WorldFAIR

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- [ ] CO: Confidential, only for members of the consortium (including the Commission)

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Abbreviations and Acronyms

ACS	American Chemical Society
ACS-CINF	American Chemical Society Division of Chemical Information
AI	Artificial Intelligence
AOSP	African Open Science Platform
APHRC	African Population and Health Research Center
ARDC	Australian Research Data Commons
CARE	Collective benefit, Authority to control, Responsibility, and Ethics
CCDC	Cambridge Crystallographic Data Centre
CDIF	Cross-Domain Interoperability Framework
CESSDA	Consortium of European Social Science Data Archives
CNPq	Brazilian National Council for Scientific and Technological Development
CODATA	Committee on Data of the International Science Council
CORDIS	Community Research and Development Information Service
DDI	Data Documentation Initiative
DDI-CDI	Data Documentation Initiative Cross-Domain Integration
DiSSCo	Distributed System of Scientific Collections
DPASSH	Digital Preservation in the Arts, Social Sciences and Humanities
DRI	Digital Repository of Ireland
DRR	Disaster Risk Reduction
DSTS_CS-WG	RDA / CODATA Data Systems, Tools, and Services for Crisis Situations WG
DwC	Darwin Core

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ELN	Electronic Laboratory Notebooks
ELSI	Ethical, Legal and Social Implications
EMMC	European Materials Modelling Council
EMODnet	European Marine Observation and Data Network
EOSC	European Open Science Cloud
EPA	Environmental Protection Agency
ESFRI	European Strategy Forum on Research Infrastructures
ETL	Extract-Transform-Load
EU-US CoRs	European Union - United States Communities of Research
FAIR	Findable, Accessible, Interoperable, Reusable
FERs	FAIR Enabling Resources
FIP	FAIR Implementation Profile
GBIF	Global Biodiversity Information Facility
GLAM	Galleries, Archives, Libraries and MuseumS
GloBI	Global Biotic Interactions
GloBI	Global Biotic Interactions platform
HRDUK	Health Data Research Innovation Gateway
IDSR	Infectious Disease Surveillance and Response
IDW	International Data Week
IGAD	Interest Group on Agricultural Data
IGAD CoP	Improving Global Agricultural Data Community of Practice
IIIF	International Image Interoperability Framework
INISS-nano	International Network Initiative on Safe and Sustainable NANOtechnology

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IOC-UNESCO	Intergovernmental Oceanographic Commission - UNESCO
IODE	International Oceanographic Data and Information Exchange
ISC	International Science Council
IUGS	International Union of Geological Sciences
IUPAC	International Union of Pure and Applied Chemistry
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KER	Key Exploitable Result
KISTI	Korea Institute of Science and Technology Information
LCA	Life Cycle Assessment
LMICs	Lower and Middle Income Countries
MEDIN	Marine Environmental Data and Information Network
ML	Machine Learning
MUBAS	Malawi University of Business and Applied Sciences
NAS-CSR	National Academy of Sciences Chemical Sciences Roundtable (US)
NCBI	National Center for Biotechnology Information
NEON	The US National Environmental Obertain Network
NSC	NanoSafety Cluster
OBIS	Oceanic Biodiversity Information Service
ODIS	Ocean Data and Information System
OHDSI	Observational Health Data Sciences and Informatics
OMOP	Observational Medical Outcomes Partnership
OMOP CDM	Observational Medical Outcomes Partnership Common Data Model

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PARC	Partnership for the Assessment of Risks from Chemicals
PSDI	Physical Sciences Data Infrastructure
RDA	Research Data Alliance
RDM	research data management
REBIPP	Brazilian Network of Plant-Pollinator Interactions
RIPE	Reliable, Interpretable, Processable, and Exchangeable
RSC	Royal Society of Chemistry
SAPRIN	South African Population Research Infrastructure Network
SDMX	Statistical Data and Metadata Exchange
SRIA	Strategic Research and Innovation Agenda
SSbD	Safe and Sustainable by Design
TDWG	Biodiversity Information Standards
TRE	Trusted Research Environments
TRE	Trusted Research Environments
UHC	Urban Health Collaborative
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization
WP	Work Package
WG	Working Group

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Executive Summary

This document outlines the sustainability and exploitation strategy and plans for the WorldFAIR project, which sets out to produce recommendations, interoperability frameworks and guidelines for FAIR data assessment. As we move forward, ensuring the sustainability of our efforts and effectively exploiting our outcomes are crucial for maximising impact and long-term success.

The deliverable first outlines the anticipated - and in some cases already documented - impact of the results in policy, knowledge transfer and capacity building, innovation and adoption, environmental and social and health areas. Each deliverable is mapped under its primary impact area.

Next, the sustainability models are outlined. The models utilised by each case study, as well as by the project as a whole are as follows:

- Take-up, adoption and adaptation by organisations, especially international organisations
- Community support, enabled by platforms such as RDA or CODATA
- Project-based sustainability based on targeted funding
- Document-based sustainability

The sustainability mechanisms, i.e., actions undertaken during the lifetime of the project, which formed the basis for the successful exploitation of project results are also outlined. Emphasis is placed on the WorldFAIR+ project, an upcoming initiative that will continue the legacy of the current work with the 11 case studies and the Cross-Domain Interoperability Framework.

The deliverable includes detailed descriptions of the case-study-specific approaches.

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1. Introduction

The WorldFAIR project has been successful in producing recommendations and a cross-domain interoperability framework to advance implementation of the FAIR (Findable, Accessible, Interoperable, Reusable) principles and, in particular, to improve interoperability and reusability of digital research objects including data, as well as domain-specific guidelines for FAIR data assessment, through the work of its 11 disciplinary and cross-disciplinary case studies and synthesis activities, drawing overarching parallels across the activities of the entire consortium.

The Committee on Data of the International Science Council (CODATA) and the Research Data Alliance Association (RDA) along with the project consortium, including authoritative international bodies (e.g., the Global Biodiversity Information Facility, the International Union of Pure and Applied Chemistry, OneGeochemistry), and institutions/projects with international reach (e.g., the London School of Hygiene & Tropical Medicine, the 5-year Salud Urbana en América Latina or Urban Health in Latin America project, the Tonkin+Taylor consultancy), have been instrumental in the dissemination of the project's results and in the realisation of the sustainability and exploitation plans, as well as the integration of the project's outputs into relevant communities.

This document outlines the Exploitation and Sustainability Strategy, which was developed to ensure the long term impact of the project results beyond the end of the funding period. It lays out the overarching continuation, sustainability and exploitation plans, as well as plans developed on a case study level.

As part of each case study plan, it outlines critical stakeholders that have been and will continue to be engaged to ensure longevity of activities through the consortium's local networks and institutions, and highlights the impact of the project results in key areas. It also highlights WorldFAIR+ as the key activity that will serve as a natural continuation of the current WorldFAIR project's work and legacy.

2. Objectives

The aim of the Exploitation and Sustainability efforts is to maximise the impact of the WorldFAIR project results beyond the funded lifetime of the project. Specifically, to:

- Present a clear vision of the project impact;
- Outline the exploitation and sustainability plans and strategies to maximise the long term potential of project activities and outputs for economic, environmental and social benefits;

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- Help the individual WPs in further defining and implementing actions to maximise the potential impact of their results beyond the end of the project;
- Outline the beneficiaries of, and specific actions related to, the exploitation of project results.

3. Impact

Each WorldFAIR case study has produced recommendations and/or a FIP for their discipline or interdisciplinary research area, and tools or approaches in their domain. Therefore, the long term exploitation of WorldFAIR results has potential impact in terms of FAIR policy and practice in 11 research areas (Chemistry, Nanomaterials, Geochemistry, Social Surveys, Population Health, Urban Health, Biodiversity, Agricultural Biodiversity, Ocean Sciences, Disaster Risk Reduction and Cultural Heritage), as well as for the whole global Research Data and Open Science community by proposing the Cross-Domain Interoperability Framework (CDIF), which will assist interdisciplinary research.

The global impact is also established through the use of the CODATA and RDA dissemination and communication channels; both organisations are of global renown, with the authority and significance of the results further ensured through CODATA's involvement in the United Nations (UN) initiatives related to data.

The identified impact areas for WorldFAIR published deliverables are 1) Policy and the European Open Science Cloud, 2) Knowledge transfer and capacity building, 3) Innovation and adoption, 4) Environmental and 5) Social and Health. It is noted that given the cross-disciplinary nature of the WorldFAIR projects, many reports may span more than one impact area. Graph 1 depicts the primary impact area for each deliverable.

This section provides an outline of the case studies and project activities' impact across the four areas noted above.

3.1 Policy and the European Open Science Cloud

In April 2023, the WorldFAIR project produced its first policy brief, which made seven policy recommendations relevant to the European Open Science Cloud (EOSC), drawing on project results and discussions held at relevant workshops. As highlighted in the policy brief, the project's Key Exploitable Results (KERs) are directly relevant to the EOSC Strategic Research and Innovation Agenda (SRIA) and the EOSC Interoperability Framework, metadata and ontologies, and FAIR metrics and certification.

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Most specifically, WorldFAIR contributes to the SRIA in the following ways:

1. Case Study Recommendations and CDIF will 'enhance' and add detail to the EOSC Interoperability Framework. (EOSC SRIA v.1.1, 8.6.2.1. Standards and Tools, p.176)[1]
2. Standards-based approach: CDIF will provide recommendations on standards to be used to enhance interoperability and combinability; international and engaged with research communities. (EOSC SRIA v.1.1, 5.7.2. Gaps, p.112)

[1] EOSC SRIA v.1.1, Nov 2022: https://eosc.eu/wp-content/uploads/2023/08/SRIA-1.1-final.pdf

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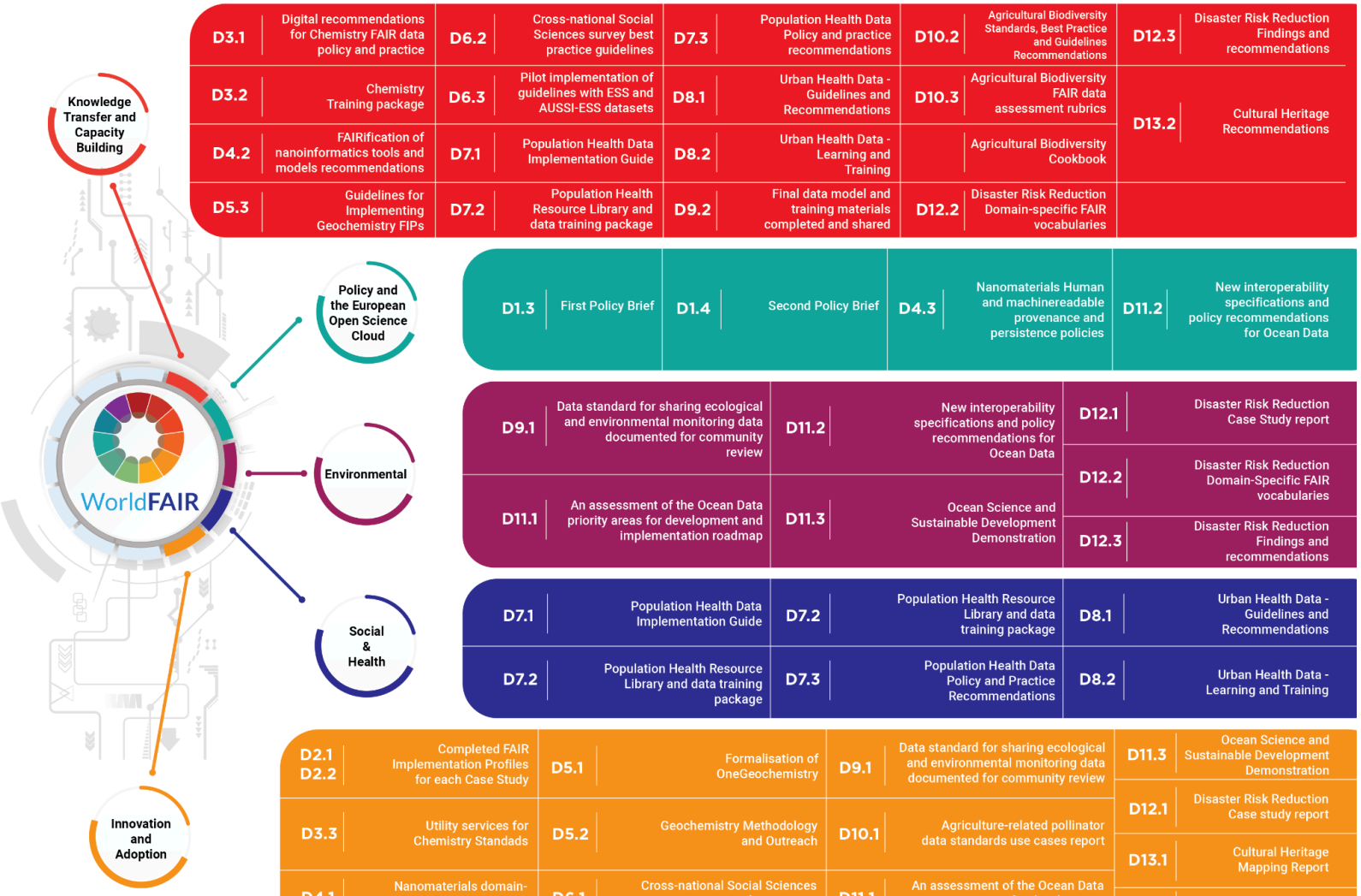

Graph 1: WorldFAIR Deliverable mapping across impact areas

3. Engagement with and of research communities: empowerment and facilitation of research communities to develop FAIR practices and Interoperability Frameworks. FIPs are an important tool for this. (EOSC SRIA v.1.1, 5.7.2. Gaps, p.112)
4. Interoperability for data combination: CDIF will propose good practices for a range of interoperability concerns, including semantics, to improve harmonisation of practices across disciplines. (EOSC SRIA v.1.1, 5.7.2. Gaps, p.113)

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In addition to the work of the WorldFAIR Case Studies, the major contribution of the WorldFAIR is to the EOSC Interoperability Framework through the CDIF:

> *[...] the WorldFAIR project makes a significant contribution to the EOSC Interoperability Framework in two important respects. First, the project underlines, and puts into practice, the need to engage research disciplines, at a global scale, in the development of agreements and frameworks for FAIR. Second, the CDIF identifies a set of functional requirements to support FAIR and identifies existing or emerging standards and protocols that can be used across domains. The CDIF is categorically not a new standard intended to replace others, but a framework of existing cross-domain standards or emerging protocols, which will add significant detail and actionability to the EOSC Interoperability Framework*.[2]

These policies will also be useful for other initiatives, including the African Open Science Platform (AOSP), a pan-African initiative guided by guided strategy, produced by a CODATA-led pilot project[3]. which is being coordinated by an office established by NRF in South Africa and has nodes in Egypt, Kenya, and Malawi. Hosted at JKUAT in Nairobi, the Kenya node[4] has a mission for capacity building and has already established links with APHRC and the INSPIRE projects. The Case Study on Population health will directly work with AOSP to develop some of these ideas, especi ally around the development of Trusted Research Environments (TRE) for the shared use of diverse data under secure and safe conditions; this is currently under development in cooperation with the Health Data Research Innovation Gateway (HRDUK)[5].

The specific policy recommendations made to EOSC are summarised thus:

1. Sufficiently Detailed, Standardised and Interoperable Metadata: Support is necessary for the development, adoption and implementation of standards and for the increased use of tools for automated metadata management.
2. Community FAIR Practices: Research communities need to be encouraged and facilitated in the process of exploring, declaring and implementing the FAIR practices that are most appropriate to their domain, while of course aligning with cross-domain standards where possible.
3. Cross-Domain Data Combination: Investment is needed to improve the capacity to provide standards, tools and metadata to support cross-domain interoperability and data granularity.

[2] Hodson, S., & Gregory, A. (2023). WorldFAIR Project (D1.3) First policy brief (Version 1). Zenodo. https://doi.org/10.5281/zenodo.7853170, pp. 2-3.
[3] https://doi.org/10.5281/zenodo.2222418
[4] See https://www.nrf.ac.za/the-african-open-science-platform-appoints-three-regional-nodes/
[5] https://www.hdruk.ac.uk/

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4. Fine-Grained Access Control: Systems that can support negotiation of access to data in a dynamic fashion are needed in order to responsibly meet the demand.
5. Data Engineering: Achieving a network for FAIR data exchange, or the EOSC vision of 'a web of FAIR data and services', will require a shift from a 'bibliographic' practice to a data engineering practice.
6. Support for Research Infrastructures: A key task of EOSC, and similar initiatives, is to ensure that research infrastructures have the capacity to partner with researchers and to provide them with the integrated or integratable data they need, upstream of analysis.
7. International Partnerships: EOSC should actively partner with existing international data infrastructures and organisations that maintain standards and metadata schema (particularly those related to the UN data ecosystem), with inter-governmental initiatives and with global representative bodies such as the International Science Council and the International Scientific Unions.[6]

The second WorldFAIR Policy Brief is due at project completion. It will synthesise and categorise the recommendations from the case studies and the synthesis work, while highlighting the most important policy recommendations for EOSC. It is envisaged, however, that many of the principle recommendations will remain substantively the same.

3.2 Knowledge transfer and capacity building

By the end of the project, the 11 WorldFAIR case studies will have produced discipline-specific guidelines and recommendations that can be used by the wider community as-is or further modified for specific needs, as well as training materials to support their uptake and community adoption. These efforts contribute to capacity-building in the community, promoting good research practices, facilitating collaboration, and advancing the FAIR principles, ultimately contributing to increasing the quality, integrity, and impact of research outcomes.

All WorldFAIR training materials and guidelines and recommendations are available on the WorldFAIR Zenodo community[7].

[6] Hodson, S., & Gregory, A. (2023). WorldFAIR Project (D1.3) First policy brief (Version 1). Zenodo. https://doi.org/10.5281/zenodo.7853170, pp. 12.
[7] https://zenodo.org/communities/worldfair-project/records?q=&l=list&p=1&s=10&sort=newest

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3.2.1 Chemistry

The Chemistry case study outlined a framework for reporting FAIR-enabled chemistry data that are Reliable, Interpretable, Processable and Exchangeable, or RIPE for sharing.[8] The broad strokes guidance described in 'D3.1 Digital recommendations for Chemistry FAIR data policy and practice' addresses descriptive metadata, file formats, unit representation, terminology and other digital motifs for describing chemical data in repositories and other systems and workflows. The framework is intended to facilitate implementation of standards by tool builders, database developers and other service providers to further empower the research community to share and reuse data and will continue to evolve as emerging standards mature and broader implementation informs best practices.

The IUPAC FAIR Chemistry Cookbook[9] was developed to support various user groups in the chemical sciences and allied fields with training in the FAIR principles and machine-readable chemical data. This web resource is designed to serve as a toolbox of interactive recipes for implementing FAIR at various levels and with different user experience, ranging from educators who need demonstration resources for instruction, to students who learn by doing, to practitioners who need a quick orientation on a tool or resource. The platform can be readily accessed with broadly available online infrastructure and exemplifies the FAIR principles and best practices in cheminformatics. As further described in 'D3.2 Training Package: FAIR Chemistry Cookbook', the sustainable infrastructure invites practical contributions from chemists, data scientists, educators, and students worldwide and enables IUPAC to leverage the collective expertise of the community in best practices for managing and reusing chemical data.[10]

3.2.2 Nanomaterials

The case study on nanomaterials had a strong focus on collating and integrating existing resources developed across a range of projects and collaborations, and documenting the current best practice into the Nanomaterials FIP with guidance on how to apply the FIP and apply the various FAIR enabling resources included in the FIP. Worked examples of nanomaterials FAIR workflows and resulting FAIR data packages have been developed and all of the information is presented in self-guided training materials via the community-developed NanoCommons User Guide[11], which is a "commons" in the sense that it is collectively owned and developed for the collective good. All

[8] McEwen, L., & Bruno, I. (2023). WorldFAIR Project (D3.1) Digital recommendations for Chemistry FAIR data policy and practice. Zenodo. https://doi.org/10.5281/zenodo.7887282
[9] https://iupac.github.io/WFChemCookbook
[10] Chalk, S., Munday, S., Kroenlein, K., McEwen, L., & Mustafa, F. (2024). WorldFAIR (D3.2) Training Package: FAIR Chemistry Cookbook. Zenodo. https://doi.org/10.5281/zenodo.10711949
[11] https://nanocommons.github.io/user-handbook/

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WorldFAIR nanomaterials-related deliverables and milestones are provided as training materials to support the community in its FAIRification efforts.

3.2.3 Agricultural Biodiversity

This Case Study gathered several collaborating initiatives, proving that an inclusive and translational approach to data re-use promotes a mutually beneficial knowledge transfer, and creates or strengthens collaborations. The Case Study team was composed of information specialists, data scientists, computer scientists and researchers in reproductive biology that exchanged knowledge and experiences to create recommendations, best practices and assessment tools tailored to this domain, which were lacking.

3.2.4 Ocean Science and Sustainable Development

This Case Study has contributed to the creation of training materials on Ocean Teacher Global Academy, an International Oceanographic Data and Information Exchange (IODE) programme component parallel to the Ocean Data and Information System (ODIS)[12]. This course is periodically run and has had global subscription. Additionally, this Work Package (WP) has dedicated time to assisting ODIS nodes (especially those in the developing world, but also many in Europe) develop their own capacities to share verifiably FAIR, linked open data.

3.2.5 Social Surveys

The social surveys case study established a set of best practice guidelines and a process model for the management of the survey data harmonisation process for social surveys. These guidelines were based on the existing practices of the project partners in the harmonisation of the European Social Survey and the International Social Survey Programme data. These best practice guidelines are designed for adoption and reuse both within the social science data archive community, and other organisations interested in survey harmonisation.

3.3 Innovation and adoption

This section provides an overview of the project's development of new ideas, methods and solutions in the field of Open Science, as well as of the adoption of the Case Studies' results by the community.

[12] https://oceanexpert.org/event/4073

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x3.3.1 Chemistry

In the greater environment of Open Science and data-driven approaches to global challenges, access to chemical information is critical for many cross-domain research areas. Representing chemical substances in structure form is one of the most critical functions in communicating chemistry, including sharing FAIR and machine-readable chemical data. However, data resources that index chemical structures lack standardised system-to-system interoperability, which can propagate errors when exchanging and compiling chemistry data. To meet this challenge, the Chemistry case study developed a prototype web service[13] to confirm chemical identity and provide real-time feedback on the machine readability of chemical representation based on IUPAC standard rule sets and community best practices. Data resources, software and other services that reference chemical information can implement the specified protocols based on their existing or preferred technologies (e.g., toolkits, programming languages).

Users often need to consider several data resources as a part of their everyday work. There are a number of scenarios where it is useful to navigate across distributed data resources using programmatic methods - for example, a global search for specific chemicals, cross-exchange of chemical information between data repositories, validation of converted or predicted chemical representations, or integration of distributed data for compiled meta-analysis. A consistent approach for chemistry resources to expose information about the chemical representations used in their system through a common protocol as outlined in 'D3.3 Utility services for Chemistry Standards' will facilitate navigation across these resources.[14] Individual data systems providing their associations between the IUPAC International Chemical Identifier (InChI) and their record identifiers can foster data hubs that provide one-stop shops for links to all resources relevant to a chemical structure using InChI as the cross-link.

3.3.2 Nanomaterials

The progression of the proposed extension of the IUPAC InChI to cover nanomaterials (and eventually also advanced materials) has been a key effort of the nanomaterials Case Study, and the submission of the formal proposal for adoption by the InChI Trust is the final step to achieve the initial version of the standard extension. Close collaboration with the InChI development team has been critical to ensuring that decisions made regarding the Nanomaterials InChI are consistent with those on the development pipeline for InChI itself. The NanoCommons User Guide and the WorldFAIR post-project sustainability activities will be important aspects of driving the adoption by databases, repositories and nanomaterials commercial providers of the Nanomaterials InChI. The

[13] https://iupac.github.io/WFChemProtocols/
[14] Thiessen, P., Bolton, E., & McEwen, L. R. (2023). WorldFAIR (D3.3) Utility services for Chemistry Standards (1.1). Zenodo. https://doi.org/10.5281/zenodo.10289785

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convergence of the Nanomaterials InChI approach with the European regulatory approach of "nanoforms" and "sets of nanoforms" is another important driver for adoption, and a NanoOpinion [15] on the final Nanomaterials InchI standard will be drafted for the European Chemicals Agency[16]. Demonstrator projects to implement the first standard version of the Nanomaterials InChI have also been identified, including the Horizon Europe funded projects MACRAME[17], PINK[18], INSIGHT[19] and CHIASMA[20].

3.3.3 Biodiversity

The Biodiversity Case Study is part of a large community-driven project to better model biodiversity data for science and policy relevance. The Global Biodiversity Information Facility (GBIF) is leading the overhaul of the Darwin Core data standard used by thousands of institutions worldwide with a new GBIF Unified Data model. The WorldFAIR Case Study is a set of studies to test the model and get community input on directions and usability. GBIF, as a Global Biodata Core infrastructure, provides sustainability for this process which will take many years to complete. It is GBIF's intention that when mature, or portions of it, are mature those components will be placed before the governance of the Biodiversity Information Standards (TDWG) for review and ratification by the community that helped develop it.

3.3.4 Agricultural Biodiversity

The Case Study produced concrete guidelines on FAIR data best practices for sharing plant-pollinator interaction data, metadata, and other digital objects. At least three of the six pilot studies conducted during the WorldFAIR project will continue to promote the adoption of the resulting KERs, namely: the Brazilian Plant-Pollinator Interactions Network (REBIPP), the United States Department of Agriculture (USDA) plant pollinator interaction prototype data and database development and the collaboration between Colecciones Biológicas from the Universidad CES and SIB Colombia, which is Colombia´s GBIF node.

The Global Biotic Interactions platform has added new functionalities to their services based on the work of this Case Study, i.e., the FAIR assessment in the data review report and the adoption of the Ecological Metadata Language for the datasets.

The RDA Improving Global Agriculture Community of Practice (IGAD CoP) will promote and disseminate the WP outputs, also encouraging and promoting adoption of the results. It is expected

[15] https://euon.echa.europa.eu/nanopinion
[16] http://echa.europa.eu/
[17] https://cordis.europa.eu/project/id/101092686
[18] https://cordis.europa.eu/project/id/101137809
[19] https://cordis.europa.eu/project/id/101137742
[20] https://cordis.europa.eu/project/id/101137613

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that the Biodiversity Informations Standards (TDWG) Biotic Interactions Interest Group will continue to disseminate and improve this case study's results. Additionally, the interest group will work together with GBIF to promote their new data model for the biotic interactions module.

3.3.5 Ocean Science and Sustainable Development

The ODIS Architecture now includes interoperability norms and patterns developed through WorldFAIR described in 'D11.1 An assessment of the Ocean Data priority areas for development and implementation roadmap'[21], 'D11.2 New interoperability specifications and policy recommendations'[22], and 11.3, and has been adopted and implemented globally by more than 40 organisations, with more in development.[23] Some of these organisations are single institutes, while others are continental-scale data aggregators. Note that the ODIS-Architecture is built upon and interoperable with schema.org/JSON-LD conventions, already adopted and in use by tens of millions of computers on the Web. All members of the ODIS Federation are able to innovate within the ODIS Architecture, adding or enhancing interoperability patterns such that they are rapidly - and often automatically - deployed across the Federation via IODE's coordination. Further, as a mechanism to sustain adoption and impact, the achievements in ODIS have resulted in the reconfiguration of the IODE's programme components: Along with the Ocean Biodiversity Information System (OBIS) and Ocean Teacher Global Academy, ODIS is one of the IODE's three pillar subcomponents, with other projects and activities federated under its interoperability norms. The innovations within cross-domain data sharing in the ocean community have led to new, global value for regional and national data coordination hubs such as the European Marine Observation and Data Network (EMODnet)[24] and the UK's Marine Environmental Data and Information Network (MEDIN)[25]. Other Horizon projects (whether ocean-focused or not) can leverage this progress to make the UN ir data more FAIR on the global stage, as exemplified by the data flow being developed in MARCO-BOLO[26] to support biodiversity reporting via the Global Ocean Observing System's Essential Ocean Variable framework.

[21] https://doi.org/10.5281/zenodo.7682399
[22] https://doi.org/10.5281/zenodo.10219933
[23] The ODIS dashboard may be used to monitor the growth and evolution of the federation http://dashboard.oceaninfohub.org/
[24] https://emodnet.ec.europa.eu/en
[25] https://medin.org.uk/
[26] https://marcobolo-project.eu/

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3.4 Environmental

A number of WorldFAIR case studies have dealt with matters with potential environmental impact, namely the WPs on Chemistry, Nanomaterials, Biodiversity, Agricultural Biodiversity, Ocean Studies and Sustainable Development and Disaster Risk Reduction.

3.4.1 Chemistry

Many different disciplines need to access and integrate chemical information, including oceanography, meteorology, astronomy, metabolomics, proteomics, bioinformatics, geology, biomedical informatics, and many others. Key facets of chemistry data practices across disciplines surfaced in the WorldFAIR Chemistry webinar series "What is a chemical?"[27] and in the International Data Week 2023 session on "Beyond FAIR: reusing chemical data across disciplines with CARE, TRUST and openness".[28] Ascertaining chemical composition is a common need in characterising research samples in many fields and further integration with other chemical property data can enrich the scientific knowledge base and enable additional analyses and activities; for example, environmental monitoring and chemicals risk assessment. The desire by some national governments for more sustainable practices and zero pollution in the chemistry industry[29] creates a need for an evolution in the way we assess chemical risk in order to protect health and the environment.[30] Being able to reliably and comprehensively capture chemical substances and associated data will be key to effectively achieving these aims. Confirming the identity of chemical substances as described in the initial specification of 'D3.3 Utility services for Chemistry Standards' is an important part of tracking provenance and reusability of chemical data and central to the practice of environmental sciences.[31]

3.4.2 Nanomaterials

Application of the recommendations and guidelines presented in WorldFAIR deliverable 'D4.1 Nanomaterials domain-specific FAIRification mapping'[32] and 'D4.3 Nanomaterials human / machine-actionable provenance and persistence policies' will ensure that nanomaterials and nanosafety research data will have greatly increased relevance and reusability for nanoinformatics modelling, for design of safe and sustainable materials and for use in regulatory risk assessment and environmental risk assessment. Implementation of InChI and the nanomaterials extension of InChI will increase data harmonisation and interoperability, and linking the nanomaterials InChI and the

[27] https://zenodo.org/doi/10.5281/zenodo.7259101
[28] https://www.scidatacon.org/IDW-2023-Salzburg/sessions/504/; *article forthcoming*
[29] *EU Chemicals strategy.* https://environment.ec.europa.eu/strategy/chemicals-strategy_en
[30] *Partnership for the Assessment of Risk from Chemicals (PARC).* https://www.eu-parc.eu
[31] Thiessen, P., Bolton, E., & McEwen, L. R. (2023). WorldFAIR (D3.3) Utility services for Chemistry Standards (1.1). Zenodo. https://doi.org/10.5281/zenodo.10289785
[32] https://doi.org/10.5281/zenodo.7887341

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materials, samples and data provenance information (as described in D4.3) will increase confidence in meta-analyses and datasets utilised in modelling and risk assessment. We note also the increased focus of the European Commission on advanced materials and Safe and sustainable by design (SSbD), both of which are derived directly from the nanosafety research community, and thus the WorldFAIR nanomaterials Case Study will thus have impact on a much larger community as these groups come together under the umbrella of a Materials Data Ecosystem and marketplace. Life Cycle Assessment (LCA), which is a central part of SSbD, is extensively dealing with matters with potential environmental impacts from the production, use and disposal of chemicals and materials, and the products into which these are embedded. As yet, LCA utilises only a small fraction of the available ecotoxicity data, and a key ambition of the new SSbD projects including PINK and INSIGHT is to develop the tools and workflows that allow existing LCA tools to integrate with a broader range of ecotoxicity data and ecotoxicity prediction models. This includes development of common data documentation approaches, data reporting standards, and especially mapping approaches to link the different semantic universes existing currently in the (nano)safety and the materials modelling communities and fill gaps especially for LCA in collaboration with PARC and others.

The WorldFAIR deliverable 'D4.2 FAIRification of nanoinformatics tools and models recommendations'[33] on making modelling FAIR is being utilised in Horizon Europe project INSIGHT who will be developing a number of predictive models for chemical and nanomaterials environmental risk assessment and wish to make them FAIR in accordance with the WorldFAIR recommendations. The guidelines are also feeding into the PARC project's work on the Safe and Sustainable by Design framework, and the work planned in the PINK and CHIASMA projects, which will develop models for environmental risk assessment and make them FAIR.

The ongoing work on identifiers and data provenance, initiated in WorldFAIR D4.3 is being continued in the PINK project and will have a major impact on data trustworthiness and, thus, availability of (nano and advanced materials) data for reuse. The importance of harmonisation of approaches with chemistry via the Chemistry Case Study has been invaluable also, since materials and chemistry are not separable. For this reason the extension of InChI for nanomaterials builds on and reuses InChIs, and the starting points for material production are chemicals and these have to be clearly defined for material provenance (D4.3).

3.4.3 Biodiversity

The Biodiversity work in WP9 facilitated the core restructuring of the GBIF data model which we anticipate will be an update of the TDWG community Darwin Core standard. The implications of this are broad and relevant well beyond the GBIF community and are beginning to have a positive impact on the community. The focus on expansion of a simple model to a more complex model based on the concept of an Event will provide opportunities for new data types to be linked to the

[33] https://doi.org/10.5281/zenodo.10629631

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biodiversity occurrence data served by GBIF. This is increasing the use of FAIR biodiversity data in policy. This Event is a common aspect of other WorldFAIR case studies and can be used in the CDIF.

The data model is being incorporated in many important international biodiversity projects. The new ecological data is being tested by the largest citizen science data network - eBird as well as groups associated with the Oceanic Biodiversity Information Service (OBIS), and The US National Environmental Obertain Network (NEON). This work has spurred data model advancement in the Agricultural biodiversity (WP10) and in biotic interactions in general (GloBI). The data model is being taken up by the GBIF community leading to richer biodiversity data. For example the Distributed System of Scientific Collections (DiSSCo)[34], which is on the European Strategy Forum on Research Infrastructures (ESFRI) road map, is using the new data model in its FAIR digital object architecture.

3.4.4 Agricultural Biodiversity

Pollination is a major ecosystem service which underpins several sustainable development goals and its importance to maintaining life on Earth is widely recognised. Data and knowledge gaps on pollination and plant-pollinator interactions were identified by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)[35] and this was one of the most important motivations for this Case Study. Having established concrete guidelines and tools to promote plant-pollination interactions interoperability, as well as tools for FAIR assessments, this effort has promoted standards adoption and ensured FAIR data for understanding plant-pollinator interactions. As mentioned above, it is expected that the outputs generated by this Case Study will continue to be adopted and improved.

3.4.5 Ocean Science and Sustainable Development

Based on work carried out by this case study, for the first time, previously isolated ocean data systems are now able to seamlessly interface with each other's metadata catalogues: they'll know who has what kind of data, what it's about, and where and when it's relevant. This will be a foothold in deepening interoperability to priority data types, which overlap with several other WorldFAIR case studies. More importantly, the work here is shifting digital cultures towards an "interoperability first" model, promoting greater collaboration to face planetary crises.

OD2030, Implementation Plan, linking layers in the Vison 2030 process, EOV BioEco via MARCO-BOLO etc, SDG indicator data flows

[34] https://www.dissco.eu/
[35] https://www.ipbes.net/node/36759

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3.4.6 Disaster Risk Reduction

Making Disaster Risk Reduction (DRR) data FAIR will allow global and regional institutions, which often have the best access to resources, to more easily collaborate with National governments and local communities to understand DRR needs and implement solutions. In addition, by promoting the transformation of DRR data to machine-readable, semantically linked data there is the opportunity to use pre-trained Artificial Intelligence (AI) algorithms that can analyse large, complex datasets and fuse heterogenous data. This is already happening with national and international space agencies, the United Nations Office for Disaster Risk Reduction (UNDRR)[36], World Meteorological Organization (WMO)[37], and other global agencies. Our case study aims to enhance this collaboration. Recent advances in technology, particularly remote sensing data, which is income agnostic and provides global coverage, provide an opportunity to reduce data gaps for lower income countries. However, unless this data is provided in a FAIR and open fashion there is the potential for the gaps to widen as countries with more resources and technical capacity make better use of DRR data. Encouraging the use of FAIR and open DRR data should help close any historical or emerging DRR data inequalities

3.5 Social & Health

3.5.1 Urban Health

The case study on Urban Health has produced guidelines and training materials that promote best practices in data provenance management within the urban health sector. These guidelines not only serve to enhance data integrity and reliability but also pave the way for improved decision-making processes that positively impact urban populations. Moreover, the Work Package has extended its efforts beyond the confines of urban health by developing guidelines and best practices that can be applied across various disciplines involved in urban planning and management. These guidelines integrate both the FAIR and CARE (Collective benefit, Authority to control, Responsibility, and Ethics) Principles for Indigenous Data Governance. By doing so, they address common challenges related to data availability, acquisition, and utilisation within urban settings. Furthermore, they tackle issues such as data integration, quality assurance, and standardisation processes, thus ensuring that data from diverse sources can be effectively compared and utilised, both within and between cities, countries, and regions.

The training component associated with these guidelines is vital for disseminating the expertise acquired during their development. By sharing knowledge and fostering a community of practice, the training initiatives facilitate collaboration and knowledge exchange within and across disciplines. Ultimately, this collaborative approach not only enhances the effectiveness of data management

[36] http://www.undrr.org/undrr-homepage
[37] https://wmo.int/

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practices but also contributes to broader societal benefits by improving urban planning, resource allocation, and public health outcomes.

3.5.2 Population Health

The impact of this case study's work will be to develop the means to make the large amount of population health data, and their associated metadata more FAIR. The data producers will have more control over access to their data through the federated data structure and can use the recommendations to structure their metadata so that it can be found and actioned over the internet. The recommendations start from the premise that study leads do not have data documentation processes, and go through the FAIR processes in simple steps which enable the metadata to become discoverable.

Common analyses using study packages built on the harmonised data will transform the use of population health data, making it available for policy makers to use. The end result will be evidence-based decision making for pandemic control and public health implementation.

3.5.3 Cultural Heritage

At the end of 2022, the Digital Repository of Ireland (DRI)[38] invited participation in a Cultural Heritage Image Sharing Working Group, aimed at bringing together cultural heritage professionals with expertise in diverse areas of policy, professional practice, and technology to provide a global perspective on recommendations for FAIR alignment in the sector. The network of connections established through the Working Group created opportunities for DRI staff to participate in a number of related events happening in the Collections as Data space, including a data exploration sprint[39] at the Museum für Kunst und Gewerbe Hamburg and the workshop "Collections as Data: State of the Field and Future Directions" held at Internet Archive Canada. DRI contributed to the position statements[40] which were used to refine the Vancouver Statement on Collections as Data[41]. Building on the momentum and interest in Collections as Data internationally, DRI partnered with representatives from the Mellon-funded project 'Collections as Data: Part to Whole' to propose a charter for a new RDA Collections as Data Interest Group[42]. At recent meetings, presentations by DRI staff on the new Cultural Heritage Citation Model developed for Deliverable 13.3 'Final Report on

[38] https://dri.ie/
[39] https://www.mkg-hamburg.de/en/neo-lab#:~:text=conceived%20and%20used.-,Data%20Exploration%20Sprint,prototypes%2C%20data%20visualisations%20and%20explorations.
[40] https://doi.org/10.5281/zenodo.7897735
[41] https://doi.org/10.5281/zenodo.8342166
[42] https://www.rd-alliance.org/groups/archives-and-records-professionals-for-research-data-ig/members/all-members/

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Cultural Heritage FAIR sharing' as well as an overview of DRI's FAIR Implementation Profile were featured.

Across DRI's established networks, the importance of the recommendations to facilitate cultural heritage-specific FAIR practices is being shared. The biennial Digital Preservation in the Arts, Social Sciences and Humanities (DPASSH) Conference[43] has taken the theme "Collections as Data / Data as Collections" and will provide another opportunity to share insights learned from WorldFAIR. Several members of the WorldFAIR Cultural Heritage Image Sharing Working Group will participate in the programme, and there will be one paper devoted to the cross-project discussion that emerged from the Dagstuhl Workshop on process documentation (also captured in a podcast[44] recorded during the IDW2023).

4. WorldFAIR Exploitation and Sustainability Strategy

4.1 Sustainability models

The sustainability strategy of WorldFAIR is based on the general concept of potential re-use of the outputs by different communities. As the WorldFAIR concept is also dependent on co-design and co-development with community members, the sustainability and exploitation activities concentrate on the uptake of WorldFAIR outputs and recommendations by relevant communities, which is heavily reliant on the potential use scenarios and interest.

Many WorldFAIR outputs are generally considered to be usable 'as-is', but even in this best case scenario, they do require community development and maintenance to stay relevant to the user communities due to the rapidly evolving nature of the field of FAIR data and objects. Thus, the definition of sustainability models is needed for exploitation.

In the case of WorldFAIR, such sustainability models can be summarised as follows:

4.1.1 Sustainability via (international) organisations

This model is based on the continued development of the WorldFAIR FAIR Implementation Profiles (FIPs) and other outputs within the existing organisational structure of the global or regional disciplinary organisations. Adaptation and further development of the outputs in these contexts can be supported by the relevant organisations and their own members, stakeholders, and funding sources. This usually requires a high level of interest on the existing or potential usability of the outputs to the organisations' goals and strategic aims. Generally, this kind of sustainability has a

[43] https://dpassh.org/programme-2024/
[44] https://worldfair-project.eu/2024/01/09/worldfair-conversations-cross-domain-interoperability-and-challenges/

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high/medium level of resources and requires a high level of commitment from the organisations involved.

4.1.2 Community sustainability

This model uses existing or newly established communities to sustain, develop and maintain the outputs. The community model is based on the interest of individuals or organisations to commit their time (or employees' time) to the community work on the outputs, but do not have a specific organisation actively committing to maintaining the output. Such communities generally need some level of organisation, which in WorldFAIR was provided by either the RDA or CODATA. This kind of sustainability generally requires only limited direct resources, and commitment from individual members, but does require the necessary framework, as well as continued interest from participants for successful operation.

4.1.3 Project sustainability

In some cases, the outputs can be further developed using existing or newly obtained project-type funding. This model requires interest from a suitable funding source (external or internal), and creation of the necessary project framework for the maintenance and development. Such projects are temporary, but as funded efforts can include more effective actions from the members. This model is highly resource intensive and time-limited, but can be extremely effective on exploitation development.

4.1.4 Document-based sustainability

In this model, the outputs are generally made public and accessible, often with significant dissemination activities, and using existing channels and repositories. This model does not expect that there is necessarily any specific user community or maintenance effort, instead ensuring that the outputs are made available for any potential community interested in the outputs.

Note that these models are not separate, and are usually used together in a consistent framework.

4.2 Sustainability mechanisms underpinning the project's lifetime

The WorldFAIR exploitation and sustainability plans and models outlined above have been underpinned by three key mechanisms throughout the lifetime of the project, which ensured that the exploitation and sustainability efforts have a robust basis that can continue to be built upon after the end of the funding period. These mechanisms are as follows:

1. A robust **communication and dissemination plan** (*document-based sustainability*) that:
    - supports and amplifies the consortium's activities in the Open Science community,
    - fosters awareness of the project's results throughout the lifetime of the project

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- helps the project partners build a solid network in which they can continue to work beyond the end of the funding period.

2. Leveraging of **CODATA and RDA channels and existing communities**(*Community-based sustainability*):
   - to facilitate the uptake of the project's results in the community,
   - to secure more partners for a spin-off project after the end of the funding period (WorldFAIR+).
3. Leveraging the multiple **global partners** (*organisational sustainability*) in the consortium and their authoritative position in their respective domains
   - to establish WorldFAIR recommendations and guidelines as a widely recognised 'state of the art'.

An important distinction for exploitation and sustainability efforts is between cross-community efforts led by the project coordination (led by WPs 2 and 14 with partner input), including activities which in WorldFAIR we refer to as 'Synthesis'[45], and community-specific activities undertaken by each of the 11 Case Studies leveraging their local communities and networks. Both of these types of activities are underlined by mechanisms 1 and 2.

Section 6 will present activities that fall under the project-wide, 'synthesis' efforts. Section 7 will analyse exploitation and sustainability plans for case-study specific results.

4.3 Integration of results into the Open Science community

A key objective of the three strategic mechanisms is the integration of the results into the wider, global Open Science community as best practice. This has been enabled by all 3 sustainability mechanisms throughout the lifetime of the project, creating the basis for post-project activities as outlined in Sections 7 and 8. These activities were led by CODATA with input from the RDA (WP14) and contributions from all partners. The dissemination activities (mechanism 1) have been a joint effort throughout the lifetime of the project with partners leveraging their networks in establishing the WorldFAIR project and its work in their communities and fostering awareness - all such activities being simultaneously amplified by WP14. The coordination efforts have been managed during the monthly WP Leads calls and ad-hoc meetings between the WP leads and WP14.

Post-project sustainability and exploitation is further ensured through the creation of CODATA and RDA Working and Interest Groups which either directly or indirectly relate to work initiated by WorldFAIR, and ensure that outputs are available to the wider communities and continue to be worked on and developed further (see section 7 for further details on specific RDA and CODATA

[45] https://worldfair-project.eu/synthesis/

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groups created as part of the WorldFAIR project and/or which draw from WorldFAIR activities, which will carry on beyond May 2024).

4.4 Maintenance of the WorldFAIR online presence

The WorldFAIR website will continue to be maintained by the RDA Association and within 12 months of project completion, it will be taken over by CODATA, in order to manage and showcase the WorldFAIR+ initiative.

4.5 WorldFAIR Intellectual Property protection measures

As identified at the commencement of the project, there have been no concerns regarding IP, which may endanger the exploitation of the WorldFAIR results generated both inside and outside the consortium. All beneficiaries involved in WorldFAIR and the communities represented and engaged fundamentally support open science and open research principles and practices. All new IP created by the project will conform to CODATA and RDA policies which are aligned: results are published and made available under Creative Commons Attribution Only 4.0 licence (CC-BY) or the Creative Commons CC0 1.0 Public Domain Waiver (CC0).

5. Key Exploitable Results (KERs)

The 32 identified Key Exploitable Results aim to provide assessments of the current status of FAIR data in each discipline, foster awareness, provide recommendations for improvement as well as ready to use and/or adjustable training materials for the community.

A list of the project's key results as identified collectively by the project consortium is provided below. Each KER and the associated exploitation and sustainability plan will be examined in detail in section 7.

KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
1	The Cross-Domain Interoperability Framework (CDIF)	Integrate or share data across different domains.	Those working on Interoperability challenges	CODATA, WP2	Guideline & Recommendation
2	WorldFAIR Case Study FAIR	Reusable and shareable FIPs can	Researchers, Data Stewards and	All	Guideline &

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
	Implementation Profiles (FIPs)	be used as 'templates' for communities wanting to adopt FAIR practices[46].	Data Managers, Data Repositories and Archives.		Recommendation
3	WorldFAIR Policy Briefs[47]	Concise summaries of key issues to inform thinking and decision processes.	EOSC, policy makers	CODATA, WP2	Policy
4	Digital recommendations for chemistry FAIR data policy and practice (D3.1)[48]	Examples that can already be used to support functions that enable FAIR	Professionals building and managing systems and services that support scientists and researchers working with data. Those involved in information management and communication. Chemists, data scientists.	IUPAC, WP3	Guideline & Recommendation
5	Training package: FAIR chemistry cookbook (D3.2)[49]	A self-serve web-based toolbox of	Publishers, Librarians, Data Scientists,	IUPAC, WP3	Training

[46] https://osf.io/6z5ed/download
[47] https://doi.org/10.5281/zenodo.7853170
[48] https://doi.org/10.5281/zenodo.7887283
[49] https://doi.org/10.5281/zenodo.10711950

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
		hands-on executable content for experiential learning	Repository staff, Software developers, Researchers		
6	Utility services: protocols for chemical data exchange (D3.3)	Specification of a shared API data model for standard web-based chemical information exchange and validation that can be implemented by any system that manages chemical records.	Chemical database providers, Chemistry application developers, Chemists, researchers accessing web services indirectly through chemical drawing programs, electronic laboratory notebooks (ELN) or other applications; Chemical toolkit developers.	IUPAC, WP3	Guideline & Recommendation
7	Community engagement model and materials	Creation of a FAIR chemistry community and outreach materials to further engage and extend collaboration beyond the project.	Target users are a wide spectrum of students, global data/ chemical organisations, toolkit developers, publishers, databases, repositories, data	IUPAC, WP3	Engagement

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
			initiatives, as well as researchers from academia and industries.		
8	Nanomaterials domain-specific FAIRification mapping (D4.1)	The mapping of existing tools and their integration into the Nanomaterials FIP allows researchers, consortia and database developers to easily understand the existing landscape and how to implement /align with this. The mapping also identified gaps where additional tools and supports are needed, or where consensus has yet to be reached, which will drive progress.	The Nanosafety Community involved in NanoCommons / FAIR activities and the GO FAIR AdvancedNano Implementation network. European Nanotechnology Data, Knowledge and Informatics Communities	University of Birmingham, WP4	Guideline & Recommendation
9	FAIRification of nanoinformatics tools and models recommendations (D4.2)	The step-by-step guidance can be utilised by nano-informatics researchers / model	Nanoinformatics models and software developers / Researchers	University of Birmingham, WP4	Guideline & Recommendation

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
		development companies to enhance the FAIRNess of their models and drive use and adoption.			
10	Nanomaterials human / machine-actionable provenance and persistence policies (D4.3)	The guidance and policy will support increased implementation of best practice around complete documentation of provenance information about nanomaterials, their samples and the data arising from their production, use, testing which will increase the comparability of datasets and facilitate clearer understanding of nanomaterials evolution prior to toxicity evaluation.	Database owners, Materials developers / suppliers, Researchers	University of Birmingham, WP4	Policy Guideline & Recommendation
11	Nanomaterials FAIR training resources via the online community-driven	Self-guided training materials for researchers and data curators to support	European Nanotechnology Data, Knowledge and Informatics Communities,	University of Birmingham, WP4	Training materials Engagement

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
	NanoCommons User Guide	implementation of tools to support FAIR nanomaterials research outputs	Researchers, Educators, Policy makers		
12	Extension of InChI for nanomaterials	Standard format for representation of nanomaterial structures and chemical composition, to allow identification / integration of data related to similar nanoforms.	Database owners, Materials developers / suppliers, Researchers	University of Birmingham, WP4	Standard
13	Use case for FAIR-enabling resources (FERs) for GeoChemistry (D5.2)		Researchers, Infrastructure providers, Data custodians (archives and repositories)	AuScope, WP5	
14	WorldFAIR Guidelines for implementing Geochemistry FIPs (D5.3)		geochemistry community: data creators and providers	AuScope, WP5	
15	Cross-national social sciences survey best practice guidelines (D6.2)	xxx	Researchers, Infrastructure providers, Data custodians	Australian Data Archive, WP6	

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
			(archives and repositories)		
16	WorldFAIR Pilot Testing Harmonisation Workflows (D6.3)	xxx	Social science data archives and providers of related data and metadata registries, repositories that might host relevant data and metadata, the DDI Alliance and user community.	Australian Data Archive, WP6	
17	Population health data implementation guide (D7.1)	Will be used to guide owners of population health data to develop and use the FIP to publish their data	Users of INSPIRE, health researchers, and professionals working in other areas of observational health research, policy makers, governmental users, UN organisations such as the WHO.	London School of Hygiene and Tropical Medicine, WP7	Guideline & Recommendation
18	Population Health Resource Library and data training package (D7.2)	As a resource available to anyone wanting to learn how to develop their own resources for FAIR	Population health scientists in low-resource settings, who know their own data and want to	London School of Hygiene and Tropical Medicine, WP7	Training materials

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
		data and metadata	make those data FAIR.		
19	Population Health Data Policy and practice recommendations (D7.3)	To guide the data owners in making their data FAIR	Study data owners and policy makers	London School of Hygiene and Tropical Medicine, WP7	Policy Guideline & Recommendation
20	Urban Health Data - Guidelines and Recommendations (D8.1)	To guide urban data owners in making their data FAIR	Urban health researchers and practitioners, and data professionals, managers, data system personnel.	Drexel University, WP8	Guideline & Recommendation
21	Urban Health Data - Learning and Training (D8.2)	To raise awareness of the relevance of FAIR and CARE in data stewardship and enable ‘ fairer’ contexts for data use	Researchers, data stewards at research performing institutions	Drexel University, WP8	Training materials
22	Biodiversity Data standard for sharing ecological and environmental monitoring data documented for community review (D9.1)	This work will be the data model for all larger biodiversity informatics work worldwide.	The large GBIF community	GBIF, WP9	Standard
23	Biodiversity Final data model and	It makes s a growing richness	The large GBIF community	GBIF, WP9	Training materials

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
	training materials completed and shared (D9.2)	of data, such as event based museum specimen data available for use.			
24	Agricultural Biodiversity Standards, best practices and guidelines recommendations (10.2)	A cookbook and a tutorial were developed and can be used by Researchers and Data Stewards.	Researchers, Data Stewards, Project Managers, Repository Managers, Funding Agencies, Journal Editors, Educational Institutions.	Embrapa, WP10	Guideline & Recommendation
25	WorldFAIR agricultural biodiversity FAIR data assessment rubrics (D10.3)	Researchers and institutions can use the result to evaluate adherence to the FAIR principles	Researchers in the Agricultural Biodiversity domain who wish to assess the FAIRness of the data they produce and take action to improve it. It can also benefit data reviewers, data stewards, data repository managers and librarians dealing with plant-pollinator data.	Embrapa, WP10	Guideline & Recommendation

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
26	An assessment of the ocean data priority areas for development and implementation roadmap (D11.1)	Ocean data systems can use this pathway to implement sustainable cross-domain (meta)data flows	Programme leads and coordinators, digital implementation leads and teams, digital strategists.	Alfred Wegener Institute for Polar and Marine Research, WP11	Guideline & Recommendation
27	New interoperability specifications and policy recommendations for Ocean Data (11.2)	A set of (meta)data interoperability specifications and recommendations and accompanying policy recommendations that ensure their meaningful implementation and development within projects such as WorldFAIR and frameworks such as the Cross-Domain Interoperability Framework (CDIF).	Project and programme managers, directorates, high-level decision makers, Chief Technology Officers. Data/informatics specialists, digital architects, software developers and team leads, data- or software-focused researchers, (research) data managers.	Alfred Wegener Institute for Polar and Marine Research, WP11	Policy Guideline & Recommendation
28	Ocean Science and Sustainable Development Demonstration (11.3)	Summarises several KERs, which are encapsulated within the digital architecture powering	All co-developers and users of any system federated through ODIS, and related systems using web-architectural	Alfred Wegener Institute for Polar and Marine Research, WP11	Guideline & Recommendation

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
		cross-domain data discovery via ODIS and its partner networks (including the WMO's WIS2, and UNEP's World Environment Situation Room).	patterns to bridge networks with high cyberdiversity.		
29	Disaster risk reduction domain-specific fair vocabularies (D12.2)	The ideas and suggested actions can be used to transform raw DRR data to valuable insights and decisions that produce tangible reductions in the impact of disasters worldwide.	DDR researchers, researchers from earth sciences, climate change and environmental sciences, social studies, cultural information, and others.	Tonkin+Taylor, WP12	Guideline & Recommendation
30	Disaster Risk Reduction Findings and recommendations (12.3)	The DRR community can use the provided guidelines and recommendations to transform raw data into valuable insights that can be used for decision-making and action.	Disaster Risk Reduction (DRR) practitioners	Tonkin+Taylor, WP12	Guideline & Recommendation
31	Cultural heritage image sharing	The 5 recommendations	Cultural heritage professionals,	DRI, WP13	Guideline &

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KER N°	Description	How results can be used	Potential Users	Lead partner	KER Type
	recommendations report (D13.2)	outlined in this report can be used by GLAM fields of practice to adopt practices that support the FAIR principles and understand their importance to the communities they serve.	those working in GLAM organisations or in service providers that facilitate image sharing on behalf of these organisations.		Recommendation
32	Final Report on Cultural Heritage FAIR sharing (13.3)	GLAM organisations can use the report to improve FAIR enabling services for depositors and researchers working with cultural heritage image data in the repository.	infrastructures supporting cultural heritage image collections	DRI, WP13	WP13

6. WorldFAIR Overarching Exploitation and Sustainability Plans

6.1 WorldFAIR+

A direct continuation of the project's work is already underway through an initiative coordinated by CODATA, named 'WorldFAIR+'. As part of the 'Making Data Work for Cross-Domain Grand Challenges'[50] programme of activity to help deliver a specific part of the International Science Council (ISC) Action Plan with the same name, CODATA will expand and sustain the vision and methodology being advanced through the WorldFAIR Project. The purpose is to provide practical

[50] https://council.science/actionplan/making-data-work-for-grand-challenges/

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guidance and technical recommendations to help ensure that the data needed for interdisciplinary research is FAIR and has maximum utility. CODATA is seeking partners around the world for this initiative, to explore case studies to use and further refine the WorldFAIR methodology. Additionally implementation pilots will test and feed back on the CDIF recommendations.

'WorldFAIR+' will aim to achieve the following objectives:

- Refining the WorldFAIR methodology, particularly concerning the use of FIPs and the CDIF.
- Expanding the number of case studies (or petals in the WorldFAIR flower diagram and logo).
- Exploring and enabling implementations of CDIF, improving the model and demonstrating the benefits of the approach.
- Securing funding in various countries of a suite of projects implementing the methodology.
- Establishing one or more International Programme Offices to coordinate the activities and provide secretariat support and expertise.[51]

Following the receipt of a grant from the International Science Council, two further case studies relating to data in emergencies will be launched: these are concerned respectively with earthquake data (Turkey) and flooding and infectious disease data (Malawi). They build on some of the existing work A further case study in earth sciences as part of a collaboration with International Union of Geological Sciences (IUGS) and Deeptime Digital Earth[52] is also in discussion at the time of writing.

The CDIF Recommendations and the work of Work package 7, will be implemented in a new Wellcome-funded project 'Data Science Without Borders',[53] which brings together health scientists, data specialists, AI experts and policy analysts to work with institutes in Kenya, Ethiopia, Senegal and Cameroon.

Discussions are ongoing with a number of partners, including the Australian Research Data Commons (ARDC), the Helmholtz Metadata Collaboration, The Consortium of European Social Science Data Archives (CESSDA)[54] , the Korea Institute of Science and Technology Information (KISTI),

[51] https://codata.org/wp-content/uploads/2023/10/CODATA-Strategic-Plan_-Data-to-Improve-our-World-2023-FINAL-Endorsed-by-General-Assembly.pdf
[52] https://www.ddeworld.org/
[53] https://codata.org/launch-of-the-data-science-without-borders-project/
[54] https://codata.org/cessda-eric-and-codata-unite-forces-to-propel-interdisciplinary-research-and-data-advancement/

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the African Open Science Platform (AOSP), the Malaysian Open Science Platform, the LIFES Institute in Leiden, the CivicDataLab India, and others.[55]

6.2 Research Data Alliance Outputs and Recommendations

WP14, lead by RDA Association, and many consortium partners (IUPAC, the Case Study team on Agricultural Biodiversity through its connections with the Community of Practice on Agricultural Data, for example), including CODATA (who co-organise the International Data Week alongside RDA and WDS), have driven the involvement and impact of the WorldFAIR project in the RDA community. The participation of the consortium in RDA Plenaries and IDW events has lead to the creation and/or contribution to RDA Working and Interest Groups that contribute to transferring the knowledge developed during the lifetime of the project to the wider community, and will further build on the project results through the development of RDA Outputs and Recommendations, which get adopted by many institutions around the world. Further details on the specific RDA Groups created through the WorldFAIR project, and case studies that have contributed to existing Groups, will be provided in Section 7.

6.3 WorldFAIR synthesis activities

Synthesis and coordination in WorldFAIR is led by CODATA in Work Package 2. There are four main components to this activity: 1) review and appraisal of the use of FAIR Implementation Profiles (FIPs); 2) development of the Cross-Domain Interoperability Framework (CDIF); 3) recommendations for Domain Sensitive FAIR Assessment; and, 4) synthesis of policy relevant recommendations. The objectives include engaging with and ensuring alignment of the substantive activities of the case studies; synthesising findings and recommendations across the case studies and project as a whole; and, extrapolating cross-domain and domain independent recommendations.

6.3.1 The Cross-Domain Interoperability Framework (CDIF)

CDIF is a set of guidelines and practices for using domain-agnostic standards to support the interoperability and reusability of FAIR data, especially across domain and institutional boundaries. It has been developed in response to the need for agreements on the use of standards in FAIR implementations, to support all areas of research but in particular those grand challenge research questions that are necessarily interdisciplinary and cross-domain in nature.

[55] The full announcement is available on the CODATA Newsletter
https://codata.org/blog/2023/12/19/fair-well-2023-and-looking-forward-to-2024/

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The development of CDIF was informed by the work of the WorldFAIR Case Studies and their FAIR Implementation profiles: the CODATA team held intensive meetings with each of the case studies to understand practices and challenges in data and metadata. A number of CDIF modules were advanced through two Dagstuhl workshops held during the WorldFAIR project and at which all case studies participated, alongside other experts.

Additionally, thirty invited experts participated in drafting the CDIF guidelines, including members of many related FAIR initiatives and standards bodies. Therefore, the CDIF guidelines draw on significant expertise both within and outside the WorldFAIR project.

Just as CDIF is designed to complement and add detail to the EOSC Interoperability Framework, as well as work coming out of other EOSC-related projects, it is also informed by a number of global developments represented in WorldFAIR. CDIF is designed to build on the work of such groups, complementing their efforts and making them practical for implementers in Europe and globally.

Work on CDIF will continue, beyond the life of the WorldFAIR project, through a series of follow-up projects (case studies and implementation pilots) coordinated as WorldFAIR+ (see section 6.1). Such guidelines are only meaningful in relation to developments in the realm of standards and technology, and must be maintained accordingly.[56] The CDIF Working Group and Advisory Group will be maintained by CODATA, as will the strong relations with standards bodies, authoritative organisations and international, regional and national infrastructures who are the key stakeholders.

KER 1. The Cross-Domain Interoperability Framework (CDIF)	
Partners contributing to development, operational and/or training aspects	The CDIF recommendations draw on the work of all project partners, as well as invited experts.
Description of the KER	CDIF is a set of guidelines and practices for using domain-agnostic standards to support the interoperability and reusability of FAIR data, especially across domain and institutional boundaries. The version 01 produced by the WorldFAIR project represents a first draft and will need further testing, development and refinement.
Value Proposition for end-user communities	The principle value proposition is to better enable the integration or combination of data and metadata for cross-domain research projects, and to do so in a standards-based way that makes the process more repeatable and automatable. The CDIF guidelines

[56] https://worldfair-project.eu/cross-domain-interoperability-framework/

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	will also benefit disciplines and communities to make their data and metadata reusable outside their domain and beyond its original purpose.
Target users and needs, including how they use the service/tool	The target users of CDIF are data infrastructures, and large data projects, that need to prepare data for integration and reuse in cross-domain research projects.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	CDIF draws on international good practice, as identified through the WorldFAIR project. The standards in the framework are domain agnostic. Further work will be required to pilot and refine the recommendations. Like any exercise requiring the enrichment of metadata, the investment of effort and resources will be necessary.
Exploitation plan per partner	Work on CDIF will continue, beyond the life of the WorldFAIR project, through a series of follow-up projects and initiatives (case studies and implementation pilots) coordinated as WorldFAIR+. The CDIF Working Group and Advisory Group will be maintained by CODATA, as will the strong relations with standards bodies, authoritative organisations and international, regional and national infrastructures who are the key stakeholders.
Sustainability model(s) planned	CODATA is committed to sustaining the ongoing work on CDIF, as part of its mission and strategy for the International Science Council and its objective to contribute towards EOSC. The sustainability model for CDIF is a combination of sustainability via international organisation, community sustainability, and project sustainability.

6.3.2 FAIR Implementation Profiles (FIPs)

FAIR Implementation Profiles (FIPs) are a methodology, developed by GO FAIR[57], through which a research community expresses its practices and decisions around FAIR. The approach involves a series of questions on how the community makes data and metadata FAIR and what 'FAIR Enabling Resources' (FERs) are used.

[57] https://www.go-fair.org/how-to-go-fair/fair-implementation-profile/

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The WorldFAIR project explored FIPs with the 11 case studies: FIPs were developed by each case study early in the project and towards the end of the project. The intention is to identify gaps and areas requiring further attention; and any progress made in awareness and potential implementation of FAIR.

The FIPs produced by the WorldFAIR case studies are available on Zenodo[58] and can be used as use cases and examples to be replicated and facilitate FAIR data practices for the disciplines addressed by the project and beyond.

KER 2. WorldFAIR Case Study FAIR Implementation Profiles (FIPs)	
Partners contributing to development, operational and/or training aspects	All case studies developed at least one FIP, and in some cases several addressing different components of their case study. These have been documented using the FIP Wizard tool, and public versions are available via the FIP Wizard as well as via Zenodo (Link to be added).
Description of the KER	The FIPs represent the current state of knowledge in each of the case study domains, and are collections of the FAIR Enabling Resources used currently by the community or planned to be used by the community. Each FIP has a start and end date (really a review date) as new tools and approaches, or new standards emerge regularly requiring the community FIPs to evolve in tandem.
Value Proposition for end-user communities	The case study specific FIPs enable members of the various communities to easily understand the current best practice and resources used in their community to support FAIR data. Users can evaluate their own practice, or the resources that they use relative to the community FIP and identify points of convergence or divergence, which can drive further development and harmonisation of practice. Community convergence can also support long-term maintenance and onward development of the tools and resources providing a route to sustainability also.
Target users and needs,	*Database developers / Registry owners*: Using the community FIPs

[58] https://zenodo.org/communities/worldfair-project-fips/

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including how they use the service/tool	developers can identify resources they can utilise to enhance the overall FAIRness of their database and increase its interoperability with other resources utilised by their target communities. *Ontology / vocabulary / metadata schema developers*: While there are many partial ontologies and vocabularies in use, these are not always themselves FAIR, and utilising the FIP can support in increasing the FAIRness and sustainability of schema/ontologies. *Research community members*: The community level FIPs provide an easily accessible listing of the FAIR Enabling Resources utilised by other members of the community that can help accelerate their individual efforts to increase the FAIRness of their research outputs.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	As noted above, the FIPWizard template includes an end-date. We suggest that this becomes a "review date" such that communities / organisations can take stock periodically and either re-confirm that the FIP is still valid, update it, or retire it if it no longer represents the community's approaches to FAIR research output management
Exploitation plan per partner	See the individual case study exploitation plans in Section 7 below, where the different communities describe their exploitation plans.
Sustainability model(s) planned	Given the range and diversity of the case study communities and the topics that the FIPs were prepared for, a range of sustainability approaches will be implemented, often with multiple approaches used for each FIP or group of FIPs. *Via international organisations:* Case study FIPs related to resources owned by specific organisations such as IUPAC, DRI, UNESCO will be maintained and sustained by the developing organisations. The onward development and maintenance of the FIPs will roll into the ongoing workplans of these organisations. As each FIP has an end-date (which WorldFAIR is recommending changes to a Review date at which point it should be updated or re-confirmed as the current best practice) there is a process for updating and maintaining them. *Via project sustainability*: Case study FIPs developed for the nanomaterials, geosciences and biodiversity and agricultural biodiversity communities for example, will be sustained by their

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	uptake into other ongoing projects and further developed or sustained by active use and implementation into project data management workflows and Data Management Plans. For example, the nanomaterials FIP is being adopted in several Horizon Europe projects such as PINK, CHIASMA and INSIGHT. *Document-based sustainability:* All WorldFARI FIPs are available in multiple formats (FIPWizard, pdf, JSON, xml) via the WorldFAIR Zenodo site and are widely promoted. As new versions are prepared or the FIPs are updated or reconfirmed as being active past their initially noted end-dates, this information will be added to the Zenodo site also. *Community-based sustainability*: Many of the case studies were build around existing communities of practice and these will continue to maintain the momentum build through WorldFAIR and promote their FIPs within their communities.

6.3.3 FAIR Assessment

There has been a lot of work in EOSC-related projects and elsewhere on FAIR assessment. So much so that it has even been remarked that "we need an assessment tool for the FAIR assessment tools".[59] This work has often been well-intentioned, and has undoubtedly helped advance understanding of the FAIR principles, while sometimes helping organisations understand what may need to be done to bridge the gap between current practice and FAIR compliance.

Nevertheless, the view of the WorldFAIR project is that in important respects the focus on FAIR assessment puts the cart before the horse. Scientific communities and disciplines, and their representative bodies at an international or regional level, have an important role in setting good practices and standards for how to make data and metadata FAIR, by articulating interoperability and FAIR frameworks. Some communities are relatively advanced, others less so. Given this context, a priority should be to encourage and enable different communities to express their view of good practice in relation to FAIR. As described above, FAIR Implementation Profiles offer a useful mechanism for doing so. Thus, the final WorldFAIR FIPs provide a useful reference and a basis on which FAIR assessment can be developed for the disciplines and communities involved.

The key recommendation from WorldFAIR is to put the FIP horse before the FAIR assessment cart, specifically to encourage and enable research communities to reflect on their practice through developing FIPs. Those FIPs can then be used as the basis for FAIR assessment. This message has

[59] Michel Schouppe, EC, Oral Statement at EOSC Lustrum event, Vienna, 19 October 2023

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chimed with the experience of other projects, and a number of EOSC-related initiatives are now looking at how to use FIPs, and integrate the information from FIPs with FAIR assessment tools.

6.3.4 Policy-Relevant Recommendations

Policy relevant recommendations from all the WorldFAIR Case Studies and deliverables, as well as from the synthesis activities, will be analysed and classified. The most significant will be synthesised and presented in the final Policy Brief.

7. WorldFAIR Individual Case Study Exploitation and Sustainability Plans

7.1 Chemistry

7.1.1 Chemistry case study overview

The goal of the WorldFAIR Chemistry project is to align IUPAC's chemistry data standards with the FAIR data principles through: development of guidelines, tools and validation services that enable scientists to share and store data in a FAIR manner; addressing gaps in standards that currently restrain chemistry in both academic and industrial areas, in particular taking advantage of developments in AI/ML; and engaging critical stakeholders in the adoption of standards and best practices to significantly increase the amount of chemical data available for all scientific disciplines.

7.1.1.1 Chemistry sustainability via (international) organisations

Chemistry via IUPAC: reference reports for deliverables posted on Zenodo will be further reviewed and adopted by IUPAC as published Technical Reports, and may be further formalised as standard specifications; IUPAC will provide ongoing stewardship of FIPs, FERs, other FAIR assessment, interoperability framework contributions; IUPAC will continue coordination of ongoing community contributions to further development of the project outcomes.

7.1.1.2 Chemistry community sustainability

The FAIR Chemistry Cookbook and exchange protocol prototypes will continue to operate via community contribution and use (coordinated through IUPAC); further community collaboration on digital standards adoption will be fostered through chemistry community initiatives (e.g., NFDI4Chem, PSDI), CODATA, RDA and other chemistry community groups.

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The WorldFAIR Chemistry WP leads are co-chairs and/or members of the RDA Chemistry Research Data IG[60]. The IG aims to foster diverse professional exchange on issues particular to data originating from the field of chemistry, and throughout the lifetime of the project the WP leads have leveraged RDA as a forum where WorldFAIR results can be presented, discussed and incorporated into future work. A summary of the WP3 team's involvement in the last RDA Plenary (IDW 2023) through Birds of a Feather and CODATA meetings is available on the WorldFAIR website[61].

IUPAC recently held a workshop in Cambridge, UK, on March 25-26, 2024, focusing on sustainable business models for digital standards in chemistry data reporting. The goal was to create a roadmap and sustainability plan for chemistry data standards aligned with FAIR data principles. The workshop tackled key questions such as maximising standards development opportunities, identifying necessary deliverables for adoption, and exploring suitable business models. Emphasis was placed on stakeholder engagement and interdisciplinary cooperation for sustainability. Participants included stakeholders from various organisations involved in data standards development. Outcomes will include a map of standards, a white paper, and a coalition for collective messaging and shared resources. The workshop aimed to foster collaborative efforts in advancing digital standards for chemistry data exchange, with support from the WorldFAIR Initiative and the InChI Trust, and hosted at the Cambridge Crystallographic Center (CCDC). Workshop materials are being hosted on Zenodo[62].

7.1.1.3 Chemistry project sustainability

IUPAC has initiated specific projects to follow up on the WorldFAIR deliverable prototypes, to further refine, document, develop use cases, strategize broader adoption, etc.; IUPAC collaborates with chemistry community initiatives on several long-term digital standards projects to address needs in digital data exchange (e.g., metadata schema, FAIR data author guidelines, etc.); additional project directions to enable FAIR are outlined in a Roadmap report addended to D3.1 as an appendix.[63]

7.1.1.4 Chemistry document-based sustainability

Community outreach materials have been posted on Zenodo[64] for broad access and promoted via IUPAC and chemistry channels, including deliverable reports, webinars, posters, Zotero bibliography, and other outcomes pending from the sustainability workshop.

[60] https://www.rd-alliance.org/groups/chemistry-research-data-ig/
[61] https://worldfair-project.eu/2023/11/10/idw2023-a-festival-of-data-with-the-worldfair-project/
[62] https://doi.org/10.5281/zenodo.10966075
[63] McEwen, L., & Bruno, I. (2023). WorldFAIR Project (D3.1) Digital recommendations for Chemistry FAIR data policy and practice. Zenodo. https://doi.org/10.5281/zenodo.7887282
[64] https://zenodo.org/communities/fairchemistry/

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7.1.2 Chemistry sustainability and exploitation plans per Key Exploitable Result

KER 4. Digital recommendations for chemistry FAIR data policy and practice (D3.1)	
Partners contributing to development, operational and/or training aspects	IUPAC, CCDC
Description of the KER	A review of some of the critical and persistent issues around description of chemical information necessary to enable FAIR for machine processability, interoperability and reuse. It also considers documentation requirements and existing chemistry data standards to achieve FAIR sharing of chemistry data in ways that are Reliable, Interpretable, Processable, and Exchangeable (RIPE).[65]
Value Proposition for end-user communities	Provides guidance and a number of examples of chemistry standards and community resources to stakeholders involved in scientific communication that can already be used to support functions that enable FAIR (including representation formats, ontologies, metadata schema, formal terminologies, etc).
Target users and needs, including how they use the service/tool	The range of professionals involved in building and managing systems and services that support scientists and other researchers working with data. Those involved in information management and communication, including professionals in publishing houses, libraries, standards organisations and at other information resources. Chemists, data scientists and other researchers who are actively working with informatics and programmatic applications, and those who are in positions to influence policy that impacts chemical data reporting and exchange.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Many communities in the chemical sciences and adjacent domains are likely not yet versed or focused on needs and opportunities for FAIR data exchange; much foundational work still to be done around optimal research data management practices (e.g., RDM) before these communities are ready to realise the potential impact of the nuanced work done in this WP and the wider

[65] https://doi.org/10.5281/zenodo.7887283

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KER 4. Digital recommendations for chemistry FAIR data policy and practice (D3.1)	
	WorldFAIR project
Exploitation plan per partner	There is ongoing work in collaborations with community and stakeholder groups to incorporate chemistry data standards and guidance into data management plans and data publishing workflows (e.g., NFDI4Chem,[66] PSDI[67]). Aspects of the guidance have been topics of several conference sessions and webinars in broad international venues (e.g., RDA, IDW) as well as domain based (e.g., American Chemical Society, ChemVoices, Royal Society of Chemistry (RSC), National Academy of Sciences Chemical Sciences Roundtable (NAS-CSR). IUPAC will continue to promote best practices in chemical data description through the Committee on Publications and Cheminformatics Data Standards.
Sustainability model(s) planned	There is continued work in IUPAC via several projects to articulate metadata and documentation requirements for chemistry data types, e.g., FAIR Spectra (FAIRSpec), Machine Accessible Periodic Table (MAPT), IUPAC Interdivisional Subcommittee on Critical Evaluation of Data (ISCED); projects include community engagement and outreach. There is also follow up planning from a recent workshop on Sustainability chemistry data standards (see description in section 8.1.2), including a high level of interest in community collaboration on messaging around chemical data exchange standards.

KER 5. Training package: FAIR chemistry cookbook (D3.2)	
Partners contributing to development, operational and/or training aspects	IUPAC, PSDI, NFDI4Chem, NCBI[68], other individual community members
Description of the KER	An online cookbook platform of interactive demonstrations of

[66] https://www.nfdi4chem.de/
[67] https://www.psdi.ac.uk/
[68] https://pubchem.ncbi.nlm.nih.gov/

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KER 5. Training package: FAIR chemistry cookbook (D3.2)	
	community best practices in machine-readable chemical data management that can be readily accessed with broadly available online infrastructure.
Value Proposition for end-user communities	The IUPAC FAIR Chemistry Cookbook is an openly accessible collaborative resource to exemplify the FAIR data principles and standards in cheminformatics. The resource functions as a self-serve web-based toolbox of hands-on executable content for experiential learning. IUPAC invites practical contributions from chemists, data scientists, educators, and students to leverage the collective expertise of the community in best practices for managing and reusing chemical data.
Target users and needs, including how they use the service/tool	This Cookbook is envisioned to serve a variety of users across a wide range of scientific domains and sectors, including commercial, research, government and educational organisations. Researchers incorporating machine learning into their research, librarians and supporting researchers, other services providers including journal editors, repository curators, systems and software developers, and anyone else handling chemical data would also find this resource especially helpful.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Active volunteer stewardship will be critical to support the resource and the contribution process. Active outreach across a wide-spread community to use and contribute to the resource will also be critical to reach critical mass of content and use cases. Lack of engagement after the current cycle of ongoing projects among collaborators could be a barrier for further exploitation. Significant changes in openly available technology and infrastructure could impact functionality and this will need to be monitored.
Exploitation plan per partner	The Cookbook's structure is designed to harness the collective intelligence of the chemical data community through submissions that provide detailed, expert insights into specific areas across a range of topics. To encourage the community to contribute to the Cookbook, the documentation wiki[69] on the project GitHub

[69] https://github.com/IUPAC/WFChemCookbook/wiki

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KER 5. Training package: FAIR chemistry cookbook (D3.2)	
	website details how to prepare and submit new recipes. Contributions to the Cookbook are managed through an open submission and review process that exemplifies FAIR. Several additional recipes are already in the review pipeline and many more in conceptual stages from active project members and collaborators. IUPAC is well positioned to expand awareness through a strong international community of educators in the Committee on Chemical Education[70] and the union's education journal, *Chemistry Teacher International* ,[71] and planning is underway for a follow up project to develop 'train the trainers' materials to familiarise educators with use of the Cookbook in teaching. Shareable promotion toolkit in development with collaborators.
Sustainability model(s) planned	The Cookbook's content is a living body of work, designed to grow and adapt as new contributions are made and as the field of cheminformatics evolves. This ensures that the resource remains relevant and continues to meet the community's needs for reliable, FAIR-enabled data practices. Ongoing work to refine the contribution process and develop the content pipeline will be continued through an IUPAC project in coordination with several active data initiatives in the chemical sciences, including NFDI4Chem and PSDI. We also hope to further engage with adjacent disciplines and affiliated projects such as PARC.[72]

KER 6. Utility services: protocols for chemical data exchange (D3.3)	
Partners contributing to development, operational and/or training aspects	IUPAC, NCBI, EPA
Description of the KER	Specification of a shared API data model for standard web-based

[70] https://iupac.org/body/050
[71] https://www.degruyter.com/journal/key/cti/html
[72] https://www.eu-parc.eu/

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KER 6. Utility services: protocols for chemical data exchange (D3.3)	
	chemical information exchange and validation that can be implemented by any system that manages chemical records. Outcomes include an informational site[73] that provides a conceptual framework and demo prototype[74] to engage community input.
Value Proposition for end-user communities	Criteria describe web-based services to confirm chemical identity and provide real-time feedback on the machine readability of chemical data and metadata representation based on IUPAC standard rule sets and community best practices. Chemical data resources and software can implement the specified protocols based on their existing/preferred toolkits, programming languages, etc.
Target users and needs, including how they use the service/tool	Chemical database providers implementing and providing API web services to the public; Chemistry application developers utilising web services directly; Chemists and other researchers accessing web services indirectly through chemical drawing programs, electronic laboratory notebooks (ELN) or other applications; Chemical toolkit developers whose toolkits are used to implement web services.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Development support for a scalable implementation of the meta-resolver based on the initial prototype is still needed. Difficulty for software developers to implement is intended to be minimal for open-source protocols but some dedicated time by adopters will still be required to properly formulate queries and handle appropriate responses that align with the criteria. Further community input needed on the interface and validation flags to fully realise potential.
Exploitation plan per partner	Community engagement is ongoing to formalise this approach to uniform system-to-system interoperability. Key aspects to drive adoption include: promoting use of the same protocol, requesting help to improve the specification, drawing in help to maintain and

[73] https://iupac.github.io/WFChemProtocols/intro.html
[74] https://github.com/IUPAC/WFChemProtocols/blob/main/book/IUPACProtocolsDemo.ipynb

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KER 6. Utility services: protocols for chemical data exchange (D3.3)	
	evolve the specification as a function of time, and communicating and engaging with the broader community through the online materials, outreach activities and other approaches. To facilitate participation, a self-registration mechanism with a low barrier of human intervention will need to be provided, coupled with a basic vetting process to ensure that each resource is legitimate.
Sustainability model(s) planned:	Ongoing work to develop the specification and additional prototype development will be coordinated by IUPAC through a continuation of the project initiated for this deliverable. Formalisation of the proposed approach will involve articulation and agreement of participating organisations on the interface. IUPAC will serve as the key forum for the specification, to steward the information content and further the needs of the community.

KER 7. Community engagement model and materials	
Partners contributing to development, operational and/or training aspects	IUPAC, ChemVoices, IUPAC National Adhering Organizations (US, UK), InChI Trust, CCDC, ACS-CINF, NFDI4Chem, PSDI, other individual community members
Description of the KER	Community has been reached widely via various outreach activities including 1. What is Chemical? Webinar series[75], 2. Workshop at the ACS Spring Meeting on "Advancing FAIR Chemistry: Developing New Services for Sharing Chemical Data"[76], 3.RDA P20: Chemistry Research Data IG session on "Describing diverse chemistry datasets across distributed data resources"[77], 4.RDA 21 Session on "Describing Chemical, Physical and Biological samples digitally: Seeking harmonisation", 5. SciDataCon 2023 Session on "Beyond FAIR: Reusing Chemical Data Across-disciplines with CARE, TRUST, and Openness". An article is under publication

[75] https://doi.org/10.5281/zenodo.7903683
[76] https://doi.org/10.5281/zenodo.7903727
[77] https://www.rd-alliance.org/groups/chemistry-research-data-interest-group/forum/topic/describing-diverse-chemistry-datasets-across-distributed-data-resources/

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KER 7. Community engagement model and materials	
	out of this session, 6. ACS Fall 2023 Session on "Helping Chemists Manage their Data", 7. Webinar on “What is Digital IUPAC”?[78] 8. Workshop on “Sustainable Business Modeling for Digital Standards Development”[79], 9. Chemistry International article on “WorldFAIR Chemistry: Making IUPAC Assets FAIR”[80], 10. Chemistry International article on “Chemistry Digital Standards: Tools for an increasingly digital research culture”[81], 11. in addition to multiple oral and poster presentations available on Zenodo[82])
Value Proposition for end-user communities	The array of activities conducted has engaged stakeholders across various levels. Some events were directed towards fostering awareness and comprehension of FAIR data principles in chemical data management among the public. Others convened decision-makers, including representatives from global organisations, toolkit developers, publishers, databases, repositories, data initiatives, as well as researchers from academia and industries. This is perhaps a unique opportunity that rarely takes place. Furthermore, other events facilitated networking and collaboration among diverse groups including WorldFAIR Work Packages. Moreover, the project prioritised sustainable business modelling for digital standards development, ensuring enduring viability and relevance within the dynamic landscape of scientific research. Overall, the project's comprehensive outreach endeavours empower end-user communities to proficiently manage and leverage digital chemical data, thereby driving forward scientific discovery and innovation.
Target users and needs, including how they use the service/tool	Target users are a wide spectrum of students, global data/ chemical organisations, toolkit developers, publishers, databases, repositories, data initiatives, as well as researchers from academia and industries. Documented events (workshops, webinars, etc.)

[78] https://doi.org/10.5281/zenodo.7992804
[79] https://doi.org/10.5281/zenodo.10966075
[80] https://doi.org/10.1515/ci-2023-0104
[81] https://doi.org/10.1515/ci-2024-0105
[82] https://zenodo.org/communities/fairchemistry

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KER 7. Community engagement model and materials	
	are listed on the FAIRChemistry Zenodo community.. Users are also engaging in the process of producing publications generated from certain events e.g a White paper from the " Sustainable Business Modeling for Digital Standards Development" workshop, and an article to be published at Science Data Journal out from " Beyond FAIR: Reusing Chemical Data Across-disciplines with CARE, TRUST, and Openness" conference session. Additionally, these materials are available on the FAIR Chemistry X account[83]. Major project updates are posted on the IUPAC project page[84], and the WorldFAIR website[85].
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	WorldFAIR Chemistry continuously published updates on its ongoing outreach activities. These updates are currently available on platforms like Zenodo and X, and they will remain accessible in the foreseeable future. However, with the project nearing completion and no additional funding secured, maintaining future updates and sustaining engagement with the community poses a challenge.
Exploitation plan per partner	Promotion plan includes utilising IUPAC website and newsletter, disseminating through a developed mailing list, collaborating with partners and collaborators to reach a wider audience, using Zenodo and X platforms, and posting updates on the WorldFAIR project main page.
Sustainability model(s) planned	The aforementioned platforms will be continue to be used, however, further engagement with the community will be challenging with the end of the funding.

[83] https://twitter.com/FairChemistry
[84] https://iupac.org/project/2022-012-1-024/
[85] https://worldfair-project.eu/

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7.2 Nanomaterials

7.2.1 Nanomaterials case study overview

Nanomaterials are chemicals but also particles, meaning that (i) most of the interesting reactions / interactions happen at their surface and (ii) that they are highly dynamic and change in response to changes they induce in the biological systems they interact with. Their numerous applications in all industrial sectors make nanomaterials high value but also potentially high risk for unknown and unpredictable effects. The interdisciplinary "nanosafety" research community is at the forefront of FAIR data, pioneering efforts such as "on the fly" metadata (Exner et al, 2023)[86], and an extension of the International Chemicals Identifier to describe and represent nanomaterials.

7.2.1.1 Nanomaterials sustainability via (international) organisations

Nanomaterials and the broader category of advanced, innovative materials are becoming the focus of EU policies (e.g., the EU safe and sustainable by design framework[87], the Communication on Advanced Materials for Industrial Leadership[88] and more) but are not governed by a central international organisation like IUPAC for chemicals (although of course nanomaterials are chemicals and IUPAC itself does develop terminology and standards relevant to nanomaterials). However, multiple large communities and projects (NanoSafety Cluster, the AdvancedNano GO FAIR implementation network, European Materials Modelling Council, the Partnership for Assessment of the Risks of Chemicals (PARC[89]) and the new IAM4EU[90] partnership formed based on the Advanced Materials 2030 Initiative and the Graphene Flagship) are teaming up to build the European Materials Data Ecosystem. PARC as the currently funded project has taken the lead to coordinate ongoing stewardship of FIPs, FERs, other FAIR assessments, interoperability framework contributions; and integrate ongoing community contributions. The future association, which will be formed as part of the AIM4EU partnership, might take over these tasks and be the foundation for an international materials-specific organisation operating in close collaboration with IUPAC.

This sustainability model applies to the Nanomaterials reference FIP and specific FERs and FSRs contained therein, as documented in deliverable reports D4.1 and D4.3; to the extension of InChI to represent nanomaterials, to the FAIRification recommendation for models/software documented in D4.2, and to the provenance standards and nano-specific identifiers documented in D4.3

[86] https://doi.org/10.3389/fphy.2023.1233879
[87] https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies/chemicals-and-advanced-materials/safe-and-sustainable-design_en
[88] https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1121
[89] https://cordis.europa.eu/project/id/101057014
[90] https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1572

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7.2.1.2 Nanomaterials community sustainability

As described above, communities organised within and around the European NanoSafety Cluster (NSC), the NanoCommons community, the European Materials Modelling Consortium (EMMC), the U.S.-EU Communities of Research and the International Network Initiative on Safe and Sustainable NANOtechnology (INISS-nano)[91] are currently in charge of further developments of FAIR approaches in the EU and integrating global developments, including broadening the implementation and application of WorldFAIR results. Since these do not have funding, they rely on voluntary work as part of the working groups as well as work done in the different EU projects that they cluster.

Alongside the WP lead for Chemistry, the lead for nanomaterials is co-chair of a new RDA WG, the Harmonised terminologies and schemas for FAIR data in materials science and related domains WG [92]. The focus of the WG is on increasing the uptake of the FAIR Principles in materials research (in particular in connection with Interoperability and Reusability), supported by improved resources, in particular widely-agreed and FAIR terminologies, metadata and ontologies. While the main focus of the WG is in the material sciences, close interactions with cognate domains, in particular chemistry, are crucial in order to avoid conflicting approaches and also to utilise and integrate with already existing semantic artefacts and resources in these fields.

This sustainability model applies to the Nanomaterials reference FIP and specific FERs and FSRs underpinning this as documented in deliverable reports D4.1 and D4.3, the extension of InChI to represent nanomaterials, FAIRification recommendation for models/software documented in D4.2, and the provenance standards and nano-specific identifiers documented in D4.3.

7.2.1.3 Nanomaterials project sustainability

With the end Horizon 2020, there is limited explicit funding for new nanosafety projects available from the EU. However, nanomaterials are an extremely important part of the larger group of advanced, innovative materials, which were the focus of many calls in the years 2021-2024 especially in the context of SSbD[93]. This focus will be strengthened even more with the AIM4EU partnership starting in 2025. Projects funded under the 2021-2024 advanced materials calls including, most importantly, PARC and more focused projects like MACRAMÉ[94] and BIO-SUSHY[95] have already started to implement WorldFAIR results and feedback from them have been included

[91] https://zenodo.org/records/5004929

[92] https://www.rd-alliance.org/groups/harmonised-terminologies-and-schemas-fair-data-materials-science-and-related-domains-wg/

[93] https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies/chemicals-and-advanced-materials/safe-and-sustainable-design_en

[94] https://cordis.europa.eu/project/id/101092686

[95] https://cordis.europa.eu/project/id/101091464

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in the WorldFAIR WP4 deliverables. In 2024, three new projects, CHIASMA[96], INSIGHT[97] and PINK[98], have started building their data and software infrastructure on WorldFAIR results and especially the nanomaterial reference FIP and model/software FAIRification recommendations. Due to the objectives and expected impact of PINK to provide digital SSbD tools for industry, it is committed to act as an ambassador of FAIRness and will continue to implementation of generally applicable FERs and FSRs and to supporting implementation of these in other projects. Outside Europe, the situation is different since there is still project funding for nanosafety. The US just updated its National Nanotechnology Initiative's Environmental, Health and Safety Research Strategy and even if no US organisation is part of the WorldFAIR Nanomaterials Case Study, strong collaboration with WorldFAIR partners exist and integration of WorldFAIR results is happening as part of knowledge exchange in the U.S.-EU Communities of Research. Similarly, knowledge exchange with other countries is happening in INISS-nano, and via the IUPAC project on extension of the InChI to nanomaterials and the related projects with CoDATA and VAMAS.

This sustainability model will be relevant for the nanomaterials reference FIP and specific FERs and FSRs as documented in deliverable reports D4.1 and D4.3, for the implementation of the nanomaterials InChI, and the recommendations on FAIRification of models/software documented in D4.2, and provenance standards and nano-specific identifiers documented in D4.3.

7.2.1.4 Nanomaterials document-based sustainability

The NanoCommons User Guidance Handbook is continued after the end of the NanoCommons[99] project as an open (both for readers and contributors) knowledge resource with support of WorldFAIR and many other projects and individuals. All of the WorldFAIR nanomaterials case study outcomes are accessible via the handbook, along with relevant materials from the Chemistry case study and the CDIF. The Registry of nanoinformatics models documented in D4.2 will be continued as a cross-community multi-community-endorsed and -supported service (developed across multiple communities and projects and extending to advanced materials and SSbD).

This sustainability model addresses the need for well maintained, up-to-date centralised documentation of FAIR approaches and corresponding training, via the NanoCommons User Guidance Handbook with content tailored to the relevant sub-domains including nanosafety, governance of advanced and innovative materials, and SSbD. Document-based sustainability is relevant for the Nanomateirals reference FIP and specific FERs such as the NanoPharos[100] modelling-ready database, the Registry of nanoinformatics models, the European Registry for

[96] https://cordis.europa.eu/project/id/101137613
[97] https://cordis.europa.eu/project/id/101137742
[98] https://cordis.europa.eu/project/id/101137809
[99] https://cordis.europa.eu/project/id/731032
[100] https://db.nanopharos.eu/Queries/Datasets.zul

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Materials identifiers (van Rijn et al., 2022)[101], the InChI for nanomaterials (Lynch et al., 2020)[102], and the eNanoMapper ontology[103].

7.2.2 Nanomaterials sustainability and exploitation plans per Key Exploitable Result

KER 8. Nanomaterials domain-specific FAIRification mapping (D4.1)	
Partners contributing to development, operational and/or training aspects	University of Birmingham, Seven Past Nine, NovaMechanics,
Description of the KER	A FAIR Implementation Profile (FIP) with a selection of FAIR Enabling and Supporting Resources (FERs and FSRs) which describes the current state of the field (via an 'As-Is' FIP) and discusses the domain-specific challenges relating to nanomaterials and its FAIR landscape. It also lays out the developments needed to reach the 'To-Be' FIP, as the optimised approach to make nanomaterials and nanosafety data FAIR, based on current best practice and adaptations to address requirements of specific setting and projects. Together, both reference FIP will provide guidance and can be used as starting points for the development or refinement of Data Management Plans of new or ongoing projects. (Deliverables 4.1 and 4.3)
Value Proposition for end-user communities	The FAIR mapping represents a critical step towards identifying both the domain-specific features and the general features needed to maximise nanosafety data and model FAIRness, highlighting areas for further development and standardisation especially in the domain-specific aspects such as metadata standards and ontologies. Existing ontologies have major gaps in their semantic coverage, and project-specific terminology is not fully integrated/accessible via ontology look-up services
Target users and needs, including how they use the	The Nanosafety Community involved in NanoCommons / FAIR activities and the GO FAIR AdvancedNano Implementation

[101] https://doi.org/10.1186/s13321-022-00614-7
[102] https://doi.org/10.3390/nano10122493
[103] https://bioportal.bioontology.org/ontologies/ENM/

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KER 8. Nanomaterials domain-specific FAIRification mapping (D4.1)	
service/tool	network. European Nanotechnology Data, Knowledge and Informatics Community. With the introduction of the EU Safe-and-Sustainable-by-Design Framework and the broadened focus on Advanced Materials, expansion to relevant neighbouring communities and domains is needed to aggregate all data into a global but distributed materials data ecosystem to support the design of advanced innovative materials for the twin green and digital transitions.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	While the fragmentation of the nanosafety data landscape has been reduced through the FAIRification activities and corresponding training provided via the WorldFAIR Nanomaterials Case study, the new challenges require increased efforts for harmonisation of all domains related to Safe-and-Sustainable -by-Design and Advanced Materials. These domains start from very different levels of implementation of the FAIR principles as well as potentially having different community-agreed FERs and FSRs. Cross-domain interoperability is not achievable by forcing everyone to use the same tools but by finding mappings from one community setting to another. One specific aspect is the harmonisation and mapping of different semantic frameworks, of the corresponding ontologies as well as the further extension of these ontologies to cover new areas like Life Cycle Assessment.
Exploitation plan per partner	The WorldFAIR Case Study 4 partners have been successful in securing new funding in the area of Safe-and-Sustainable-by-Design (SSbD) of nanomaterials and advanced materials. In all these projects, they are responsible for the data management and FAIRification task and work packages. The PINK project, which is developing computational and digital tools for the implementation of SSbD in industry, is highlighted here since it took on the role to sustain and further develop the FAIRification approaches and provide improved concepts, guidelines and training. Other projects worth mentioning are MACRAMÉ, BIO-SUSHY, CHIASMA, PROPLANET, CompSafeNano and INSIGHT, taking more the role of beneficiaries of the new concepts and tools by building their data management approach on the reference FIP from WorldFAIR and

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KER 8. Nanomaterials domain-specific FAIRification mapping (D4.1)	
	reusing recommended FERs and FSRs.
Sustainability model(s) planned	This KER will be sustained by using a mixture of the models proposed above. As described in the previous row, project sustainability is already well established with a number of projects reusing and, in this way, further increasing the user base as well as contributing to further developments and integration of new cross-domain requirements. Additionally, due to their active and leading roles in many community activities (e.g. NanoSafety Cluster, the AdvancedNano GO FAIR implementation network, ELIXIR Toxicology Community, European Materials Modelling Council, PARC and the new IAM4EU partnership formed based on the Advanced Materials 2030 Initiative and the Graphene Flagship), the WorldFAIR WP4 partners are also in a good position to sustain the results of WorldFAIR and build on them in work performed by these communities (e.g. as part of the work performed by working groups and implementation studies). This and especially the IAM4EU partnership are meant to finally lead to a European or even international organisation taking responsibility for the governance of the materials data ecosystem and corresponding FAIRification actions. Finally, document-based sustainability will complement these activities by providing documentation, tutorials and recordings of training events/ webinars as part of the NanoCommons User Guidance Handbook.

KER 9. FAIRrification of nanoinformatics tools and models recommendations (D4.2)	
Partners contributing to development, operational and/or training aspects	University of Birmingham, NovaMechanics, Seven Past Nine
Description of the KER	A set of recommendations and prototypes for FAIRification of nanoinformatics tools and models (Deliverable 4.2).
Value Proposition for end-user communities	This deliverable report focuses on practical approaches to be implemented primarily by nanoinformatics model and software

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KER 9. FAIRrification of nanoinformatics tools and models recommendations (D4.2)	
	developers, to enhance the FAIRness of nanoinformatics tools and software and their underlying datasets.
Target users and needs, including how they use the service/tool	1) Nanoinformatics model and software developers, who will use the recommendations to make their services FAIRer and in this way, support their users by harmonising input / output data formats, making the tools interoperable with other software to be integrated into complex workflows like integrated approaches to testing and assessment, and integrating the results into the semantic framework. 2) Users of the software tools will be able to more easily find required models and software, understand how to use them and combine them with other tools to address specific needs.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Scientific software is often developed by scientists lacking the knowledge about state-of-the-art deployment options and access routes like DOCKER, KUBERNETES and REST APIs. Additional training and constant updating to the new software development standards is needed to stay up-to-date in these fast moving fields (both nanosafety and software development).
Exploitation plan per partner	As for KER 8, the prototype for FAIRification of models and software will be exploited in the recently started Horizon Europe SSbD projects, using it as a starting point for the real-world implementation of a harmonised and interoperable digital SSbD platform. PINK, INSIGHT, PROPLANET, CompSafeNano, and BIO-SUSHY have a strong focus on digital and computational approaches and are excellent platforms via which to demonstrate and even improve the applicability of the recommendations. In the case of CompSafeNano and PINK, it is also planned that they will take the role as successor of the WorldFAIR, NanoCommons and NanoSolveIt projects to promote FAIR and support its implementation comprehensively in the relevant communities (nanosafety and increasingly SSbD and Advanced Materials).
Sustainability model(s) planned	WP4 sees data, models and software as units of digital tools needed to achieve the goals of the twin green and digital

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KER 9. FAIRrification of nanoinformatics tools and models recommendations (D4.2)	
	transitions. Therefore, KER 9 will be based on the same mix of sustainability models described for KER 8, with the goal to establish a European or international organisation for governance of the global, distributed and federated materials ecosystem / universe.

KER 10. Nanomaterials human/machine-readable provenance & persistence policies (D4.3)	
Partners contributing to development, operational and/or training aspects	University of Birmingham, NovaMechanics, Seven Past Nine
Description of the KER	A set of recommendations and prototypes for documentation of nanomaterials provenance and persistence policies, covering materials, samples and data flows (Deliverable 4.3).
Value Proposition for end-user communities	The guidance and policy will support increased implementation of best practice around complete documentation of provenance information about nanomaterials, their samples and the data arising from their production, use and testing which will increase the comparability of datasets and facilitate clearer understanding of nanomaterials evolution prior to toxicity evaluation.
Target users and needs, including how they use the service/tool	1) Nanomaterials and advanced materials researchers who will be enabled to document the provenance of their materials more effectively, from initial synthesis or production, through storage, shipping, formulation into products and/or sample preparation for characterization or safety evaluation. Nanomaterials are highly dynamic and react with their surroundings, which can change their surface characteristics and properties (so called extrinsic properties) such that the material used for testing may have evolved compared to the material as synthesised, which has important consequences for understand the nanomaterials properties responsible for specific functional properties or toxicity effects (for example). Thus, increased use of nanomaterials identifiers, and documentation of materials, samples and data

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KER 10. Nanomaterials human/machine-readable provenance & persistence policies (D4.3)	
	flows will increase the 2) Database owners and registries - increased awareness of the need to document batch and lot numbers, opening dates of nanomaterials vials, potential impacts from shipping and storage of materials and other transformations on the nature and properties of the sample in order to enhance data harmonisation for machine learning and modelling. We note that there are many parallels to the approaches developed for geochemistry where samples extracted from specific sites need to have the entire provenance chain documented and linked to subsequent chemical and physical analyses. Database owners need to make provision for materials transformations and evolution, linked to the initially manufactured samples - this was implemented for example in the NanoCommons Knowledge Base (Maier et al., 2023)[104], and is the basis for Instance Maps[105] also, which document every step where a transformation of the nanomaterial may occur (e.g., during storage, upon dispersion, upon exposure to cells or organisms, following uptake into the cell / organism etc.)
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The community has long been aware of the need for provenance information, and shelf-lives of nanomaterials (and similar challenges hold for advanced materials) but the lack of tools and resources to support easy documentation of material and sample provenance and feed these into data provenance workflows, has hampered systematic implementation of good practice both by experimentalists and data managers. The goal of D4.3 is to help overcome these barriers and provide workflows and tools for documentation of provenance information regarding the materials themselves, samples (and formulations) utilising these nanomaterials and characterization and toxicity data generated on the materials dispersion samples. The Deliverable also addresses the need for persistence of this information, particularly the metadata, and provides good practice on how to implement this.

[104] https://doi.org/10.3389/fphy.2023.1271842
[105] https://doi.org/10.3762/bxiv.2024.26.v1

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KER 10. Nanomaterials human/machine-readable provenance & persistence policies (D4.3)	
Exploitation plan per partner	As for KERs 8 and 9, the human and machine-actionable nanomaterials provenance and persistence policies will be exploited in the recently started projects by using it as a starting point for the real-world implementation of a harmonised and interoperable digital SSbD platform. PINK, INSIGHT, PROPLANET, CompSafeNano, and BIO-SUSHY have a strong focus on FAIR data and models, and are excellent cases to demonstrate and even improve the applicability of the recommendations regarding materials, samples and data provenance. CompSafeNano and PINK are taking on the role as successor of the WorldFAIR, NanoCommons and NanoSolveIt projects to promote FAIR and support its implementation comprehensively in the nanosafety and increasingly SSbD and Advanced Materials communities.
Sustainability model(s) planned	WP4 sees data, models and software as a unit of digital tools needed to achieve the goals of the twin green and digital transitions. Therefore, sustainability of KER 10 will be based on the same mix of sustainability models described for KER 8, with the goal to establish a European or international organisation for governance of the global, distributed and federated materials ecosystem / universe. We also aim for the Instance Map Tool and the provenance workflows for materials, samples and data to become a standard, for example via a CEN workshop agreement initially, and to integrate some of the provenance considerations into the AuxInfo for the Nanomaterials InChI in the second iteration of the standard extension to InChI.

KER 11. Nanomaterials FAIR training resources via the online community-driven NanoCommons User Guide	
Partners contributing to development, operational and/or training aspects	University of Birmingham, NovaMechanics, Seven Past Nine

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KER 11. Nanomaterials FAIR training resources via the online community-driven NanoCommons User Guide	
Description of the KER	The NanoCommons user guide[106] is an online knowledge resource for the nanosafety community developed by data and nanoinformatics "shepherds" to guide users through the best practice to FAIRify their data and models. This online resource started by collecting and organising knowledge and training materials for the interconnected areas of data management for nanosafety and nanoinformatics and is constantly being extended to also cover areas like risk assessment, Safe-and-Sustainable-by-Design and nanofabrication which direct profiting from nanomaterials (safety) data, tools and services.
Value Proposition for end-user communities	The NanoCommons user guide provides a one stop shop for best practice, training materials, user guidance, worked examples and case studies on implementation of FAIR for nanomaterials, covering the data life cycle, tools and supports, FAIR metrics and more. It is community driven so all projects and researchers can contribute topics, training materials and tools. A summary of the WorldFAIR nanomaterials case study deliverables is being finalised and guides for each of the tools utilised in the Nanomaterials FIP are being compiled to further support use of the FIP by the broader community.
Target users and needs, including how they use the service/tool	1) Nanomaterials and advanced materials researchers who will be enabled to follow step-by-step training and guidance to increase the FAIRness of their own research outputs (data and models); 2) Nanoinformatics model and software developers, who will use the recommendations to make their tools and services FAIRer and interoperable with other tools and frameworks. 3) Policy makers, regulators and others in professional roles related to nanomaterials (and advanced materials) governance, safety and sustainability, who need to upskill in key areas related to FAIR for nanomaterials, advanced materials and SSbD. The materials in the user guide are intentionally written to be accessible with jargon explained clearly. Some materials are

[106] https://nanocommons.github.io/user-handbook/

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KER 11. Nanomaterials FAIR training resources via the online community-driven NanoCommons User Guide	
	specifically targeted to less expert users to bridge the gap from technical FAIR solutions to practically implementable solutions that can be utilised by practitioners in their daily workflows.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The field is evolving rapidly and contiguous communities are merging, including nanomaterials and advanced materials, and safety assessment and sustainability assessment. Thus the community resource needs to be continuously updated and links checked for functionality to ensure a positive user experience. Additional training and constant updating to new standards and tools, both related to FAIR overall and to the implementation in different sub-domains related to nanomaterials. This includes active mapping of the research landscape for emerging tools and approaches. For example the recent NSC Roadmap Safe and Sustainable Advanced and Innovative Materials 2024-2030[107] and the forthcoming roadmapping exercise by the Nanomaterials Chemicals Leads in PARC[108] to identify regulatory gaps and needs, will feed into the NanoCommons User Guide.
Exploitation plan per partner	As for KERs 8-10, maintenance, sustainability and exploitation of the NanoCommons user guide will be dependent on uptake and implementation by the materials community, by data inputs and utilisation by the relevant research communities. Implementation in new nanomaterials and advanced materials projects PINK, INSIGHT, PROPLANET, CompSafeNano, and BIO-SUSHY will enable demonstration of the applicability of the recommendations, and provide feedback on the guidances to support their further improvement. CompSafeNano and PINK will take the role as successor of the WorldFAIR, NanoCommons and NanoSolveIT projects to promote FAIR and support its implementation by the nanosafety, SSbD and Advanced Materials communities.
Sustainability model(s) planned	KER 11 sustainability is based mainly on community support and project support, with documentary standards also an important

[107] 10.5281/zenodo.10876679.
[108] https://www.eu-parc.eu/

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KER 11. Nanomaterials FAIR training resources via the online community-driven NanoCommons User Guide	
	route. The long-term maintenance nda development of the NanoCommons user guide could also be passed over to a European or international organisation for governance of the global, distributed and federated materials ecosystem / universe in due course.

KER 12. Extension of InChI for nanomaterials	
Partners contributing to development, operational and/or training aspects	University of Birmingham, NovaMechanics, Seven Past Nine
Description of the KER	Standard format for representation of nanomaterial structures and chemical composition, to allow identification / integration of data related to similar nanoforms. This is described initially in D4.1, with further updates in D4.3. The formal standard extension request will be submitted to IUPAC / InChi Trust as part of the finalisation of WorldFAIR activities.
Value Proposition for end-user communities	The Nanomaterials InChI (NInChI) addresses a number of gaps in representation of nanomaterials and specific nanoforms as per EU chemicals legislation. The NInChI specification describes the nanomaterials components and their composition, morphologies, and surface functionalisation, and their arrangement relative to one another in space. It will enable clearer more systematic identification of nanomaterials and their environmentally transformed forms, and facilitate data integration and increased confidence in data for re-usability in modelling and risk assessment. This deliverable report focuses on practical approaches to be implemented primarily by nanoinformatics models and software developers, to enhance the FAIRness of nanoinformatics tools and software and their underlying datasets. Database owners, Researchers
Target users and needs,	1) PubChem who assign InChIs to new chemicals will ideally assign

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including how they use the service/tool	Nanomaterials InChIs to nanomaterials and advanced materials. 2) Materials developers / suppliers developing new materials will also be invited / encouraged to assign NInChIs to their materials in the first instance, and to include this information in their materials safety data sheets, and web catalogues and other platforms, as well as in their ECHA registration dossiers. 3) Academic labs developing and using nanomaterials will be encouraged to use NInChIs also in their materials description sections to facilitate grouping and machine-actionability in terms of curating datasets based on specific Nanomaterials InChIs. 4) Nanoinformatics models and software developers, will use the Nanomaterials InChI to support data curation and harmonisation, and to feed into machine learning and predictive modelling. 5) Regulators and risk assessors will use Nanomaterials InChIs as a means to group nanoforms and sets of nanoforms.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	There are already some InChIs for nanoscale materials but these are basically just the chemical composition of the core materials (e.g., silica, ceria) and provide no 3D information about the nanomaterial or how it is stabilised or coated and if multiple forms exist they will all have the same InChI. Widespread promotion and training on the use of Nanomaterials InChI, and constant updating of the standard to cover the challenges of advanced materials of increasing compositional and structural complexity will be required. Back mapping of entries in nanomaterials data repositories may be needed to add Nanomaterials InChIs to existing nanomaterials entries.
Exploitation plan per partner	Key exploitation partners include the InChI Trust and IUPAC. As for KERs 8-11, the adoption of the Nanomaterials InChI by new nanomaterials and advanced materialsSSbD projects PINK, INSIGHT, PROPLANET, CompSafeNano and BIO-SUSHY will play a critical role in embedding NanoInChI in the everyday workflows of the experimental and nanoinformatics communities. In the case of CompSafeNano and PINK, it is also planned that they will take the role as successor of the WorldFAIR, NanoCommons and NanoSolveIT projects to promote FAIR and support its implementation in nanosafety, SSbD and Advanced Materials.

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Sustainability model(s) planned	KER 12 will be based on the same mix of sustainability models as described for KERs 8-11, but the formal Nanomaterials InChI standard specification will be owned and maintained by the InChI Trust and IUPAC. Community adoption and use in new nanomaterials and advanced materials projects will drive acceptance and adoption of the nanomaterials InChI, and its use in modelling and software data harmonisation and upload, and in databases will further embed its use by relevant communities.

7.3 Geochemistry

7.3.1 Geochemistry case study overview

The WorldFAIR Geochemistry Case Study set out to develop methodologies in making its community data resources more FAIR. It also set out to generate an overview of available resources that support geochemistry data standardisation and where possible make these resources machine actionable. Formalising the OneGeochemistry initiative with a governance structure, for the group that concerns itself with geochemical data standardisation, and engaging with critical stakeholders and community members or associations, societies, unions and other organised groups representing the community is part of the purview of this case study's activities and essential to exploitation of its key outcomes.

7.3.1.1 Geochemistry case study KERs sustainability via (international) organisations

As the geochemistry project proponents have become formalised in the OneGeochemistry CODATA Working Group[109]: its mission is to advance geoscientific knowledge and discoveries by building and maintaining consensus-driven standards that make geochemistry research data globally findable and accessible, and truly interoperable and reusable to both humans and machines. Although this Working Group has been established in the context of the WorldFAIR Project and the process of formalising OneGeochemistry in it, the working group and the initiative will continue beyond the life of the WorldFAIR project, ensuring continuity and sustainability in the process of progressing geochemical data standardisation and FAIR geochemistry data.

Many International organisations besides CODATA support and endorse the OneGeochemistry initiative such as The Geochemical Society, The Association of Applied Geochemists, The Meteoritical Society, The European Association of Geochemistry, The IUGS Commission on Geochemical Baselines and The International Association of Geochemistry. Through engagement with these international stakeholders the initiative connects with a community representation,

[109] https://codata.org/initiatives/decadal-programme2/worldfair/onegeochemistry-wg/

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besides direct engagement with members of the community during conferences and their associations and collaborations with laboratories and universities.

7.3.1.2 Geochemistry community sustainability

The OneGeochemistry initiative is largely a voluntary effort by data repository managers and representatives from the Geochemistry community at large. The initiative is endorsed by six international community societies/associations and currently the interim board is making efforts to engage additional individual community members on a voluntary basis. Over the last two years the initiative has benefited from a funded secretary, which led the development of methodologies, in particular FIPS, for making geochemical data more FAIR within the WorldFAIR project, and has supported keeping track of OneGeochemistry activities, the organisation of meetings and internal as well as external communication. With the funding coming to an end by June 2024, this role will have to be taken up by members of the community or through voluntary efforts, there has not yet been a plan implemented that includes a funded position.

7.3.1.3 Geochemistry document-based sustainability

OneGeochemistry has documented its work on their website, in addition to the WorldFAIR milestone and two deliverable reports (D5.2, D5.3) and an associated reference FIP. Individual FIPs have been produced for each of the data repositories within the Geochemistry WP of the WorldFAIR project, to support the development of other community repositories while also establishing a reference for future convergence between participating data systems. Active promulgation of these documents and the information they hold is planned for the coming years to help the exploitation of the efforts from the WorldFAIR Geochemistry case study and the documented information in these reports.

7.3.2 Geochemistry sustainability and exploitation plans per Key Exploitable Result

The WorldFAIR Geochemistry Work Package 05 (WP05) is about bringing the diverse international Geochemistry community together and creating a global network of key geochemical data infrastructures. Through the formalisation of the OneGeochemistry initiative, generation of FAIR Implementation Profiles (FIPs) and community engagement this work package supports knowledge sharing of best practices and standardisation of geochemical data, enabling researchers to use and reuse data in large scale (big data) research and cross disciplinary studies.

KER 13. Use case for FAIR-enabling resources (FERs) for Geochemistry (D5.2)	
Partners contributing to development, operational	AuScope, the AuScope Geochemistry Network (AGN), Digital Geochemistry Data Infrastructure for GEOROC 2.0 (DIGIS),

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KER 13. Use case for FAIR-enabling resources (FERs) for Geochemistry (D5.2)	
and/or training aspects	EarthChem, GFZ Data Services, EPOS - Multi Scale Laboratories, NFDI4Earth, Astromaterials Data System
Description of the KER	A document presenting ways in which the community can increase FAIRness through the publication of FAIR Enabling Resources (FERs) for different levels of data granularity and FAIR community size and complexity.
Value Proposition for end-user communities	The report will foster alignment across the complex and heterogeneous geochemistry community, in producing and integrating FAIR data for the huge diversity of sample types and target analytes of this community, each often having numerous analytical methods.
Target users and needs, including how they use the service/tool	Data standardisation initiatives and collective groups advising on how best to reduce and format data from specific techniques in geochemistry. Geochemical data producing laboratories globally. Any group that has a structured and systematic manner in which they collect, organise and promulgate geochemical data.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The fact that additional work is required from users and other groups providing the basis for FERs that can then be shared with a wider community is a barrier. Also the lack of stable funding for the driving force behind the standardisation and generation of FERs from community reports and publications provides a barrier.
Exploitation plan per partner	No concrete plan has been drafted by WP05 partners yet, but the work will be continued through the OneGeochemistry initiative. DIGIS, EarthChem, Astromat, AGN and GFZ Data Services work on the publication of FERs in the form of structured, machine-legible and actionable vocabularies both individually and jointly. One joint vocabulary “Analytical methods for geochemistry and cosmochemistry” has been published through Research Vocabularies Australia. Further exploitation of this and future resources will be driven by the OneGeochemistry initiative.
Sustainability model(s) planned	The sustainability models described under subchapters 8.3.1 apply here with predominantly promulgation of report D5.2 via the

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KER 13. Use case for FAIR-enabling resources (FERs) for Geochemistry (D5.2)	
	international stakeholders and the voluntary OneGeochemistry initiative in mind as sustainability model. With the ending of WorldFAIR funding active engagement with the community will be challenging and dependent on voluntary efforts, published work will remain available for use by the community. As a CODATA Working Group the OneGeochemistry initiative will remain active and seeks funding to enhance their future exploitation efforts of results.

KER 14. WorldFAIR Guidelines for implementing Geochemistry FIPs (D5.3)	
Partners contributing to development, operational and/or training aspects	AuScope, the AuScope Geochemistry Network (AGN), Digital Geochemistry Data Infrastructure for GEOROC 2.0 (DIGIS), EarthChem, GFZ Data Services, EPOS - Multi Scale Laboratories, NFDI4Earth, Astromaterials Data System
Description of the KER	A document presenting ways in which the community can increase FAIRness through use of an overview of published and used FERs by and for the geochemistry data community.
Value Proposition for end-user communities	Together with the second deliverable (D5.2) of the WorldFAIR Geochemistry Work Package which outlined the usefulness and importance of FIPs, this report and the associated reference FIP can be used by the geochemistry community – particularly by data creators and providers – to improve their FAIRness.
Target users and needs, including how they use the service/tool	Geochemistry community: data creators and providers New and emerging geochemistry data producers and providers can consult the geochemistry reference FIP and ideally choose to implement existing FERs, although the selection and implementation of FERs should align with the principles and community needs that the specific data system serves. The goal is to facilitate the implementation of commonly-used FERs, and so improving data FAIRness, with a resource that fosters interoperability, accelerates convergence on data standards, and

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KER 14. WorldFAIR Guidelines for implementing Geochemistry FIPs (D5.3)	
	ultimately enhances the accessibility and reusability of geochemical data. This report and the reference FIP aim to encourage the reuse of available resources, prevent duplication, and enhance convergence on data standards within the geochemistry community. Community collaboration, the continuous evolution of the living reference FIP document to support FAIR compliance and convergence towards standardisation are needed to continue improving FAIRness in the geochemistry data community.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	An available but not well known resource like this geochemistry reference FIP can be a barrier to exploitation of this resource, promulgation of it is key to success. The need to keep the resource updated without a funded person in the OneGeochemistry initiative to do so would also hamper its usefulness.
Exploitation plan per partner	No concrete exploitation plan has been drafted by WP05 partners yet. Further exploitation will be driven by voluntary efforts of the OneGeochemistry initiative.
Sustainability model(s) planned	The sustainability models described under subchapters 8.3.1 apply here with predominantly promulgation of report D5.3 via the international stakeholders and the voluntary OneGeochemistry initiative in mind as sustainability model. With the ending of WorldFAIR funding active engagement with the community will be challenging and dependent on voluntary efforts, published work will remain available for use by the community. The call for action to the community to add to the Geochemistry Reference FIP will involve the community increasing the likelihood of sustainability and exploitation of this resource. It is intended as a living document and the basis for a future Geochemistry Best Practice System website, which would be modelled on the Oceans Best Practices System website, a future intention of the OneGeochemistry initiative. As a CODATA Working Group the OneGeochemistry initiative will remain active and seeks funding to enhance their future exploitation efforts of results.

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7.4 Social Surveys

7.4.1 Social Surveys case study overview

This case study undertakes a comparative study of the data management, harmonisation and integration practices of one of the satellite countries – Australia, through the AUSSI-ESS – and the core ESS, an ERIC social science infrastructure. It leverages the DDI metadata standards to understand how such multi-national collections could be made increasingly interoperable and reusable through shared procedural and technical development, and establish a set of guidelines and tools for the development of cross-national collections into the future.

7.4.2 Social Surveys sustainability and exploitation plans per Key Exploitable Result

KER 15. Cross-national social sciences survey best practice guidelines (D6.2)	
Partners contributing to development, operational and/or training aspects	Australian National University, Sikt
Description of the KER	A set of recommended practices for improved management and automation of ESS data going forward. These recommendations focus on : 1) Aligning standards, 2) Establishing common tools 3) Establishing and using registries in order to advance implementation of the FAIR principles, and to improve interoperability and reusability of digital data in social sciences research.
Value Proposition for end-user communities	This best practice guide outlines key elements of the survey data harmonisation process and an integrating process model based on current practices. The process model also aligns key conceptual, technical and practical requirements that a user community needs to consider in implementation of harmonisation practices.
Target users and needs, including how they use the service/tool	The target users here are social survey data managers and social science data archives. The report outlines the proposed means for implementing this management in the two partner organisations. However, as representative institutions in the broader social

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KER 15. Cross-national social sciences survey best practice guidelines (D6.2)	
	survey and social science archive community, these implementation practices can be then targeted to these broader communities to establish improved practices for survey harmonisation management.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The key limitation for the exploitation of this resource is changes to technical infrastructure for supporting registries for social science variables and metadata. ESS support is also necessary for the adoption of standardised technical practices
Exploitation plan per partner	ADA and Sikt will work within the data archive community to promote the practices document among user communities, including ESS, ISSP and other cross-national surveys.
Sustainability model(s) planned	ADA and Sikt will continue to evolve the best practice guidelines to reflect ongoing developments in the social survey community.

KER 16. WorldFAIR Pilot Testing Harmonisation Workflows (D6.3)	
Partners contributing to development, operational and/or training aspects	Australian National University, Sikt
Description of the KER	Report on proof-of-concept implementations of the workflows outlined in D6.2 to trial the use of standardised workflows based on registry services available at the Australian Data Archive (ADA) and Sikt through their respective Colectica registries. Further recommendations.
Value Proposition for end-user communities	The report outlines pilot testing of the process workflows developed in D6.2. These pilots provide an understanding for users of the best practice guidelines to understand the workflows, and to support development of their own pilot activities.
Target users and needs, including how they use the	Social science data archives and providers of related data and metadata registries, repositories that might host relevant data and

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KER 16. WorldFAIR Pilot Testing Harmonisation Workflows (D6.3)	
service/tool	metadata, the DDI Alliance and user community. The recommendations can be used for standardising and progressively automating the process of survey data harmonisation
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The key limitation for the exploitation of this resource is changes to technical infrastructure for supporting registries for social science variables and metadata. For the survey harmonisation tool, there is also additional development required to
Exploitation plan per partner	ADA and Sikt will work within the data archive community to promote the practices document (from D6.2) and pilot implementations among user communities.
Sustainability model(s) planned	ADA and Sikt will continue to evolve the best practice guidelines to reflect ongoing developments in the social survey community, and continue to pilot best practices within our institutions and programs. The pilot variable harmonisation tool developed as part of this deliverable will continue to be developed and supported by ADA going forward, with code and a demonstrator site provided through GitHub.

7.5 Population Health

7.5.1 Population health case study overview

The case study is on data from Infectious Disease Surveillance and Response (IDSR). These data are collected in many Lower and Middle Income Countries (LMICs), but data from Malawi, Kenya and Uganda are used. The data are collected from many different sources, and the aim is to harmonise the data and make them available for analysis by policy makers and public health specialists. Greater use of these data would be useful for preventing and managing future pandemics which might arise in African countries.

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7.5.1.1 Population health community sustainability

The case study will use the INSPIRE data network to further disseminate the results and promote their update from population health professionals.

7.5.1.2 Population health document-based sustainability

The resources produced under the WorldFAIR project will be integrated in existing documentation and training materials, where they can be easily reused and further updated as needed.

7.5.2 Population health sustainability and exploitation plans per Key Exploitable Result

KER 17. Population health data implementation guide (D7.1)	
Partners contributing to development, operational and/or training aspects	London School of Hygiene and Tropical Medicine, through the INSPIRE network[110], which is a collaboration with the African Population and Health Research Center (APHRC), CODATA, Malawi University of Business and Applied Sciences (MUBAS) and the South African Population Research Infrastructure Network (SAPRIN)
Description of the KER	An implementation guide describing the way all aspects of the data are made available for use, both within and from outside the INSPIRE Network community, using standard metadata to describe the data.
Value Proposition for end-user communities	This INSPIRE implementation guide outlines how to expose (meta)data as a FAIR resource, and brings several important themes into focus.
Target users and needs, including how they use the service/tool	Users of INSPIRE, health researchers, and professionals working in other areas of observational health research, policy makers, governmental users, UN organisations such as the WHO.
Potential barriers to exploitation, e.g. lack of update, issues with service	• Lack of money for data documentation. • Lack of national and international coordination for the data use.

[110] https://aphrc.org/inspire/

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KER 17. Population health data implementation guide (D7.1)	
providers/other key players	
Exploitation plan per partner	The Implementation plans will be available through the INSPIRE data network. They will be disseminated in internal meetings and through interactions with the target audience (population health data owners).
Sustainability model(s) planned	Utilising document-based sustainability, we are working on finalising the demonstration of one complete dataset, which will make it easier to follow for new datasets. Using community sustainability, the Implementation plans will be made available through the INSPIRE data network.

KER 18. Population Health Resource Library and data training package (D7.2)	
Partners contributing to development, operational and/or training aspects	London School of Hygiene and Tropical Medicine, through the INSPIRE network, which is a collaboration with APHRC, CODATA, MUBAS and SAPRIN
Description of the KER	An introduction to the processes involved in making population health data FAIR in a pipeline that spans data collection through data analysis into an SDMX indicators database, and gives seven tutorials on what is needed at each step in this pipeline. It outlines the need to describe the study and the study context, how to use DDI Codebook and DDI Lifecycle with study data and how to use repositories like GitHub to make the metadata available. The next tutorials describe the extract-transform-load (ETL) process for putting the data into an Observational Medical Outcomes Partnership Common Data Model (OMOP CDM)[111] and the role of JSON-LD[112] in preparing the data for machine searching in Schema.org in line with the Data Documentation Initiative

[111] https://www.ohdsi.org/data-standardization/
[112] https://json-ld.org/

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KER 18. Population Health Resource Library and data training package (D7.2)	
	Cross-Domain Integration (DDI-CDI)[113]. Together these tutorials give an overview of the steps in the OMOP processes which are a pipeline for the data, and how these steps can be performed and documented. Finally the tutorials show how predictive and causal analysis can be conducted and documented using the OMOP CDM and the Observational Health Data Sciences and Informatics (OHDSI) data analysis workbench and how the results can be integrated into an Statistical Data and Metadata Exchange (SDMX) data cube, which would align with UN standards for SDG indicators.
Value Proposition for end-user communities	The objective of WP07 is to develop a suite of methods and standards to provide the framework for the FAIR principles for population health data. These standards form the basis of an AI-Ready description of data suitable for use by population health scientists, and understandable across domain and institutional boundaries. The first deliverable (D7.1) identified the Implementation Guide that could be used for population health data, and how it can be developed. This deliverable (D7.2) provides a step-by-step guide as to how to achieve the standards
Target users and needs, including how they use the service/tool	Population health scientists in low-resource settings, who know their own data and want to make those data FAIR.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	INSPIRE needs to get the website sorted so that these resources can be given a DoI and be made available to everyone.
Exploitation plan per partner	Training is a key part of INSPIRE and these resources will be added to the INSPIRE training folders.

[113] https://ddialliance.org/Specification/ddi-cdi

'Global cooperation on FAIR data policy and practice' (WorldFAIR) has received funding from the European Union's Horizon Europe project call HORIZON-WIDERA-2021-ERA-01-01, grant agreement 101058393.

KER 18. Population Health Resource Library and data training package (D7.2)	
Sustainability model(s) planned	Using document-based sustainability, these resources will be Integrated with existing training resources to make them available to others. These will be updated as new components come on stream.

KER 19. Population Health Data Policy and practice recommendations (D7.3)	
Partners contributing to development, operational and/or training aspects	London School of Hygiene and Tropical Medicine, through the INSPIRE network, which is a collaboration with APHRC, CODATA, MUBAS and SAPRIN
Description of the KER	A set of recommendations that could be used by leaders of projects collecting population health data. The recommendations assume there are data scientists who have completed the training and know how to document data and make it visible and FAIR
Value Proposition for end-user communities	To enable individual studies to make their work, data and metadata more widely known to health professionals and to researchers in other domains.
Target users and needs, including how they use the service/tool	Study leaders, and data scientists, working with population health data. Policy makers with an interest in the findings from population health data. UN agencies compiling resources and indicators under SDG 3 and other SDG indicators referring to health.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Lack of knowledge of FAIR among some study leaders. Lack of training by data scientists responsible for the data. Lack of money to pay for DOI services.
Exploitation plan per partner	The recommendations will be publicised by INSPIRE through internal meetings and external collaborations.

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KER 19. Population Health Data Policy and practice recommendations (D7.3)	
Sustainability model(s) planned	Using document-based sustainability, recommendations will be incorporated into plans for trusted research environments (TRE) which aim to share, harmonise and analyse specific data from population health studies. This will give the recommendations greater visibility among study leaders.

7.6 Urban Health

7.6.1 Urban health case study overview

This case study aims at creating guidelines and training in good practices on data stewardship and provenance for the urban health sector that could also be integrated into other disciplines using data in cities. The guidelines will integrate FAIR and CARE principles in addressing common challenges related to data availability, acquisition, and use; data integration; data quality and completeness; adequate standardisation processes to make data comparable (across cities within and between countries and regions). The training component will disseminate the expertise gained during the process of guidelines elaboration, fostering a community of practice within and across disciplines.

7.6.1.1 Urban health community based sustainability

The team will leverage the communities at the Urban Health Collaborative (UHC) through the creation of a community of practice, and through the SALURBAL project, where lessons will be shared.

7.6.1.2 Urban health project based sustainability

The WP8 team will continue to utilise the SALURBAL project for the purposes of project-based continuation of the results developed during the lifetime of the project.

7.6.1 Urban health sustainability and exploitation plans per Key Exploitable Result

KER 20. Urban Health Data - Guidelines and Recommendations (D8.1)	
Partners contributing to development, operational and/or training aspects	SALURBAL (Salud Urbana en América Latina - Urban Health in Latin America)

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KER 20. Urban Health Data - Guidelines and Recommendations (D8.1)	
Description of the KER	An assessment of the implementation of FAIR principles within the Urban Health field through two case studies. It focuses on the data collection and harmonisation process of health survey data. This allowed the elaboration of consensus on terminologies and procedures that facilitates the use of survey health data in cities for research and action.
Value Proposition for end-user communities	This deliverable can guide key stakeholders carrying out National Health Surveys in future data collection efforts and may facilitate the use of survey health data for urban health research and practice in Latin American countries. A valuable case study for raising awareness of the existing gaps in FAIR data among the urban health community and particularly in relation to the accessibility, interoperability, and (re-)use of key sources of data such as health surveys.
Target users and needs, including how they use the service/tool	Urban health researchers and practitioners, and data professionals, managers, data system personnel.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Standardisation of terminologies across countries and domains can be sometimes difficult due to different incentives and motivation for the use of data. Cost -related matters can be also a barrier for data standardisation and increased interoperability among information systems cross- country
Exploitation plan per partner	SALURBAL is working on a peer-reviewed manuscript describing the process of harmonisation of health surveys across 11 Latin American Countries. The manuscript will be soon under review at the International Journal fo Epidemiology
Sustainability model(s) planned	Project-based (very focused on the SALURBAL project)

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KER 21. Urban Health Data - Learning and Training (D8.2)	
Partners contributing to development, operational and/or training aspects	SALURBAL (Salud Urbana en América Latina - Urban Health in Latin America)
Description of the KER	A report on efforts from WorldFAIR WP08 to create a community of practice in FAIR and CARE principles for urban health, train this community of practice, and show improvements in our own implementation of the FAIR principles in our work. This deliverable has two key parts: 1) describing a training course developed in June 2023 on FAIR (Findable, Accessible, Interoperable and Reusable) and CARE (Collective Benefit, Authority to control, Respect, and Ethics) principles and an activity taking place in May 2024 to bring together the local FAIR/CARE community in Philadelphia (and beyond); and 2) an updated FAIR implementation profile as part of the SALURBAL (Salud Urbana en América Latina - Urban Health in Latin America) project.
Value Proposition for end-user communities	1) The course "How to create a data management plan with CARE and FAIR", conducted 26-30 June 2023 aimed to bridge gaps in understanding the FAIR and CARE principles. We found an increase in participants' knowledge and emerging interests in the topics through pre- and post-course surveys. 2) The updated FAIR Implementation Profile describes our efforts to harmonise multi-country urban health data, aiming to create a machine-actionable resource that aligns with the FAIR principles. This initiative represents a critical step in addressing the data management complexities of urban health research, offering a pragmatic approach to the harmonisation of extensive datasets across various countries and domains
Target users and needs,	1) The course target audience was intended to include people

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KER 21. Urban Health Data - Learning and Training (D8.2)	
including how they use the service/tool	from many disciplines including public health, health care, and data science, as well as public health practitioners working with data in community projects. 2)Urban health researchers and practitioners, and data professionals, managers, data system personnel.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	For the creation of a community of practice, we found challenges in engaging academics in FAIR/CARE principles, especially if funders are not requiring these to be followed. Another big challenge was finding examples of FAIR/CARE implementations within urban health. For the FAIR implementation profile, we had challenges in recruiting the appropriate personnel with the needed data engineering skills and also involving other analysts that had not engaged with FAIR principles before; we also encountered challenges in finding specific software implementations needed for our data models. One of the largest challenges is that we were implementing FAIR principles on a project that was already very mature with specific data structures that were not conducive to FAIR implementation, so we had to do a lot of work to adapt those data structures.
Exploitation plan per partner	At the Urban Health Collaborative (UHC), where we are building the community of practice, we will have two key aspects to exploit these results: a webinar by Dr. Theresa Anderson on data provenance and ethics that will be livestream for the UHC and WorldFAIR community, and also recorded for the future. At the SALURBAL project, we will create open-access documentation of the fair implementation process.
Sustainability model(s) planned	Community-based (Creation of a community at the Urban Health Collaborative to share lessons learned from FAIR implementation.)

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7.7 Biodiversity

7.7.1 Biodiversity case study overview

This case study consults community members on the development of a new FAIR data model that encompasses long-term biodiversity monitoring data from newly developing biodiversity monitoring projects around the world and makes it easier to integrate, share and reuse. The aim of the consultation is to identify improvements to data models and processes that could then in turn lead to improvements in the Darwin Core (DwC) standard and its implementation of FAIR principles.

7.7.1.1 Biodiversity sustainability via (international) organisations

GBIF is a global network of over 100 nodes and thousands of data providers, all of which will eventually be using the enhanced model. To facilitate the uptake GBIF perform regulat webinars and training sessions at appropriate meetings such as GBIF community meetings, TDWG, SPNCH and others. The training materials and other data model resources will be maintained on the GBIF Data model webpage[114].

7.7.1.2 Biodiversity community sustainability

The large GBIF community is developing the updated standards. This includes the Biodiversity Information Standards (TDWG). TDWG is a volunteer consortium of biodiversity informatics experts. Both GBIF and TDWG are embedded in the global network of natural history museums and related efforts such as citizen science initiatives. Therefore the work is global.

7.7.1.3 Biodiversity document-based sustainability

The WP is using GBIF's Strategic Framework 2023-2027[115], an open source model, as the basis of the new data model sustainability.

7.7.2 Biodiversity health sustainability and exploitation plans per Key Exploitable Result

KER 22. Biodiversity Data standard for sharing ecological and environmental monitoring data documented for community review (D9.1)	
Partners contributing to	GBIF, TDWG

[114] https://www.gbif.org/resource/search?contentType=literature
[115] https://doi.org/10.35035/doc-0kkq-0t82

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KER 22. Biodiversity Data standard for sharing ecological and environmental monitoring data documented for community review (D9.1)	
development, operational and/or training aspects	
Description of the KER	The key result of the work is a new draft core Unified Model. Later in 2024 we expect that portions of the model to be presented to the community as an update to the Darwin Core data model. The key improvement of the new model is its basis on the event instead of the occurrence. This factor will allow much broader data such as plant animal interactions which has already been demonstrated in WP10.
Value Proposition for end-user communities	This report offers a detailed examination of how to improve the 'I' in FAIR, Interoperability, for biodiversity data. Before this work biodiversity interoperability in GBIF was largely focussed around the occurrence. The expansion to the event permits interoperability of the varied aspects of the event such as permitting interoperability pertaining to sampling events. These sampling events need to be the basis of global biodiversity monitoring efforts as required by nations to meet the requirements of the Convention for Biological Diversity[116]. This work promotes cross-domain interaction, as the Unified Model will enhance sharing of data in related Work Packages such as Agricultural Biodiversity, Ocean Science and Sustainable development and Geochemistry in the final portion of the grant period.
Target users and needs, including how they use the service/tool	The large GBIF community is the primary user base. This is a very large community of thousands of data publishers in hundreds of countries around the globe. This work will be the data model for basically all larger biodiversity informatics work worldwide. The connection to GBIF's growing network will facilitate the difficult job of dissemination and training.
Potential barriers to	The large GBIFglobal network can help disseminate the data model

[116] https://www.cbd.int/

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KER 22. Biodiversity Data standard for sharing ecological and environmental monitoring data documented for community review (D9.1)	
exploitation, e.g. lack of update, issues with service providers/other key players	but it also points out the immense amount of communication and coordination ahead. GBIF has a strong sustainability plan based on national government participation and will invest the necessary time and resources. This program will run well beyond GBIF's current strategic Framework which ends in 2027 and will remain a core function afterwards.
Exploitation plan per partner	The data model improvement is a core component of GBIF Strategic Framework 2023-2027,in particular Activity 4.4: Drive data standards development[117]. Each year GBIF writes an annual work programme and in 2024 the indicative tasks align with the WorldFAIR project such as 1) Mature the unified data model aiming to become a candidate standard within Biodiversity Information Standards (TDWG) and 2) Advance data models for interaction data. Similar tasks will be undertaken throughout the entire Strategic Framework period and beyond.
Sustainability model(s) planned	The model used is sustainability via an international organisation, GBIF. GBIF as an intergovernmental organisation is governed by national government members. These members contribute annually to fund the work programme which sets out to meet the goals of the Strategic Framework 2023-2027. GBIF is growing and is recognized as a key data provider to UN conventions such as the Convention for Biological Diversity. This further promotes GBIF's sustainability.

KER 23. Biodiversity data model and training materials completed and shared (D9.2)	
Partners contributing to development, operational and/or training aspects	GBIF, TDWG, SPNCH
Description of the KER	The result is a growing richness of data, such as event based

[117] https://docs.gbif.org/2024-work-programme/en/#activity4-4

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KER 23. Biodiversity data model and training materials completed and shared (D9.2)	
	museum specimen data being made available for uses. These extended digital specimens are an advancement of GBIF FAIR data. The addition of the event model is a key component of the WorldFAIR CDIF.
Value Proposition for end-user communities	The added value of the new Unified Model to the user community is much richer and deeper biodiversity data for science and research. An expected growth area is data use for the Sustainable Development Goals and the goals of the Global Biodiversity Framework of the Convention for Biological Diversity. Our documented literature use is expected to increase with the inclusion of ecological monitoring data for example environmental DNA (eDNA). eDNA is a focus on several European and global initiatives and is expected to be a growing contributor to the bioeconomy.
Target users and needs, including how they use the service/tool	The large GBIF community is the primary data provider base. The GBIF is also the use of the data make FAIR in the data model. During 2023, GBIF ran an outreach program to data providers and expanded to data users in 2024 for example at the TDWG annual meeting. The Unified Model will continue to be supported by new training and the GBIF User club.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Similar to KER 22, the size of the community and data needs will necessarily provide a barrier to quick uptake of data supported by the data model. That said, the expanding global network will counterbalance this weakness.
Exploitation plan per partner	GBIF will continue developing the Unified Data Model along many similar pathways, as has been reported in the WorldFAIR grant. The GBIF focus for 2024 is ecological data including better interpretation of sampling event data. GBIF also hopes to start a trait data model prototype. These two areas are ripe for progress because they, like the camera trap community, already have advanced model development that should make them easier to include in the unified model.

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KER 23. Biodiversity data model and training materials completed and shared (D9.2)	
Sustainability model(s) planned	The models utilise are document based and sustainability via an international organisation. GBIF's Strategic Framework 2023-2027 [118] and its underlying strong governance supported by over 60 nations and growing are the basis of the data model sustainability. As an open source model the community can propagate the updated Unified model.

7.8 Agricultural Biodiversity

7.8.1 Agricultural Biodiversity Sustainability and Exploitation plan overview

Plant-pollinator interactions are recognized for their pivotal role in ecosystem functioning and sustainable agriculture. Within this context, plant-pollinator data becomes essential in addressing relevant questions such as the impact of domesticated bees on wild ecosystems, the contribution of wild pollinators to crop pollination, and the reciprocal effects of crops on these same wild pollinators. However, at present plant-pollinator data is scattered across various networks and country-specific initiatives, stored in isolated silos. The Agricultural Biodiversity Case Study is about ensuring FAIR data for understanding plant-pollinator interactions at biologically-relevant scales for crops by collaborating with relevant communities worldwide.

7.8.1.1 Agricultural Biodiversity results Exploitation and Sustainability through the Research Data Alliance

The WP lead for this case study is a co-chair in the Improving Global Agricultural Data Community of Practice (IGAD CoP)[119], formerly called The Interest Group on Agricultural Data (IGAD), which came to life in Gothenburg (Göteborg, Sweden) in 2013 at the beginning of the Research Data Alliance and has since grown to include over 260 registered members, from across continents. IGAD is a domain-oriented interest group working on all issues related to food and agricultural data. It represents stakeholders in managing data for food and agricultural research and innovation, including producing, aggregating and consuming data.

7.8.1.2 Agricultural Biodiversity Community sustainability

The Standards, Best Practices and Guidelines Recommendations and the Agricultural Biodiversity FAIR Data Assessment Rubrics produced by WP10 will be disseminated and improved through the several communities, with emphasis on the IGAD/RDA Community of Practice, the Biodiversity

[118] https://doi.org/10.35035/doc-0kkq-0t82
[119] https://archive.rd-alliance.org/groups/igad-community-practice

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Informations Standards (TDWG) Biotic Interactions Interest Group, the Global Biotic Interactions platform (GloBI) and the Brazilian Network of Plant-Pollinator Interactions (REBIPP).

7.8.1.3 Agricultural BiodiversityProject sustainability

The actions will be continued by the ongoing project funded by the Brazilian National Council for Scientific and Technological Development (CNPq) entitled “Pollination: knowledge, conservation and sustainable use of pollinators” (Award Number: 406976/2022-8) and other grants being currently pursued.

7.8.1.4 Agricultural Biodiversity Document-based sustainability

Deliverables 10.2 and 10.3 provide, respectively: (i) tools and guidelines to standardise plant-pollinator interactions data, including the Deliverable itself[120], a Cookbook[121] and a Tutorial[122]; and (ii) FAIR Data Assessment tools tailored to the plant-pollinator data domain, (Deliverable 10.3) [123] and the FAIR Implementation Profile - FIP[124].

7.8.2 Agricultural Biodiversity Sustainability and Exploitation plans per Key Exploitable Result

KER 24. Agricultural Biodiversity Standards, Best Practices and Guidelines Recommendations (D10.2)	
Partners contributing to development, operational and/or training aspects	Embrapa, REBIPP, GloBI, KALRO, HiveTracks, Meise Botanic Garden, USDA, Universidad de Buenos Aires, Universidad CES, SIB Colombia
Description of the KER	Concrete guidelines on FAIR data best practices for sharing plant-pollinator interaction data, metadata, and other digital objects, promoting the scalable adoption of these standards and FAIR data best practices by multiple initiatives. The primary focus of this work is to enhance the interoperability of data on plant-pollinator interactions, aligning with WorldFAIR efforts to develop a Cross-Domain Interoperability Framework. A description of the work conducted with the pilot projects for standards adoption and the workflow used to adhere to the FAIR

[120] https://doi.org/10.5281/zenodo.10666593
[121] https://rebipp.github.io/worldfair-agrobio
[122] https://doi.org/10.5281/zenodo.10688865
[123] https://doi.org/10.5281/zenodo.10719265
[124] https://fip-wizard.ds-wizard.org/wizard/projects/9542ef0d-66d3-4851-b53a-3eaf5ece921c

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KER 24. Agricultural Biodiversity Standards, Best Practices and Guidelines Recommendations (D10.2)	
	principles within the biotic interactions' domain, more specifically plant-pollinator interactions. It includes reusable materials tailored to this domain based on lessons learned by the pilots' results and estimate costs incurred for the adoption of standards. Presentation of the publishing model for biotic Interactions developed together with the GBIF as part of the proposed New Data Model, as well as a concrete example of its use by one of the pilots. A description of how the WP efforts are aligned with the emerging Cross-Domain Interoperability Framework (CDIF) and pointers for future developments.
Value Proposition for end-user communities	Addresses concrete and diverse examples, generates tailored reusable materials, and obtains more accurate estimates of adoption costs for future projects. Promotes the adoption of standards and increased the interoperability of plant-pollinator interactions data. Establishes concrete guidelines for FAIR data best practices customised for pollination data, metadata and other digital objects. Promotes increased interoperability of plant-pollinator interactions data, resulting in a process that allows for tracing the provenance of the data, as well as facilitating the reuse of datasets crucial for understanding this essential ecosystem service and its changes due to human impact.
Target users and needs, including how they use the service/tool	A cookbook and a tutorial were developed and can be used by Researchers and Data Stewards.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The large number of plant-pollinator interactions data producers and diverse data practices can bring complexity to the uptake, as well as the lack of clear understanding of the benefits.
Exploitation plan per partner	Embrapa and other partners of the Brazilian Network of Plant-Pollinator Interactions (REBIPP) will continue to work together with the Global Biotic Interactions Platform and with the Biodiversity Information Standards (TDWG) to promote

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KER 24. Agricultural Biodiversity Standards, Best Practices and Guidelines Recommendations (D10.2)	
	plant-pollinator interactions data and reuse.
Sustainability model(s) planned	Community sustainability: IGAD/RDA Community of Practice, TDWG Interest Group on Biotic Interactions Data, the Global Biotic Interactions platform and the Brazilian Network of Plant-Pollinator Interactions (REBIPP). Project sustainability: Pollination: knowledge, conservation and sustainable use of pollinators (Award Number: 406976/2022-8, National Council for Scientific and Technological Development, CNPq) Document-based sustainability: Deliverable 10.2[125], Cookbook[126] and Tutorial[127]

KER 25. WorldFAIR Agricultural Biodiversity FAIR Data Assessment Rubrics (D10.3)	
Partners contributing to development, operational and/or training aspects	Embrapa, REBIPP, GloBI
Description of the KER	A set of FAIR assessment tools tailored to the plant-pollinator interactions domain. These tools are designed to help researchers and institutions evaluate adherence to the FAIR principles.
Value Proposition for end-user communities	We believe the tools described in this report will encourage data publishing and reuse in the plant-pollinator interactions domain. Moving from diverse approaches and siloed initiatives to widely available FAIR plant-pollination interactions data for scientists and decision-makers will enable the development of integrative studies that enhance our understanding of species biology, behaviour, ecology, phenology, and evolution.
Target users and needs, including how they use the	Researchers in the Agricultural Biodiversity domain who wish to assess the FAIRness of the data they produce and take action to

[125] https://doi.org/10.5281/zenodo.10666593

[126] https://rebipp.github.io/worldfair-agrobio

[127] https://doi.org/10.5281/zenodo.10688865

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KER 25. WorldFAIR Agricultural Biodiversity FAIR Data Assessment Rubrics (D10.3)	
service/tool	improve it. It can also benefit data reviewers, data stewards, data repository managers and librarians dealing with plant-pollinator data.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Lack of clear understanding of the benefits.
Exploitation plan per partner	Embrapa and other partners of the Brazilian Network of Plant-Pollinator Interactions (REBIPP) will continue to work together with the Global Biotic Interactions Platform and with the Biodiversity Information Standards (TDWG) to promote plant-pollinator interactions data and reuse.
Sustainability model(s) planned	Community sustainability: IGAD/RDA Community of Practice, TDWG Interest Group on Biotic Interactions Data, the Global Biotic Interactions platform and the Brazilian Network of Plant-Pollinator Interactions (REBIPP). Project sustainability: Pollination: knowledge, conservation and sustainable use of pollinators (Award number: 406976/2022-8) Document-based sustainability: Deliverable 10.3[128] and FIP[129]

7.9 Ocean Science and Sustainable Development

7.9.1 Ocean Science and Sustainable Development case study overview

The Oceans and Sustainable Development case study is working with the International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, alongside 50+ partners around the world. This federation is co-developing digital bridges for the future of global research and sustainable ocean management, led by implementations in Africa, Latin America and the Caribbean, and the Pacific Small Island Developing States. Its work is embedded within the framework of the UN Decade of Ocean Science for Sustainable Development, and coordinates with the IODE's Ocean InfoHub project and its underlying digital architecture: the Ocean Data and Information System (ODIS). In WorldFAIR, this

[128] https://doi.org/10.5281/zenodo.10719265

[129] https://fip-wizard.ds-wizard.org/wizard/projects/9542ef0d-66d3-4851-b53a-3eaf5ece921c

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digital transformation is being scaled up and out through the Cross-domain Interoperability Framework (CDIF), where the achievements of ODIS will be integrated with those of other case studies to create cross-domain functionality.

7.9.1.1 Ocean Science and Sustainable Development project sustainability

The WP has incorporated its results into the ODIS foundational architecture and interoperability specifications. This initiative receives maintenance funding through the IOC Regular Programme, and will be expanded through third-party funding. The results will also be sustained and further developed through the Regular Programme funding of ODIS and through UN Ocean Decade partner implementations.

7.9.1.2 Ocean Science and Sustainable Development document-based sustainability

Core recommendations have been integrated into the ODIS codebase and documentation, as well as into the UN Ocean Decade Data and Information Strategy Implementation Plan.

7.9.2 Ocean Science and Sustainable Development sustainability and exploitation plans per Key Exploitable Result

KER 26. An assessment of the ocean data priority areas for development and implementation roadmap (11.1)	
Partners contributing to development, operational and/or training aspects	Alfred Wegener Institute for Polar and Marine Research
Description of the KER	This report draws from the first round of FIPs generated by the WorldFAIR consortium to identify the most viable routes to establish and sustain cross-domain data interoperability. After a review of each partner's FIP, a viable route to promote cross-domain interoperability was outlined in a roadmap, setting the basis for D11.2 and D11.3.
Value Proposition for end-user communities	Provides a pathway for ocean data systems - especially those aligning to the UN Ocean Decade's Data and Information Strategy and Implementation Plan - to implement sustainable cross-domain (meta)data flows to inform and support the current development of the Cross-domain Interoperability Framework (CDIF).

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KER 26. An assessment of the ocean data priority areas for development and implementation roadmap (11.1)	
Target users and needs, including how they use the service/tool	Programme leads and coordinators, digital implementation leads and teams, digital strategists. These actors can derive strategic insight from this deliverable.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The insights in this deliverable are static, and may be out of date within 2-4 years. A high degree of digital literacy and multi-domain experience in data handling is required to maximally benefit from this resource.
Exploitation plan per partner	This KER has been, is being, and will be used by AWI personnel in the formulation of further IOC-UNESCO, IODE, and UN Ocean Decade digital strategies and guidance documents, improving their ability to address multi- and cross-domain data flows.
Sustainability model(s) planned	The KER's content via the document-based sustainability model is being continously integrated into a succession of globally impactful data implementation plans (described above). Its content is already being sustained through such alignment, and will evolve as ODIS and other ocean data systems improve their handling of cross-domain data.

KER 27. New interoperability specifications and policy recommendations for Ocean Data (11.2)	
Partners contributing to development, operational and/or training aspects	Alfred Wegener Institute for Polar and Marine Research
Description of the KER	This deliverable introduces a set of (meta)data interoperability specifications and recommendations and accompanying policy recommendations that would ensure their meaningful implementation and development within projects such as WorldFAIR and frameworks such as the Cross-Domain Interoperability Framework (CDIF).
Value Proposition for	A concrete step towards interoperable regional and global data

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KER 27. New interoperability specifications and policy recommendations for Ocean Data (11.2)	
end-user communities	spaces (in the terms technical and accurate sense) using domain and regionally neutral interoperability conventions. This is essential to power the emerging integrative, AI-augmented ecosystems such as digital twins, cloud-native solutions, and virtualisation engines.
Target users and needs, including how they use the service/tool	Project and programme managers, directorates, high-level decision makers, Chief Technology Officers. Data/informatics specialists, digital architects, software developers and team leads, data- or software-focused researchers, (research) data managers.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Lack of uptake and practical testing, bureaucratisation (failure to prioritise technical implementation, in favour of unnecessary or superfluous bureaucratic procedure) continued silo-building or idiosyncratic implementations by data systems, weak leadership / governance with low digital literacy
Exploitation plan per partner	The AWI personnel have transferred the technical content of this KER into the ODIS codebase, created a CDIF Organization and code repository for further collaborative development, and attempted to align the emerging CDIF recommendations to the ODIS Federation's already functioning and successful cross-domain data system. As this KER is now in a living codebase, it has the potential to be integrated into further downstream developments, if the emerging CDIF content is determined to be fit for purpose. The policy recommendations are being used to enhance UN Ocean Decade digital strategies and implementations, which will have global impact and evolve according to the needs of hundreds of systems worldwide.
Sustainability model(s) planned	The core recommendations of this KER have been integrated into the ODIS codebase and documentation, as well as into the UN Ocean Decade Data and Information Strategy Implementation Plan. They will thus be sustained and evolved through the Regular

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KER 27. New interoperability specifications and policy recommendations for Ocean Data (11.2)	
	Programme funding of ODIS (as a new programme component of IODE) and through UN Ocean Decade partner implementations / alignment to the policy recommendations in the KER.

KER 28. Ocean Science and Sustainable Development Demonstration (11.3)	
Partners contributing to development, operational and/or training aspects	Alfred Wegener Institute for Polar and Marine Research
Description of the KER	This deliverable will briefly summarise several KERs, which are encapsulated within the digital architecture powering cross-domain data discovery via ODIS and its partner networks (including the WMO's WIS2, and UNEP's World Environment Situation Room). WorldFAIR has refined the initial approach used in ODIS, and raised WP11's awareness of the challenges and opportunities faced by other participating domains. Recognising that many domains are not yet willing to interoperate beyond their siloed conventions, using web architectural patterns and dominant metadata transfer standards, the KERs described in the deliverable will note future measures to secure interoperability.
Value Proposition for end-user communities	The core value of the KERs described in 11.3 is the assurance that alignment to these data exchange patterns will - concretely - expose data to the millions of machines processing schema.org/JSON-LD, upon which the ODIS specifications are based. Through the careful curation, validation, and verification of these patterns by AWI and IODE staff, as well as third-parties across the ODIS Federation, end-users are assured that cross-domain FAIRness of their holdings will be realised. Further, the tracked and documented evolution of these specifications will be incorporated into the ODIS Federation's core processes, and fed forward to Programmes such as Ocean Data 2030. CDIF alignment is a potential value, dependent on whether the CDIF recommendations are workable in and accepted by ODIS.

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KER 28. Ocean Science and Sustainable Development Demonstration (11.3)	
Target users and needs, including how they use the service/tool	All co-developers and users of any system federated through ODIS, and related systems using web-architectural patterns to bridge networks with high cyberdiversity.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The primary barrier for exploitation is short-termist, non-digitally-fluent, or unilaterally focused leadership and bureaucratisation blocking concrete, immediately useful, and globally impactful technical uptake and co-implementation: Many systems claim FAIR credentials, but fail to *demonstrate* these at scale with independent third parties from other domains. Despite the ODIS approach being globally viable, inherently cross-domain, and aligned to foundational web architectural patterns (therefore governed by consortia far larger than ODIS, ensuring ODIS does not "capture" other domains in its governance processes), many domain-, regionally, or community-focused data systems still prefer to silo their (meta)data catalogues. The cost to federate systems is minimal in a European context, if properly directed and led and assuming personnel or contractor availability with intermediate information technology skills.
Exploitation plan per partner	AWI and the IODE, as well as the newly created Operations Committee of the ODIS Federation, will continue to build upon the KERs described in 11.3. Opportunities to deepen interoperability with specific domain standards and data flows will be systematically addressed and workable outcomes added to the KERs described here, dovetailing the work from multiple other European and international projects and programmes.
Sustainability model(s) planned	As noted above, the KER itself is incorporated into the ODIS foundational architecture and interoperability specifications, which now receives maintenance funding through the IOC Regular Programme, and will be expanded through third-party funding raised by ODIS nodes and regional organisations.

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7.10 Disaster Risk Reduction

7.10.1 Disaster Risk Reduction Sustainability and Exploitation plan overview

The global Disaster Risk Reduction (DDR) community is a diverse group of people and organisations encompassing NGOs, governmental bodies, academic researchers, practitioners, and institutions actively engaged in mitigating disaster risks and fortifying resilience. The objective is to enhance the safety of people, assets, and the environment by reducing vulnerabilities to natural hazards. The community believes that local solutions are superior to top-down expert-led solutions but these localised, grassroots solutions has led to a variety of data formats, terminologies, and analysis techniques, unique and specific to different regions. This case study aims to describe this plethora of detailed, locally specific data and linguistic variants and find ways to unify them. We envision it as a significant step towards the creation of a communal language and mutual understanding within the DRR arena. The ability of DRR community members to better share data, terms, and solutions should lead to a more global understanding on the current state of DRR, lead to better solutions, and ultimately save lives.

7.10.1.1 Disaster Risk Reduction Community Sustainability

A new RDA WG, the RDA/CODATA Data Systems, Tools, and Services for Crisis Situations WG (DSTS_CS-WG)[130] has recently been formed. The vision of the DSTS_CS-WG is to contribute to a mapping and understanding of the scientific and Ethical, Legal and Social Implications (ELSI) characteristics of data systems, innovative tools, and comprehensive services that contribute to reliable and resilient preparation, response, and recovery to crisis situations. With the contribution of the WorldFAIR coordinator in the initiative, and the fact that the WorldFAIR WP lead has been invited to participate in the WG, there is potential for furthering the work carried out during the lifetime of the project using this forum.

7.10.2 Disaster Risk Reduction Sustainability and Exploitation plans per Key Exploitable Result

KER 29. Disaster risk reduction domain-specific fair vocabularies (D12.2)	
Partners contributing to development, operational and/or training aspects	Tonkin+Taylor

130 https://archive.rd-alliance.org/group/rda-codata-data-systems-tools-and-services-crisis-situations-wg/case-statement/rdacodata-data

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KER 29. Disaster risk reduction domain-specific fair vocabularies (D12.2)	
Description of the KER	This deliverable explores the use of vocabularies in the DRR domain and how controlled vocabularies coupled with ontologies can enhance the semantic value of DRR data thereby improving interoperability. Enhancing semantic interoperability would result in improved collaboration and communication within the DRR domain and facilitate collaborations with other scientific domains. The final sections of this report provide examples of the use of remote sensing data and AI for DRR.
Value Proposition for end-user communities	The ideas and suggested actions in this report can be used to transform raw DRR data to valuable insights and decisions that produce tangible reductions in the impact of disasters worldwide.
Target users and needs, including how they use the service/tool	DDR researchers, researchers from earth sciences, climate change and environmental sciences, social studies, cultural information, and others.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	Much DRR data is collected and provided by local statistical departments and government agencies from all over the world. This creates some barriers as DRR terms have been developed locally often over long-time scales. Connecting these different terms will require collaboration between people who are not communicating of a regular basis. While metadata is now accepted to be crucial for maintaining and sharing DRR data, the data is so diverse that there are no metadata standards that cover all DRR data types and the individual metadata standards are not easily linked. At the local level there is a lack of understanding of the knowledge modelling required to enable fully linked open data.
Exploitation plan per partner	Tonkin and Taylor are currently working on a metadata standard for flood hazard models and for landslide models. These standards are based on current ISO standards but have been adapted to suit modelled outputs more effectively. We are

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KER 29. Disaster risk reduction domain-specific fair vocabularies (D12.2)	
	working with local New Zealand governments and science originations to agree to these standards. Recommendations from these activities will be developed and published via RDA or our social media platforms.
Sustainability model(s) planned	Tonkin and Taylor are aiming to work with the Coalition for Disaster Resilient Infrastructure to link the Indian Government Flood database with spatial footprints for each of these floods and with the Indian Meteorological Department rainfall statistics. The aim is to improve the FAIRness of these data sources, particularly the interoperability component. It is envisioned that the data can be provided as open linked data that can be fed directly into machine learning algorithms. The findings of these studies will be shared with RDA and the UNESCO group to provide some recommendations for adding spatial footprints to the UN Sendai Disaster database.

KER 30. Disaster Risk Reduction Findings and recommendations (12.3)	
Partners contributing to development, operational and/or training aspects	Tonkin+Taylor
Description of the KER	This report provides recommendations to DRR practitioners for increasing FAIRness in data used for all phases of DDR. These recommendations are formed based on literature reviews; our first deliverable, which provided a detailed assessment of FAIRness of data for two country case studies; our second deliverable on the state of data management and vocabularies in DRR; and from our own opinions as DRR researchers.
Value Proposition for end-user communities	The DRR community has a long way to go in the process of transforming raw data into valuable insights that can be used for decision-making and action. We hope the recommendations in this report will help this process.

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KER 30. Disaster Risk Reduction Findings and recommendations (12.3)	
Target users and needs, including how they use the service/tool	DRR practitioners
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	There is a lack of capacity and resources at the local level to improve the FAIRness of DRR data. Disaster data is also politically sensitive in nature. Reporting statistics on DRR impact and fatalities may lead to unfavourable reports on incumbent governments so there is a reluctance to report on this data. Data on human impact and damage is also highly personal by nature so there are potential privacy issues that will need to be addressed at the local and global scale before DRR data can be fully disaggregated.
Exploitation plan per partner	Tonkin and Taylor are working with the Asian Disaster Preparedness Centre and the Coalition for Disaster Resilient Infrastructure to develop sub national models for Disaster Risk Management and Financial Risk Assessment at the sub national and national level for several countries in Asia Pacific. A large part of this project is working with governments to provide and share disaggregated DRR data and to set up systems for this data to be shared between local DRR agencies. The findings of this study will be published in 2024/25.
Sustainability model(s) planned	The report Authors are members of the RDA WorldFAIR Working Group and will be working with that group to enhance DRR data FAIRness. Jill Bolland has recently joined the UNESCO Open Science Toolkit working Group. The toolkit is designed to support implementation of the UNESCO Recommendation on Open Science[131]. The Toolkit is a set of guides, policy briefs, factsheets and indexes. We expect these initiatives will increase the availability and usefulness of DRR data globally.

[131] https://www.unesco.org/en/open-science/about

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7.11 Cultural Heritage

7.11.1 Cultural Heritage Sustainability plan overview

The Cultural Heritage case study explores how established image sharing practices within the 'GLAM' sector (represented by Galleries, Archives, Libraries and Museums) can be more closely aligned with the FAIR principles for research data: first, by mapping the policies, practices and technologies which already facilitate the interoperability of both image data and associated metadata provided by GLAM organisations; second, by producing a set of recommendations that build on the sector's successful practices and third, by implementing the recommendations at the Digital Repository of Ireland, a national repository for the arts, social sciences and humanities. The overall outcome of the case study will be the production of an implementation example for other repositories and image sharing platforms seeking to support the FAIR sharing of image data.

7.11.1.1 Cultural Heritage Community Sustainability

The Case Study lead is actively involved in the RDA, and has recently kickstarted a WG on 'Collections as Data' which will incorporate work carried out under WorldFAIR.

7.11.1.2 Cultural Heritage Document-based Sustainability

The Digital Repository of Ireland's policies, guides and repository documentation are in the process of being updated in response to development work carried out for WorldFAIR, which will be made persistently available in the repository in the collection 'DRI Publications[132].' A showcase of student work demonstrating improved engagement with the implemented changes in the repository interface at the DRI-sponsored conference Digital Preservation in the Arts, Social Sciences and Humanities[133] are planned following the project close, and will be documented in a DRI blog post[134].

7.11.2 Cultural Heritage Sustainability and Exploitation plans per Key Exploitable Result

KER 31. Cultural heritage image sharing recommendations report (13.2)	
Partners contributing to development, operational and/or training aspects	Digital Repository of Ireland (DRI)
Description of the KER	This report describes a community co-created set of

[132] https://doi.org/10.7486/DRI.3b591898r
[133] https://dpassh.org
[134] https://dri.ie/news-type/blog/

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KER 31. Cultural heritage image sharing recommendations report (13.2)	
	recommendations which build on our understanding of what it means to support FAIR in the sharing of image data derived from GLAM collections.
Value Proposition for end-user communities	The idea of 'Collections as Data' has been gaining momentum in the cultural heritage sector for nearly a decade now, with the result that there is a greater understanding and agreement around the issues that cultural heritage institutions face in doing the work. As it becomes clearer the scope of the work required to shift the approach to collections from access to interoperability and reuse, there is a need for concise and achievable recommendations to be made which will focus and align the work across the sector, especially for those organisations just getting started. The 5 recommendations outlined in this report are generalisable across the GLAM fields of practice and easily interpreted in different contexts, making it relatively easy for GLAM organisations to adopt practices that support the FAIR principles and understand their importance to the communities they serve.
Target users and needs, including how they use the service/tool	The report was written for cultural heritage professionals, those working in GLAM organisations or in service providers that facilitate image sharing on behalf of these organisations. Each recommendation addresses an area of practice common to all GLAM organisations and advocates for a change in practice to support a particular goal. The report does not advise how to reach that goal, and so can be used both as a starting point for discussion and an assessment tool for evaluating organisational services. The report was also used at DRI to create an implementation plan for the repository.
Potential barriers to exploitation, e.g. lack of update, issues with service	The size of the community this report addresses is very large, and while we have been able to reach the key figures advocating for change in collections delivery, there will be many for whom this is

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KER 31. Cultural heritage image sharing recommendations report (13.2)	
providers/other key players	a new concept and not one that can be quickly and easily supported with limited funds and staff resources. It will take time and continued advocacy for the recommendations to significantly influence practice across GLAM organisations of all sizes.
Exploitation plan per partner	The recommendation report was shared broadly through the professional networks of Working Group members, via DRI news and social media, and through WorldFAIR Project communications channels, including RDA and CODATA networks. The results were presented in a poster session at the DARIAH annual conference, in a panel session at the LIBER Annual Conference, at the first National Open Research Festival in Ireland, in a Birds of a Feather session at the 21st RDA Plenary event in Salzburg, and in a Collections as Data Workshop at the in Brussels. The recommendations were also promoted via webinars hosted by DRI, RDA, WorldFAIR, and the International Image Interoperability Framework (IIIF) Consortium.
Sustainability model(s) planned	Community Sustainability Utilising community connections developed or strengthened during the WorldFAIR Project, the Research Data Alliance Collections as Data Interest Group will continue to advocate for adoption of the Cultural Heritage Image Sharing Recommendations.

KER 32. Final Report on Cultural Heritage FAIR sharing (13.3)	
Partners contributing to development, operational and/or training aspects	Digital Repository of Ireland (DRI)

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KER 32. Final Report on Cultural Heritage FAIR sharing (13.3)	
Description of the KER	This is a summary report describing a use case for infrastructures that host image data for the cultural heritage sector. DRI reviewed the 5 recommendations made in D13.2 and developed a plan to improve repository functionality, policies, and training materials in response. The report outlines steps taken to improve FAIR enabling services for depositors and researchers working with cultural heritage image data in the repository.
Value Proposition for end-user communities	The report is highly specific to DRI, but is laid out to describe how the choices were made (around technical functionality, policy, training, etc.) so that other infrastructures supporting cultural heritage image collections can clearly understand the motivations, roadblocks and challenges which influenced the results.
Target users and needs, including how they use the service/tool	Each section of the report begins with a narrative introduction providing background discussion on the recommendation and describing the thought processes and considerations of the project team. This is then followed by information in a tabular form, providing the rationale for FAIR alignment, outlining where DRI is positioned in relation to the recommendation, describing the proposed changes, and reporting the result (or, in some cases, the direction taken towards a future result). GLAM organisations and the service infrastructures that support image sharing in this sector can use this as guidance for local adoption of the general recommendations.
Potential barriers to exploitation, e.g. lack of update, issues with service providers/other key players	The recommendations offered a roadmap for DRI to follow in improving repository services, but the changes had to take into consideration DRI's role in communicating versus mandating member practices. For instance, the decision to implement a CC0 licence statement on all metadata records going forward required the development of a process for allowing members to request a CC-BY licence for special circumstances. There may be other requests raised by members for exemption as DRI continues to socialise the changes.

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KER 32. Final Report on Cultural Heritage FAIR sharing (13.3)	
	The case study report shows some changes which are still in progress, and changes which are indicated in the report may not be visible in the repository at the time of publication. Additional documentation will be useful to link to the report as the described changes go live in the repository, or are published in supplementary DRI publications and training materials.
Exploitation plan per partner	The results of the report were shared with the RDA Collections as Data Interest Group and WorldFAIR Working Group, at a Collections as Data Workshop[135] hosted by the Royal Library of Belgium, via a lightning talk at the International Digital Curation Centre (IDCC24[136]) annual conference, and a Members' Coffee Morning[137] at the DRI. The report was published on Zenodo and shared with the Interest Group and former Working Group members. As changes are formalised and made visible to members and end users, additional training, webinars, blog posts, etc. will be created to support their successful adoption.
Sustainability model(s) planned	Document-based Sustainability DRI's policies, guides and repository documentation are in the process of being updated in response to development work carried out for WorldFAIR, which will be made persistently available in the repository in the collection 'DRI Publications[138].' A showcase of student work demonstrating improved engagement with the implemented changes in the repository interface at the DRI-sponsored conference DPASSH are planned following the project close, and will be documented in a DRI blog post[139].

135 https://docs.google.com/document/d/1aD5xROxFMzDzfr-n7rLOohrzr7-8-325rssevKooY5U/edit#heading=h.o19k1w3yx3i5
136 https://www.dcc.ac.uk/events/idcc24/programme
137 https://dri.ie/events/dri-coffee-morning-march-2024/
138 https://doi.org/10.7486/DRI.3b591898r
139 https://dri.ie/news-type/blog/

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8. Conclusion

The WorldFAIR sustainability and exploitation plans leverage the multiple communities engaged by the project consortium such as CODATA, RDA, GBIF, IUPAC, SALURBAL. The plans were developed throughout the lifetime of the project, and were being implemented as work was taking place, organically and systematically, having been integrated into day-to-day activities, further enabled and amplified through the dissemination and communication strategy. The extensive and detailed plans of each of the WorldFAIR case studies are a testament to the commitment of the consortium, and the project's proactive engagement with the target communities.

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DOCUMENT MOVED OFFLINE - NO FURTHER CONTRIBUTIONS

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