, description and managing process, highlighting FAIR-IMPACT's contribution to FAIR SAs. We begin by presenting a "FAIR-by-design" methodology for developing FAIR SAs (Section 2.1.1). Next, we discuss the standardised approach to describe SA's metadata using MOD vocabulary (Section 2.1.2). Subsequently, we explored the process of metadata curation and harmonization which enabled collaboration with WP5 on the FAIRness assessment of SAs (Section 2.1.3).

2.1.1 FAIR-by-design methodology for Semantic Artefact

The FAIR-by-design methodology is an approach that ensures data, software, and other digital objects are FAIR from the outset of their creation. Instead of retroactively applying FAIR principles to existing datasets or tools, this methodology integrates them into the development process from the beginning. The FAIR-by-design methodology has been adopted in other EOSC projects and applied to their specific digital assets (e.g., In Skills4EOSC, to training materials).¹⁷ We developed a "**FAIR-by-design**" methodology tailored for creating FAIR ontologies, with the potential to extend its application to other types of vocabularies or SAs. The focus was primarily on vocabularies and ontologies, formalised using semantic web representation languages (RDF-S, OWL, SKOS). The proposed approach builds upon the Linked Open Terms (LOT) methodology¹⁸ and integrates the expertise of developers, best practices, guidelines, and already available tools for ontology creation and management. By aligning ontology development activities with identified needs, existing FAIR recommendations, and available tools, our work has highlighted both the areas already addressed, and the gaps that must be addressed to establish the LOT4FAIR methodology presented in M4.2. We presented the first version of the LOT methodology¹⁹ equipped with FAIRness assessment steps at the FOAM workshop 2024.²⁰

¹⁷ <https://zenodo.org/records/8305540>

¹⁸ <https://lot.linkeddata.es/> and <https://doi.org/10.1016/j.engappai.2022.104755>

¹⁹ FAIR principles for Ontologies and Metadata in Knowledge Management: <https://onto4fair.github.io/foam/>
 See also the peer-reviewed accepted paper in <https://doi.org/10.1016/j.engappai.2022.104755>

²⁰ <https://hal.science/hal-04678381/>

The methodology addressed the gaps where no recommendations or guidelines exist to ensure SA FAIR at design phase. These gaps were methodically found by mapping with recommendations and guidelines for FAIR SAs development brought by FAIR-IMPACT's partners: O'FAIRe (INRAE), FOOPS! (UPM), FsF (eSDF), 10-Simple Rules (STFC), and FVF (UNIMAN).

Related milestone / deliverable

M4.2	Processes & tools to engineer FAIR semantic artefacts	UPM	https://doi.org/10.5281/zenodo.10551053
M5.3	Semantic artefact assessment methodology	UPM	https://doi.org/10.5281/zenodo.8305172

2.1.2 Specification of Semantic Artefacts description with MOD

We provide a standardised methodology to describe the metadata of SAs, called the *Metadata for Ontology Description and Publication* (MOD) ontology. **MOD provides a comprehensive vocabulary for describing SAs.** Developed to address the need for consistent and aligned metadata for SAs, MOD builds on the W3C metadata standard *Data Catalogue Vocabulary*²¹ (DCAT) and incorporates recommendations from the FAIRsFAIR project and the Research Data Alliance (RDA) *Vocabulary and Semantic Services Interest Group* (VSSIG). Previously, MOD has been used to create a common minimum metadata schema for FAIR SAs in the context of the FAIRsFAIR project?^{22,23} With M4.3 (which corresponds to MOD v3.0, March 2024), FAIR-IMPACT did produce a metadata vocabularies adopting and extending MOD by proposing a DCAT-based approach for describing SAs and SACs, alongside mappings to other metadata vocabularies and a methodology for creating machine-actionable MOD profiles. The release of MOD3.2 (July 2024. Cf. Figure 2) included the following updates:

- Mechanisms to allow MOD properties to be assigned to multiple classes within MOD, e.g., `dcterms:accrualMethod` can now either be used to describe how terms (concepts, classes) are added to a `mod:SemanticArtefact`, and to describe how SAs are added to a `mod:SemanticArtefactCatalog`.
- The class `mod:SemanticArtefactCatalog` is now explicitly described with properties from MOD ensuring a comprehensive representation not only of the objects (SAs) being catalogued but also of the catalogue itself.
- Additional properties were added to enrich the description of both `mod:SemanticArtefactCatalog` and `mod:SemanticArtefact`, expanding the metadata descriptive capabilities.
- The MOD description with MOD properties²⁴ has been updated to incorporate and reflect all properties introduced in versions 3.0, 3.1, and 3.2, ensuring clarity and consistency across versions.

²¹ <https://www.w3.org/TR/vocab-dcat/>

²² <https://doi.org/10.5281/zenodo.6675295>

²³ <https://hal.science/hal-04106533>

²⁴ <https://github.com/FAIR-IMPACT/MOD/blob/main/mod.ttl#L42>

- MOD new versioning file organisation to better address URI's resolution.

These updates enhance the scope and utility of MOD for describing SAs and their catalogues. As presented in Section 3.1, MOD serves as a foundational framework to harmonize metadata across diverse SA catalogues, facilitating interoperability and providing unified descriptions of both SAs and the catalogues themselves.

Related milestone / deliverable

M4.3	Specification of semantic artefact description	STFC / INRAE	https://doi.org/10.5281/zenodo.10725303
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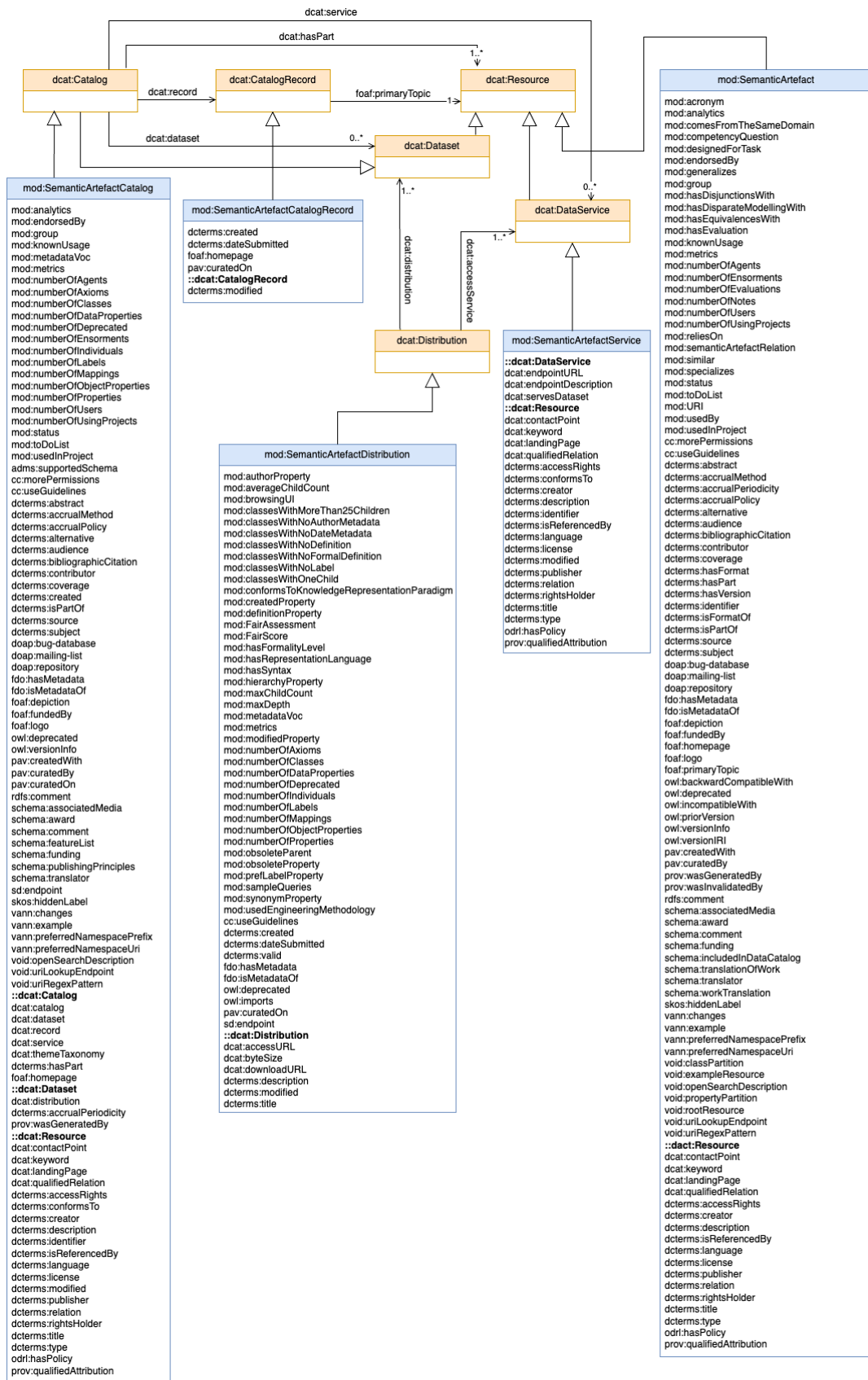


Figure 2. Metadata for Ontology Description and Publication (MOD) ontology (v3.2).

2.1.3 Metadata Curation and FAIRness Assessment

A crucial initial step for FAIR-IMPACT’s activities related to SACs was the **re-harmonization of metadata models** used by SACs, particularly AgroPortal and EcoPortal. This task was both tedious and technically challenging, requiring the alignment of the two diverged metadata models and the resolution of discrepancies to ensure uniformity across platforms. MOD was therefore instrumental in this process. Following harmonisation, all catalogues —especially EarthPortal, EcoPortal, and AgroPortal— faced **significant metadata curation** challenges. These efforts were essential to ensure that the SAs hosted in these catalogues were accurately and comprehensively described, enabling tools like O’FAIRe²⁵ to assess their level of FAIRness effectively. These metadata curation and harmonization processes laid the groundwork for improving the overall quality and interoperability of SAs, enhancing their integration and reuse across diverse scientific domains. In parallel, this work enabled to “merge” FAIRness assessment generic methodologies brought by the partners: O’FAIRe (INRAE), FOOPS! (UPM), FsF (eSDF), 10-Simple Rules (STFC), and FVF (UNIMAN).

Related milestone / deliverable

M5.3	Semantic artefact assessment methodology	UPM	https://doi.org/10.5281/zenodo.8305172
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2.2 FAIR Semantic Artefact Sharing

This section discusses, through community examples, different aspects of the SA publication and sharing, highlighting how FAIR-IMPACT’s WP4 addresses the challenges of the EOSC-IF and FAIR principles. It begins with an overview of the current landscape of SACs (Section 2.2.1), including a description of those explicitly used or created within the FAIR-IMPACT project (Section 2.2.2). The section concludes by exploring the use of SAs for enhanced data indexing and search in scientific data repositories (Section 2.2.3)

2.2.1 Review of Semantic Artefact Catalogues

FAIR-IMPACT’s WP4 conducted a comprehensive review of SAs catalogues to assess their current state and historical development, including the technologies used, the communities involved and their alignment to FAIR SAs. For such a review, SACs were collected from diverse sources, categorised by type, discipline and technology. And finally assessed using FAIR-enabling dimensions to determine how SACs support the implementation of the FAIR principles. The review illustrated first, a wide diversity of SACs , ranging from basic lists of SAs to advanced repositories offering structured metadata and specialised services, such as browsing, visualisation, recommendations, and annotation. To better understand their deployment management and usage, SACs were further classified according to their architecture and/or the services they provide. This categorisation offered valuable insights to the role SACs pay in supporting FAIR practices.

²⁵ <https://github.com/agroportal/fairness>

In this comprehensive review (M4.4), we successfully **collected information on 172 SACs**, of which 112 are still active, 56 are retired or inactive and 4 are considered as prototypes. Among the active catalogues, 15 different technologies are employed across 18 disciplines. 68% of the active SACs are categorised as “repositories”, and more than a half of the technology used (54%) for SACs falls under “other technology” that we were unable to specifically define. However, the 3 most prevalent known technologies, which are SKOSMOS, OntoPortal and OLS, represent almost one third of the SAC listed. Moreover, the “general” category accounts for 40% of the disciplines served by SACs, indicating that a significant range is domain-agnostic. Our review underscores the fragmented landscape of SACs and offers opportunities for better synchronisation by pointing out the heterogeneity of technologies used and the prevalence of domain-agnostic applications. For example, reusable technologies such as SKOMOS and OntoPortal can play a crucial role in simplifying the creation and further interoperability of SACs.

We also conduct cross-analysis of SACs, analysing their use by discipline, in relation with their type and underlying technology. Additionally, we identified 10 key dimensions for assessing FAIR-enabling capabilities of SACs, leveraging FAIRness assessment methodologies and tools brought by FAIR-IMPACT’s partners, e.g., O’FAIRe,²⁶ FOOPS!,²⁷ FsF,²⁸ 10-SR,²⁹ and FVF.³⁰ The underlying compiled into a spreadsheet detailing our collection is published as an live document³¹, where anyone can contribute to enrich the landscape analysis.

Related milestone / deliverable

M4.4	Review of Semantic Artefact Catalogues and guidelines for serving FAIR semantic artefacts in EOSC	INRAE	https://doi.org/10.5281/zenodo.12799795
M4.4 (associated data)	FAIR-IMPACT Review of Semantic Artefact Catalogues and technologies	INRAE	https://doi.org/10.5281/zenodo.12799861

2.2.2 SACs within FAIR-IMPACT

This section details the SACs explicitly used or created within FAIR-IMPACT to synchronise and harmonise the SA lifecycle and governance across various communities, in alignment with the EOSC-IF requirements. These SACs are developed and maintained by one project partner.

²⁶ <https://dx.doi.org/10.1504/IJMSO.2022.131133>

²⁷ Garijo, Daniel, Oscar Corcho, and María Poveda-Villalón. "FOOPS!: An Ontology Pitfall Scanner for the FAIR principles." ISWC (Posters/Demos/Industry). 2021.

²⁸ <https://doi.org/10.5281/zenodo.4314320>

²⁹ <https://doi.org/10.1371/journal.pcbi.1009041>

³⁰ <https://doi.org/10.1186/s13326-023-00286-8>

³¹ <https://doi.org/10.5281/zenodo.12799861>

2.2.2.1 AgroPortal

Since its launch in 2015, AgroPortal (<https://agroportal.lirmm.fr>) has been a pivotal platform for managing and sharing SAs in the agri-food domain and beyond. It plays a key role in the governance of multiple SAs in this domain. Leveraging the OntoPortal technology, AgroPortal serves as a comprehensive platform for hosting, searching, versioning, visualising, annotating, and aligning ontologies. Its purpose is to enable the seamless integration and reuse of SAs in agro-informatics applications, supporting the FAIR principles. AgroPortal has become a critical tool for the community, hosting 220+ SAs (including many not available in other catalogues), for 500+ registered users, with more than 2000 unique visits/months).

Over the past two years, associated to the context of FAIR-IMPACT, AgroPortal has seen remarkable progress,³² adopting a dynamic monthly release cycle to ensure continuous improvement. Key updates between versions 2.3 and 3.0 include new mappings capabilities, better SKOS support, new user interfaces, multilingual support, new indexing and search capabilities, consolidation of the metadata model (based on MOD, see Section 2.1.2), an embedded SPARQL query editor, URI resolution and negotiation services, enhanced property support, and overall platform optimization. These advancements –such as the Ontology FAIRness evaluator (O’FAIRe)– have been always developed in a generic approach, that can be transposed to other OntoPortal-based SACs, following FAIR-IMPACT’s vision to transpose FAIR enabling tools across communities.

AgroPortal has also become a vital node in the OntoPortal ecosystem, collaborating closely with platforms like EcoPortal, EarthPortal, and BiodivPortal, and contributing to forthcoming initiatives such as OntoPortal-Astro and LovPortal. AgroPortal’s team has led the development of the FAIR-IMPACT joint federated release of these 4 SACs done in Dec. 2024. It is also used in three of the connectors to data repositories.

2.2.2.2 EcoPortal

EcoPortal (<https://ecoportal.lifewatch.eu>) serves as a repository for SAs in the ecological domain, designed to support a broad community of stakeholders, including researchers, vocabulary managers and curators, data managers, data scientists, and ontology developers. Its purpose is to facilitate the creation, management, and alignment of FAIR SAs, which make the meaning of research data clear and explicit, ultimately increasing their impact, and now host more than 60 SAs. The platform acts as an access point for SAs, allowing users to maximise the efficiency of search, annotation and other scientific data management processes. Developed using the OntoPortal technology, EcoPortal has continuously evolved since 2019 to incorporate new features tailored to the needs of the scientific community. Key enhancements include the integration of VocBench, web-based, multilingual, collaborative space for the editing and development of SAs, incorporation of DataCite in the metadata schema, enabling the assignment of DOIs to SAa following the validation of their metadata.

³² Check [AgroPortal’s release notes](#) for details.

In the context of FAIR-IMPACT, EcoPortal has improved its functionalities, and key updates have been done within the versions 2.0.0 and 3.0.0, including the adoption of MOD as metadata schema, the integration of the O'FAIRe tool as its SAs FAIRness evaluator, multilingual support and better SKOS support. Lastly, as per December 2024, EcoPortal has joined the OntoPortal federation along with AgroPortal, EarthPortal and BiodivPortal, ultimately increasing the findability of SAs across related domains.

During this period, parallel efforts have been made to improve data sharing and integration. As part of these efforts, EcoPortal has been integrated into the LifeWatch Italy Data Portal and Metadata Catalogue (see Section 2.2.3).

2.2.2.3 EarthPortal

In the Earth system communities, there is an emerging need concerning SA sharing to which the EarthPortal is the answer. Since it went online during September 2023, endeavours were made toward gathering Data Terra clusters SAs and creating a connector with the EaSy Data repository³³ to enhance the metadata during the dataset deposit process. It is the first use-case that has been successfully implemented in the context of FAIR-IMPACT. The presentation of the EarthPortal (<https://earthportal.eu>) to the annual Data Terra seminar sparked interest from the clusters, which will help to improve their artefacts with more and better metadata but also to suggest new use cases of EarthPortal tools with external applications. Other collaborations are on the way, such as the use case done between FAIR-IMPACT and FAIRE-EASE projects that produced the Semantic analyzer tool to annotate metadata, using the EarthPortal within their knowledge base.

Content-wise, 57 SAs are hosted and with 50 more are candidates to be and with a total of 43 registered users at the start of 2025. During the upcoming year, we plan to pursue existing collaborations and have new ones, to curate and manage the growing amount of resources and to enhance the technology. EarthPortal is also part of the ongoing efforts towards the federation of content with AgroPortal, EcoPortal and BiodivPortal.

2.2.2.4 LOV

Linked Open Vocabularies (LOV - <https://lov.linkeddata.es>) is a vocabulary and ontology index released more than ten years ago dedicated to catalogue vocabulary data and metadata in any domain. Currently (2024), more than 860 vocabularies or ontologies are indexed related to a variety of domains like metadata, environment, geography, industry, time, biology, IoT, etc. Vocabularies or ontologies can be suggested by anyone and there is some mandatory metadata that should be provided to be included in the index following LOV recommendations.³⁴ LOV provides different ways to consult the stored metadata not only through a web user interface but also through a SPARQL endpoint, dump download to process it locally or through the REST API. As part of FAIR-IMPACT, the current LOV REST API is being analyzed to identify gaps with respect to the MOD-API. The system is also being extended with FAIR assessment capabilities.

³³ <https://www.easydata.earth/>

³⁴ https://lov.linkeddata.es/Recommendations_Vocabulary_Design.pdf

Before the end of FAIR-IMPACT, INRAE, working in collaboration with UPM, will deploy a version of LOV using the OntoPortal technology. This initiative, named LovPortal, aims to host, share, and serve vocabularies and ontologies critical to the semantic web community or that are currently stored on the LOV platform. During an initial phase, the LovPortal will be “read-only” and regularly synchronized with the content of the LOV platform. This action has three main goals: (i) offer an OntoPortal-based point of entry for the 800+ SAs of LOV; (ii) enable the FAIRness assessment of each vocabularies with O’FAIRe; (iii) offer an MOD-API compliant endpoint to LOV (through the generic implementation done by other OntoPortal-based SAC in FAIR-IMPACT). In addition, the LovPortal, by hosting and serving the W3C vocabularies or other standard metadata vocabularies can play an important role in the OntoPortal federation where each thematic SAC needs to rely on another service for domain-agnostic semantic web vocabularies.

2.2.2.5 OntoPortal Alliance

The OntoPortal Alliance³⁵ is a collaborative, non-formal consortium established to promote and advance ontology repository technologies and services across various scientific disciplines. Formed in 2020, it brings together research teams, infrastructure providers, and stakeholders from domains such as biomedicine, agri-food, ecology, biodiversity, earth sciences, material sciences, astronomy. The Alliance fosters the reuse of the OntoPortal software³⁶, an open-source platform for ontology repositories and SACs, enabling consistent and interoperable SA management. Through its activities, the Alliance supports scientific communities in hosting, sharing, and curating SAs, thus contributing to the realization of the FAIR principles. Teams in the Alliance develop and maintain several openly accessible SACs or ontology repositories in multiple disciplines –such as AgroPortal, EcoPortal, EarthPortal presented above. The list of repositories is available on the Alliance web page³⁷ and the teams are listed on GitHub.³⁸ The OntoPortal software, initially developed by Stanford University for BioPortal³⁹, has evolved into a flexible framework capable of serving diverse domains. It provides an extensive suite of services, including ontology hosting, indexing, search, versioning, visualization, and alignment management. It supports semantic annotation, mapping generation, and metadata curation while offering tools to assess the FAIRness of SAs. By integrating features such as a mapping repository and a SPARQL endpoint, OntoPortal enables advanced workflows and interoperability with the semantic web. The software’s open-source nature ensures adaptability to various use cases and communities.

The OntoPortal Alliance has played a pivotal role in FAIR-IMPACT’s WP4 by providing robust technological and community-driven solutions for the management of SAs. Within this context, OntoPortal-based repositories have been instrumental in addressing challenges related to the life cycle of FAIR SAs, including ontology hosting, metadata curation and alignment, and inter-repository alignment as illustrated in this report. FAIR-IMPACT has

³⁵ <https://ontportal.org/>

³⁶ <https://github.com/ontportal>

³⁷ <https://ontportal.org/about/>

³⁸ <https://github.com/orgs/ontportal/teams>

³⁹ <http://biportal.bioontology.org/>

leveraged the OntoPortal software to support the discovery, evaluation, and reuse of SAs across diverse domains, ensuring that these resources adhere to the FAIR principles and can effectively be integrated into broader research infrastructures in the European Open Science Cloud (EOSC). The OntoPortal software has enabled FAIR-IMPACT to harmonize efforts across fragmented SACs. By facilitating interoperability, the platform has supported the transmission of FAIR enabling tools e.g., the *Ontology FAIRness Evaluator* (O'FAIRe) tool is now available in 6 OntoPortal-based SACs (including the 3 done in FAIR-IMPACT). With its use within FAIR-IMPACT, the OntoPortal software and use cases have demonstrated their commitment to advancing the FAIR ecosystem, enabling SAs governance, interdisciplinary collaboration, and the seamless sharing of SAs across scientific communities.

2.2.2.6 Other SAC projects inspired by FAIR-IMPACT

Other prototypes SAC that FAIR-IMPACT's T4.2 helped setup included:

- **BiodivPortal** (<https://biodivportal.gfbio.org>): an OntoPortal-based SAC designed to support biodiversity research supported by the German NFDI4Biodiv project.
- **TechnoPortal** (<https://technoportal.hevs.ch>): an OntoPortal-based SAC for wind energy and technological sciences developed by Ost / Hevs in Switzerland.
- **OntoPortal-Astro**: a prototype of an OntoPortal-based SAC (<http://voparis-ontoportal-dev.obspm.fr> - Not yet publicly released) for astronomy tested by OBS-PARIS. The prototype started during the FAIR-IMPACT collaboration has sparked the OPAL project⁴⁰ (a selected tender from EOSC project OSCARS) which aims is to establish OntoPortal-Astro, a dedicated SAC for astronomy, that will integrate vocabularies and other SAs from various domains within the ESCAPE cluster⁴¹ of research infrastructures –including observational astronomy, planetary sciences, heliophysics, and particle physics.
- **LovPortal**: the initiative (described above) started during the last year of FAIR-IMPACT aims at deploying a dedicated SAS for semantic web vocabularies using the OntoPortal technology, inspired by the LOV platform.

FAIR-IMPACT's WP4 is currently actively engaging with other scientific communities and we are expecting other OntoPortal-based SAC before the end of the project. This includes a catalogue in the cultural heritage domain (in collaboration with the new ECHOES EU project) and another in the social sciences and humanities (in collaboration with CESSDA).

2.2.3 SAs for Enhanced Data Search and Indexing Data in Repositories

FAIR-IMPACT collaborates with nine different use cases across various domains such as social sciences, astronomy, earth sciences, life science, and agronomy to demonstrate the impact of FAIR SAs on data repositories and (meta)data catalogues. Each use case has focused on the development and testing of software connectors to enable the use of controlled

⁴⁰ <https://oscars-project.eu/projects/opal-ontology-portal-astronomy-linked-data>

⁴¹ <https://projectescape.eu/>

vocabularies for data annotation and indexing documentation. Peer-reviewed descriptions of each use case have been produced to support internal communication, contribute to the project website, and establish a foundation for a dedicated deliverable (D4.6) coming at the end of the project. Prototype demonstrations, such as PHIS-AgroPortal (INRAE), RDG-AgroPortal (INRAE), EasyData-EarthPortal (CNRS), LifeWatchMDC-EcoPortal (LifeWatch) and DataStation-Skosmos (DANS), showcased progress during several events. Whenever feasible the connectors were designed to be generalizable to either the underlying SAC technology (mostly OntoPortal) or the underlying data repository technology (such as Dataverse, GeoNetwork, OpenSILEX or DSpace). These efforts highlighted reproducible connection processes and measurable impacts of SA integration on improving (meta)data FAIRness. The use cases listed below have produced fully described and operational connectors:

Use case	Data repository	SAC	Description	Leader
PHIS-AgroPortal	Phenotyping Hybrid Information System	AgroPortal	Enabling interoperability between AgroPortal and PHIS information system data repository for enhanced phenomics data annotation and exchange	INRAE
LifeWatchMDC-EcoPortal	LifeWatch Metadata catalogue & Data Portal	EcoPortal	Improving ecological (meta)data FAIRness through semantic services: integration of EcoPortal in LifeWatch Italy new platforms	LifeWatch ERIC
DANS data station	DANS data repositories	SKOMOS DataStation Vocabularies	FAIR vocabularies in DANS Data Stations	DANS Data Station
EasyData-EarthPortal	Earth System Data repository	EarthPortal	Enhance the semantic functionality of the national Earth & Environmental Data Repository by integrating it with the EarthPortal	Data Terra (CNRS)
RDG-AgroPortal	Recherche Data Gouv (Data INRAE)	AgroPortal	Leveraging AgroPortal ontologies to ease metadata completion and data discovery in Data INRAE	INRAE
IVOA Astronomy	N/A	http://voparis-ontportal-de.v.obspm.fr/	Semantic Artefacts Alignment for Improving Interoperability in Astronomy	Observatoire de Paris
AnaEE	SemData	AgroPortal	AnaEE uses case: Semantic interoperability in ecosystem studies	INRAE

Table 1. List of the use cases indexing in data repositories

Related milestone / deliverable

D4.6	Use case driven validation of semantic artefact exploitation within data repositories	INRAE	(not yet published)
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3 Approaches to Semantic Artefact Catalogues Interoperability

In sections 2.1 and 2.2, we outlined FAIR-IMPACT’s work to develop engineering methodologies and catalogues for sharing SAs in accordance with the FAIR Principles and the EOSC-IF. This section focuses on SAC interoperability. FAIR-IMPACT’s WP4 has identified three main approaches for SAC interoperability each with its own advantages and disadvantages (Fig. 3):

- 1) **MOD-API specification and implementations.** This approach requires each SAC implementing a shared, standardised API; in our case the MOD-API proposed by FAIR-IMPACT. It provides a robust and sustainable solution without the need for intermediary proxies. However, it requires significant effort to collaboratively produce and maintain the API specification and relies on SACs committing both adopting the standard and maintaining their implementations. Despite these challenges, this approach fosters active engagement among SACs in a shared interoperability effort.
- 2) **Federation of OntoPortal-based SACs:** In this approach, the SACs using OntoPortal are already interoperable at the API/backend level and can “easily” federate their content at the user interface level. This method avoids the need for new API implementations, streamlining federation and leveraging the richness, complexity and stability of a mature API. Its main limitation is that it applies exclusively to OntoPortal-based SACs.
- 3) **API Gateway:** This strategy allows SACs to maintain their existing systems and not necessarily engage in any interoperability effort. Instead, a gateway (e.g., the one developed by the TS4NFDI project)⁴² implements wrappers to consume SACs content. TS4NFDI project is currently processing content coming from platforms based on the three technologies: SKOSMOS, OLS, and OntoPortal. While this approach is convenient for SACs as it requires no additional effort on their part, it relies on a proxy, which reduces sustainability and does not actively encourage SACs to adopt interoperable practices

Each approach involves different tiers ranging from the engagement to the project members only, to external parties through open calls, or a broader collaboration with (national) infrastructures. FAIR-IMPACT is explicitly working on approaches 1) and 2) and it has close collaboration with TS4NFDI and NFDI4Biodiv projects, which are developing approach 3).

⁴² Historically, this approach was also prototype by eSDF in 2018 in the context of the EUDAT project.

Fig. 3 hereafter summarised the three described approaches.

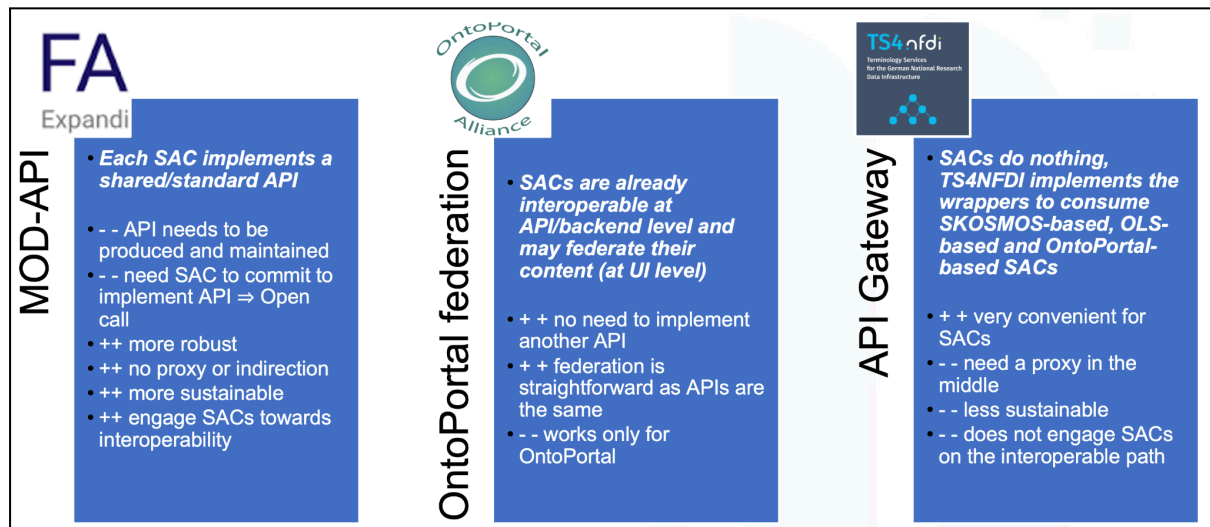


Figure 3. Approaches to Semantic Artefact Catalogues (SACs) interoperability.

3.1 MOD-API implementations

This section provides a detailed description of the MOD-API specification (Section 3.1.1) and how its implementation enhances the interoperability of SACs and, indirectly, the FAIRness of SAs by adopting a common API for querying the catalogues. It also highlights the various communities that have agreed to implement this shared API across their SACs, and discusses its impact on interdisciplinary research and cross domain interoperability (Section 3.1.2).

3.1.1 MOD-API specification

The MOD-API is built on the MOD vocabulary and provides a uniform interface to SA through the API, enabling stakeholders to query seamlessly regardless of the domain. The API has been documented using an Open API YAML file that can be found in GitHub.⁴³ A description of the API can be found in D4.3. The API can be split into four sections:

- the semantic artefact catalogue (SAC);
- artefacts in the catalogue;
- artefact catalogue records;
- search functionality.

Each endpoint is supposed to return a semantic object, either defined by the MOD vocabulary or compliant with a Semantic Web W3C standard (RDF, OWL or SKOS). The API endpoints should implement content negotiation whenever possible but with the minimum requirement to support JSON-LD . The endpoints that return a list of objects are expected to

⁴³ <https://fair-impact.github.io/MOD-API>

also implement pagination functionality, managed via the URL parameters page and pagesize. Information about the catalogue in the form of mod:SemanticArtefactCatalog object, is obtained from the root endpoint “/”. This endpoint supports the use cases where a client wants to get a description of the catalogue itself. The “/artefacts” endpoints retrieve information about one or all the SAs within a catalogue. Where an artefact ID is provided, the metadata returned is specific to that artefact. Return types include a list of mod:SemanticArtefact, a mod:SemanticArtefact, a list of mod:SemanticArtefactDistribution, a mod:SemanticArtefactDistribution, plus many more. For the full list of artefacts endpoints and their return objects see <https://fair-impact.github.io/MOD-API/>. The “records” endpoint can return all mod:SemanticArtefactCatalogRecord objects, or a specific one for a given artefact. The “search” endpoint provides a means to search the metadata and/or the content.

GET	/artefacts	Get information about all semantic artefacts.	▼
GET	/artefacts/{artefactID}	Get information about a semantic artefact.	▼
GET	/artefacts/{artefactID}/distributions	Get information about a semantic artefact's distributions.	▼
GET	/artefacts/{artefactID}/distributions/{distributionID}	Get information about a semantic artefact's distribution.	▼
GET	/artefacts/{artefactID}/distributions/latest/resources	Get information about a semantic artefact's resources for the latest distribution.	▼
GET	/artefacts/{artefactID}/record	Get information about a semantic artefact catalog record.	▼
GET	/artefacts/{artefactID}/resources	Get a list of all the resources within an artefact.	▼
GET	/artefacts/{artefactID}/resources/{resourceID}	Get a specific resources from within an artefact.	▼
GET	/artefacts/{artefactID}/resources/classes	Get a list of all owl:Classes within an artefact.	▼
GET	/artefacts/{artefactID}/resources/concepts	Get a list of all skos:Concept within an artefact.	▼
GET	/artefacts/{artefactID}/resources/properties	Get a list of all the rdf:Property within an artefact.	▼
GET	/artefacts/{artefactID}/resources/individuals	Get a list of all the instances (owl individuals) within an artefact.	▼
GET	/artefacts/{artefactID}/resources/schemes	Get a list of all the skos:Scheme within an artefact.	▼
GET	/artefacts/{artefactID}/resources/collection	Get a list of all the skos:Collection within an artefact.	▼
GET	/artefacts/{artefactID}/resources/labels	Get a list of all the skos-xl:Label within an artefact.	▼

Figure 4. Web service calls specification in MOD-API v1.

Related milestone / deliverable

D4.3	Specification of shared metadata description of semantic artefacts and their catalogues including common reference API	STFC / INRAE	https://doi.org/10.5281/zenodo.12579778
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3.1.2 MOD-API expected implementations

The 3rd FAIR-IMPACT Open Call offers financial support to external parties for implementing and contributing to the MOD-API.⁴⁴ The implementation phase, scheduled for Spring 2025, is a unique opportunity for SACs to participate in a community-driven effort to improve the interoperability of their catalogues by adopting and customising this shared API.

At the time of closing this deliverable (end of January 2024), the participation to the Open Call has been quite successful and five participants have been selected by FAIR-IMPACT to receive financial support (8K€) to implement MOD-API in their systems. Additionally, six other parties will join as “observers”, allowing them to participate in all the workshops. Table 2 lists the 15 participants (as project members, funded applicants or observers) for the MOD-API implementation coming action and hence the expected upcoming MOD-API implementations.

Participation	Name	SAC and/or technology represented	Website & GitHub	Domain
Project Member	Clement Jonquet	AgroPortal (OntoPortal technology)	https://agroportal.lirmm.fr/	Agri-food
			https://github.com/agroportal	
Project Member	Ilaria Rosati	EcoPortal (OntoPortal technology)	https://ecoportal.lifewatch.eu/	Ecology
			https://github.com/lifewatch-eric	
Project Member	Guillaume Alviset	EarthPortal (OntoPortal technology)	https://earthportal.eu/	Earth sciences
			https://github.com/EarthPortal	
Project Member	Maria Poveda, Daniel Garijo	Linked Open Vocabulary (ad-hoc technology, will be using OntoPortal)	https://lov.linkeddata.es/	General
			https://github.com/lovportal	
Funded	Alexandra Kokkina	NERC Vocabulary Server (NVS) (using the VocPrez technology)	https://vocab.nerc.ac.uk/	Natural sciences
			https://github.com/nvs-vocabs	
Funded	Osma Suominen	SKOSMOS	https://finto.fi/https://skosmos.org/	General
			https://github.com/NatLibFi/Skosmos	
Funded	Manuel Fiorelli	ShowVoc	https://showvoc.uniroma2.it	General
			https://bitbucket.org/art-uniroma2/showvoc/	
Funded	Naouel Karam	BiodivPortal (using the OntoPortal technology) and TS4NFDI's API Gateway developer)	https://biodivportal.gfbio.org/	Biodiversity
			https://ts4nfdi.github.io/api-gateway/	

⁴⁴ <https://fair-impact.eu/implementing-shared-api-for-semantic-catalogues>

Funded	Oliver Koepler	TIB Terminology Service (using OLS)	https://terminology.tib.eu	Natural sciences
Observer	Helen Parkin on, Henriette Harmse	EBI Ontology Lookup Service (using OLS)	https://www.ebi.ac.uk/ols/	Biomedical and health sciences
			https://github.com/EBISPOT/ols4	
Observer	Nicholas Car	VocPrez / Prez	https://github.com/RDFLib/VocPrez	Engineering and technology
Observer	Rafael Gonçalves	BioPortal (using OntoPortal)	https://bioportal.bioontology.org/	Biomedical and health sciences
			https://github.com/ncbo/	
Observer	Robert Hoehndorf	AberOWL	http://aber-owl.net	Biomedical
			https://github.com/bio-ontology-research-group/aberowlweb	
Observer	Marita Kristiansen	TermPortalen	https://www.termportalen.no/	Humanities
Observer	Miled Rousset	OpenTheso	https://opentheso.huma-num.fr/	Humanities
			https://github.com/miledrousset/Opentheso	

Table 2. List of participants in the FAIR-IMPACT Open Call for MOD-API implementation.

With the participation of the stakeholders developing the most important technology for SACs i.e., SKOSMOS, OntoPortal, OLS, VocPrez, OpenTheso and Showvoc, our implementation action will **involved providers of technologies used in 94% (46/49) of the SACs using a generic technology** as identified in our comprehensive review of SACs (Section 2.2.1) (Fig.5). This comprehensive representation of various SACs' technology providers will enable FAIR-IMPACT to actively engage in a collective effort to enhance SAC interoperability.

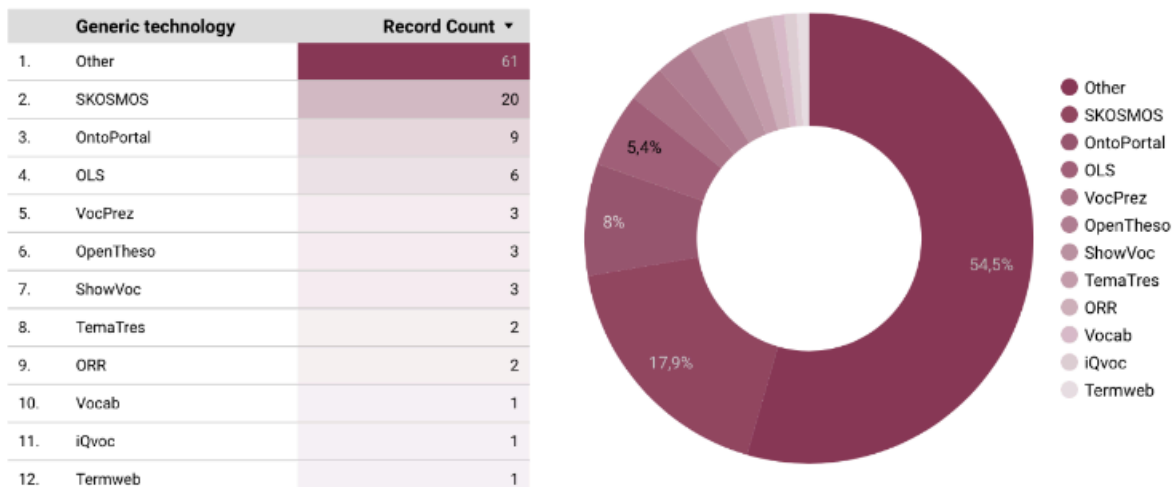


Figure 5. Number and distribution of all active SAC listed by generic technology used, extracted from SAC review.

3.2 OntoPortal federation

This section highlights the work done for OntoPortal-based SACs federation in collaboration with the OntoPortal Alliance, more precisely: **AgroPortal**, **EcoPortal**, **EarthPortal** (all 3 members of FAIR-IMPACT), and **BiodivPortal** (external to FAIR-IMPACT). A **joint federated release was completed in December 2024** and announced in January 2025 including some new key functionalities such as federated documentation, harmonized user interfaces, portal descriptions, federated categories, browsing, and search capabilities. The OntoPortal federation allows seamless content sharing and consumption across portal; it supports efficient and effective semantic discovery across domains, significantly advancing FAIR-IMPACT’s mission of enhancing interoperable and FAIR SAs.

This release enables users to browse and search ontologies and concepts across AgroPortal, EcoPortal, EarthPortal, and BiodivPortal. **Each portal is now connected and displays content from each portal.** From a technical point of view, this federation is done “at the user interface level” as the backends and APIs of each portal already align.⁴⁵ Improvements include an updated architecture for querying multiple backends and redesigned user interfaces to integrate federated results effectively while addressing performance considerations.

As mentioned in the previous Section, the OntoPortal federation demonstrates the potential of a shared API that delivers results in a standardized format, enabling seamless integration and interoperability across multiple SACs.

The technical and collaborative approach of the OntoPortal federation are summarised in the following sections.

⁴⁵ AgroPortal and EcoPortal codebase and metadata models have been realigned during the first half of FAIR-IMPACT while EarthPortal and BiodivPortal have been originally deployed, based on the AgroPortal codebase in parallel.

3.2.1 Federated documentation

A shared documentation framework⁴⁶ has been established to streamline user guidance from other portals without duplicating effort. Each portal maintains its custom documentation while seamlessly integrating shared sections. This framework enables the import user guidance and promotes consistency across portals. Currently, documentation is available for EcoPortal, EarthPortal, and the default OntoPortal software.

3.2.2 Federated categories

All federated portals adopted the UNESCO Thesaurus⁴⁷ as a unified vocabulary for categorizing ontologies, enhancing comparability and enabling federated filtering by domain. Categories have been harmonised across portals through manual re-assignment and ongoing curation to ensure accuracy and relevance. This shared categorization enhances consistency in ontology selection and exploration.

3.2.3 Federated user interfaces and portal descriptions

Portals now share a unified interface design, maintaining consistency in look and feel with a specific color theme. EcoPortal, EarthPortal and BiodivPortal have then embraced the changes done in AgroPortal releases 2.7 series related to new UI/UX.

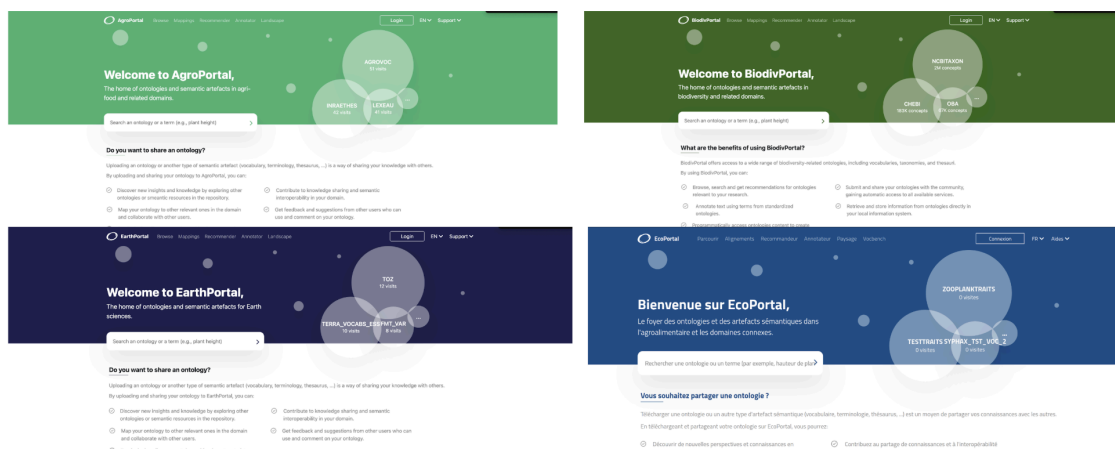


Figure 6. Harmonized user interfaces and look and feel for a seamless SAC experience.

When mousing over the OntoPortal logos on the homepages, **the federated portals display** descriptive information and ontology counts, linked through a new standardised web service. This functionality is implemented by a dedicated web service endpoint that each federated portal to describe itself. Eventually, these portal descriptions will be based on the `mod:SemanticArtefactCatalogue` object specified by the MOD v3.2 metadata vocabulary.

⁴⁶ <https://ontoportal.github.io/documentation>

⁴⁷ <https://vocabularies.unesco.org/browser/thesaurus/en/>

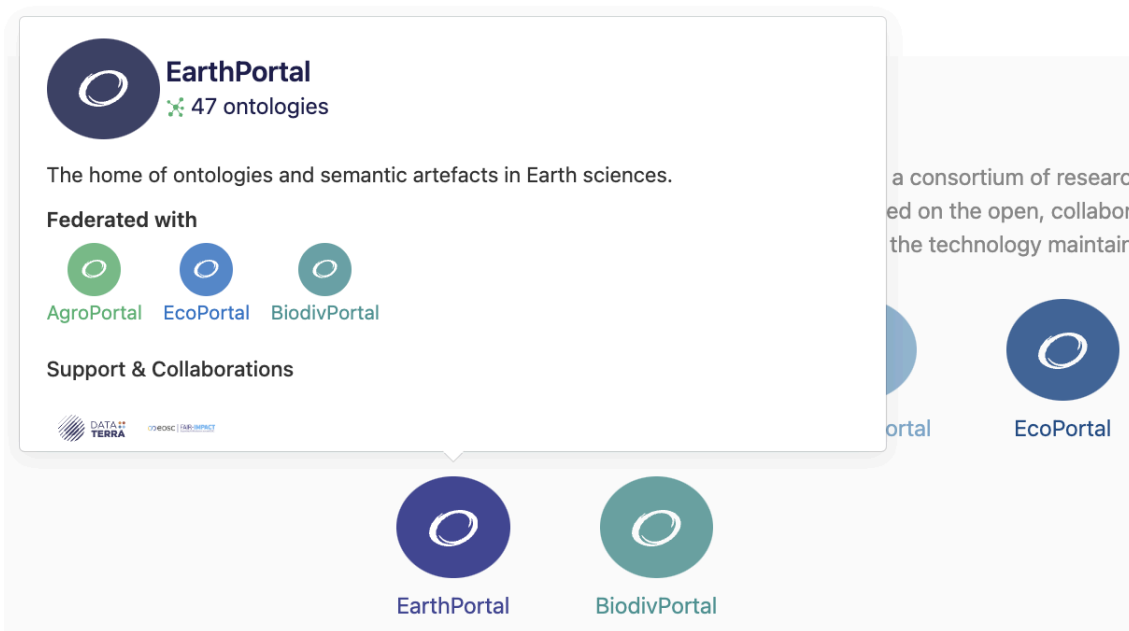


Figure 7. One Homepage showing the information about EarthPortal.

3.2.4 Federated Browsing (Ontology Selection)

This feature enables users to seamlessly discover SAs not only from SAC but also from other federated catalogues. The browsing experience integrates SAs from all federated portals into a unique interface, expanding discovery to 376 artefacts across the federation. Federated results are integrated alongside local ontologies, maintaining the familiar interface while broadening the scope of discovery. All unified filters remain fully functional within the constraints of the metadata available from each portal, ensuring relevance and usability. The number of ontologies retrieved from each portal are automatically updated with filters or parameters Duplicate SAs are aggregated into a single unified card, with the canonical portal determined based on references. Incremental loading enhances performance, and visual indicators distinguish federated content.

The screenshot shows the AgroPortal browse page. At the top left is a 'Submit ontology' button. A search bar contains the text 'Start typing to filter ontologies, e.g., AGROVOC...'. To the right of the search bar are 'All formats' and 'Sort by name' dropdown menus. Below the search bar, it says 'Showing 285 of 376 from AgroPortal (203), EcoPortal (32), EarthPortal (42), BiodivPortal (46) in 1.74s'. On the left side, there is a 'Filters' section with several categories: 'Show ontology views' and 'Show retired ontologies' (both with toggle switches), 'Categories', 'Groups', 'Natural languages', 'Formality levels', 'Ontology types', and 'Results from external portals' (with checkboxes for EcoPortal, EarthPortal, and BiodivPortal). The main content area displays a list of ontology results. Each result includes the ontology name, a brief description, statistics (instances, classes, notes, projects), a FAIR score bar, and submission information (date, author, year, and portal).

Ontology Name	Instances	Classes	Notes	Projects	FAIR Score	Submitted	Author	Year	Portal(s)
A stratified lexicon of water related geophysical and textual data (LEXEAU)	786	385	1	1	274.0	11 days ago	Jean Louis Janin	2015	OWL
ABCD Base Ontology (ABCD)	79	65				over 1 year ago	David Fichtmueller	2019	OWL, BiodivPortal
ACTRIS Controlled Lists (ACTRIS_CL)	98	2				11 months ago	Markus Fiebig	2022	SKOS, EcoPortal, EarthPortal
ACTRIS Vocabulary (ACTRIS_VOCAB)	4,315	2				11 months ago	Markus Fiebig	2022	SKOS, EcoPortal, EarthPortal

Figure 8. Browse page in AgroPortal showing results from EcoPortal and EarthPortal too.

3.2.5 Federated Search

Federated search allows users to query concepts and classes across all federated portals while maintaining a consistent interface. Search results are visually coded by portal, with duplicates managed similarly to the browsing feature. Relevance is also balanced across portals using against results labels to ensure meaningful and accurate results.

Search 🔍

Search language

🌐 All languages
 ▼

Include in search

Property values

Obsolete classes

Ontology views

Ontologies

Clear selection Ontologies advanced selection

Results from external portals

AgroPortal

EcoPortal

BiodivPortal

Match in 48 ontologies from [EarthPortal](#) (13), [AgroPortal](#) (34), [EcoPortal](#) (6) in 2.26s

{ } API JSON 🔒 Hide options

temperature sensor - Environmental Thesaurus (ENVTHES)

http://vocabs.lter-europe.net/EnvThes/EnvEU_519

An electrical, electronic, or automatic device that automatically identifies changes in temperature EN

⚙️ Details

👁️ Visualize

🔗 0 mappings

📄 32 more from this ontology ▼

↔️ Reuses in 1 ontologies ▼

Temperature sensor - Ontology for Experimental Phenotypic Objects (OEPO) [🔗](#)

<http://www.phenome-fppn.fr/vocabulary/2018/oepo#TemperatureSensor>

📄 7 more from this ontology ▼

🌐 AgroPortal

Temperature sensor - Smart Applications REFerence ontology (SAREF) [🔗](#)

<https://saref.etsi.org/core/TemperatureSensor>

A sensor that is used for the purpose of sensing a property of type saref:Temperature. A saref:TemperatureSensor is typically used to saref:accomplish saref:Comfort. EN

📄 4 more from this ontology ▼

↔️ Reuses in 5 ontologies ▼

🌐 AgroPortal

Figure 9. Search page in EarthPortal showing results from other portals.

4 FAIR-IMPACT related Semantic Artefact Catalogues

Name	URL	Domain	Organization (partner Y/N)	Relation to FAIR-IMPACT WP4	Technology used	MOD compliant	O'FAIRe	MOD-API (planned)	SAC federation	T4.5 connectors or use cases
AgroPortal	https://agroportal.lirmm.fr	Agri-food	INRAE (Y)	Pre-exist, new features, leading use case	OntoPortal			within project		PHIS, OpenSILEX, RDG, AnaEE
EcoPortal	https://ecoportal.lifewatch.eu	Ecology	LifeWatch (Y)	Pre-exist, consolidated, harmonized	OntoPortal			within project		LW Data Cat , LW Metadata Cat
EarthPortal	https://earthportal.eu	Earth Sciences	CNRS Data Terra (Y)	Created	OntoPortal			within project		EasyData
LOV	https://lov.linkeddata.es	General / Sem Web	UPM (Y)	Pre-exist, no relation	(ad-hoc)					
DANS-SKOSMOS	https://vocabs.datastations.nl	Social Science, Archo	DANS (Y)	Pre-exist, no relation	SKOSMOS			via Open Call		DANS Data Stations
OntoPortal-Astro	http://voparis-ontoportal-de.vobsmp.fr	Astronomy	OBS-PARIS (Y)	Created	OntoPortal					IVOA
OpenArcheo	https://pactols.frantiq.fr	Archeology	CNRS Humanum (N)	Pre-exist, no relation	OpenTheso					AMU
BiodivPortal	https://biodivportal.gfbio.org	Biodiversity	NFDI4Biodiv (N)	Created	OntoPortal			via Open Call		
TechnoPortal	https://technoportal.hevs.ch	Technological Sciences	Ost / Hevs (N)	Created	OntoPortal					
LovPortal	(not yet)	General / Sem Web	INRAE (Y)	Planned	OntoPortal					
NA	(not yet)	Cultural Heritage	U. Tours / ECHOES project (N)	Planned	OntoPortal					
NA	(not yet)	Social Sciences & Humanities	CESSDA (Y)	Planned	OntoPortal					





5 Conclusions and next steps

FAIR-IMPACT has established a strong foundation for advancing the interoperability, accessibility, and FAIRness of Semantic Artefacts (SAs) by advancing different components of the lifecycle including Semantic Artefact Catalogues (SACs). The development and federation of OntoPortal-based catalogues, combined with standardization efforts like MOD and the MOD-API specification, exemplify how collaborative communities can bridge gaps across scientific disciplines with respect to FAIR SAs. By addressing critical challenges such as metadata harmonization, FAIRness assessment, FAIR-by-design methodology, shared APIs, etc. FAIR-IMPACT has significantly enhanced the functionality and interoperability of SACs as key tools for interdisciplinary research.

Looking ahead, several key steps remain to be undertaken to further advance this work:

- **Expanding OntoPortal federation.** The OntoPortal federation roadmap includes key development such as metadata synchronization, user and agent federation, mapping alignment, and federation of key services like annotation and recommendation. These improvements will strengthen cross-catalogue collaboration and enrich user experience.
- **Broader adoption of MOD-API.** Supporting SACs to adopt the MOD-API beyond FAIR-IMPACT's open call and technical assistance will be critical for achieving widespread SAC interoperability. This effort requires outreach and supporting the groups in maintaining and improving APIs.
- **Scaling standardization efforts.** Consolidating MOD as a mature and widely accepted standard for SA description will further unify SACs and promote consistent practices across disciplines. Continued collaboration with other FAIR initiatives, such as TS4NFDI, OBO Foundry will be crucial for scaling up these efforts.
- **Engaging the community.** Continue fostering an active community of SAC developers, curators, and users to ensure the sustainability and relevance of these initiatives. Regular workshops, documentation updates, and feedback loops will facilitate ongoing engagement.
- **Expanding domain coverage.** The initial federation has focused on agri-food, ecology, biodiversity, and earth sciences, while other interoperability approaches include actors from additional domains. Future efforts should aim to integrate SACs from more disciplines, broadening for interdisciplinary research opportunities.
- **Monitoring and evaluating progress.** Establishing benchmarks to measure the impact of SAC advancements, such as the adoption of the MOD-API, growth in federated catalogues, and measurable improvements in SA FAIRness.

Through these steps, FAIR-IMPACT will further advance in developing a unified ecosystem of interoperable SACs and FAIR SAs. This will empower researchers and communities worldwide to seamlessly discover, reuse, and build upon SAs across disciplines, and thus addressing multiple EOSC semantic interoperability challenges within the EOSC-IF.

