FAIR-IMPACT
Expanding FAIR solutions across EOSC

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Object Type and Discipline-Specific Harmonisation of FAIR Assessment Metrics

A FAIR-IMPACT Reflections Paper

Work Package	**WP5 - Metrics, certification, and guidelines**
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TERMINOLOGY

Terminology/Acronym	Description
API	Application Programming Interface
AUTHORS	A file listing authors which is in plain text with human- and machine-readable information
CESSDA	Consortium of European Social Science Data Archives
CITATION.cff (CFF)	Files which are in plain text with human- and machine-readable citation information for software (and datasets)
CONTRIBUTORS	A file listing contributors which is in plain text with human- and machine-readable information
Data	Facts, measurements, recordings, records, or observations about the world collected by scientists and others, with a minimum of contextual interpretation.
DDI	Data Documentation Initiative
ENVRI	A collaboration and joint development among environmental research infrastructures across Europe that are studying different aspects of the Earth system.
EOSC	European Open Science Cloud
ERIC	European Research Infrastructure Consortium
LICENSE	A plain text file which contains license information. Often this is an Open Source license so that others are free to use, change, and distribute the software in the repository
README	A text file that introduces and explains a project. It contains information that is commonly required to understand the project.
Research Software	Research Software includes source code files, algorithms, scripts, computational workflows and executables that were created during the research process or for a research purpose.
Semantic Artefacts	Semantic artefacts are machine readable models of knowledge such as controlled vocabularies, thesauri, and ontologies which facilitate the extraction and representation of knowledge within data sets using annotations or assertions.
SSH	Social Sciences and Humanities

1. Introduction

The FAIR-IMPACT project has worked towards realising a FAIR EOSC for the past three years. One of the main objectives of the project has focused on expanding metrics and tools for assessing FAIRness to cover different object types and communities. Previously, the focus has mainly been on data as the main digital object, and on discipline-agnostic or generic approaches to defining and evaluating the FAIR principles. The FAIR-IMPACT work package on metrics, certification, and guidelines was designed to advance these two areas of FAIR assessment to cover a scope more fitting to the actual EOSC landscape and ecosystem.

Different activities have been undertaken to define how other object types, such as research software and semantic artefacts, could also be assessed on FAIRness. Work was done to develop metrics for FAIR assessment that fit specific communities. Advancements on both these threads of work have been reported in project milestones, deliverable reports and other dissemination activities. However, as FAIR-IMPACT is coming to its close, there was a desire to group these different outcomes and lessons learned into one final piece to share with the community. This reflection paper presents the final remarks from FAIR-IMPACT on the topics of FAIR assessment metrics and tools, linking the preceding outputs and further supporting these with considerations from the current perspective. The aim of this paper is to summarise the knowledge gained over the course of the whole project and to support its perpetuation by putting it in writing and allowing others to read and reuse it to take the next steps beyond it.

2. Exploration of metrics for different objects and communities

FAIR-IMPACT explored the creation of metrics for different object types and communities. This section presents how these metrics were created, tested, and validated in the different communities. The section concludes with lessons learned that reach across the different efforts or show to be unique for specific contexts. It should be mentioned that the FAIR assessment of semantic artefacts has also been covered in the FAIR-IMPACT project, resulting in an initial methodology approach that received community input

Discipline-specific metrics for data

In the predecessor project FAIRsFAIR[1] domain-agnostic metrics were developed for the FAIR assessment of data. Subsequent work to extend the metrics and address disciplines specifics, aligns with the objectives of the FAIR-IMPACT project. The metrics were implemented in the automated FAIR assessment tool F-UJI[2], therefore the experiences covered here relate to the implementations in that tool but can be applied more broadly.

Motivation for discipline-specific FAIR metrics

Although Wilkinson et al.[3] tried to make the FAIR principles as universal as possible, some of the language implied a need for further clarification[4], not only terms like "rich", "clear", "explicit", but also references to "domain-relevant community standards" (R1.3). Concerns were soon expressed, especially in Europe, that a domain agnostic approach to FAIR could ignore discipline specifics, or as formulated by the European Commission's FAIR in practice task force[5]:

> *"... Our observation is that, although the scientific needs differ between disciplines, which also have different organization and culture, and thus each discipline searches for its own solutions and follows its own path towards FAIR data, the difficulties as well as enablers encountered are often shared…"*

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[1] https://www.fairsfair.eu/

[2] Anusuriya Devaraju, & Robert Huber. (2020). F-UJI - An Automated FAIR Data Assessment Tool. Zenodo. https://doi.org/10.5281/zenodo.6361400

[3] Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

[4] Hervé L'Hours, Ilona von Stein, Mustapha Mokrane, Jessica Parland-von Essen, Jerry de Vries, Frans Huigen, Anusuriya Devaraju, Joy Davidson, & Benjamin Mathers. (2020). FAIR Principles: Baseline Comments. (02.00). Zenodo. https://doi.org/10.5281/zenodo.6472149

[5] European Commission: Directorate-General for Research and Innovation, Six Recommendations for implementation of FAIR practice by the FAIR in practice task force of the European open science cloud FAIR working group, Publications Office, 2020, https://data.europa.eu/doi/10.2777/986252

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Furthermore, it was assumed that discipline-specific FAIR implementations according to the specifications of individual communities would also have specific requirements with regard to their evaluation.

> *"... Different expert domains encounter dramatically different datasets – in terms of complexity, quality, secrecy, and volume (to name only a few). Thus various domains will look at the FAIR Principles, and their assessment, through the lens of the kinds of data they collect, and the metadata requirements surrounding their domain-specific datasets. ..."*[6]

Further, concerns have been raised that FAIR testing tools could have negative effects e.g on funding.

> *"...the process of developing, approving and implementing FAIR metrics should follow a consultative methodology with research communities, including scenario planning to minimise any unintended consequences and counter-productive gaming that may result. ..."* (European Commission, 2021)

or as expressed by Wilkinson et al. (2022):

> *"... mechanisms to evaluate FAIRness can be misused and misinterpreted, especially when these become a decision-making instrument in funding scenarios."*

Therefore, inadequate assessments by immature or 'discipline-blind' FAIR tools should be avoided. For example, different levels of maturity of data centres in relation to their application of FAIR principles should be taken into account, or at least assessments should consider the different adoption levels and implementations of FAIR within individual scientific disciplines. As a result, within the EOSC, the recommendations were to "*take diversity into account*"[7].

Varied FAIR testing can be achieved with three different approaches: firstly, very specific FAIR metrics tailored to the needs of individual communities can be developed and FAIR assessment tools can be built or made capable of implementing additional sets of discipline-specific metrics, using the same or similar tests, and may requiring additional development

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[6] Mark D. Wilkinson, Susanna-Assunta Sansone, Eva Méndez, Romain David, Richard Dennis, David Hecker, Mari Kleemola, Carlo Lacagnina, Anastasija Nikiforova, & Leyla Jael Castro. (2022). Community-driven Governance of FAIRness Assessment: An Open Issue, an Open Discussion (Final). Zenodo. https://doi.org/10.5281/zenodo.7390482

[7] European Commission: Directorate-General for Research and Innovation, Aronsen, J., Beyan, O., Harrower, N., Holl, A. et al., Recommendations on FAIR metrics for EOSC, Jones, S.(editor) and Genova, F.(editor), Publications Office, 2021, https://data.europa.eu/doi/10.2777/70791

of the tool; secondly, FAIR assessment tools could also be developed in such a way that they recognise as many variants of FAIR principle implementations as possible and take these into account when applying domain-independent or domain-aware metrics, although the number of tests that the tool may need to be run may make the assessment slow and complex. The third approach would be to create APIs for each test that is performed and returns a result then these could be selected to provide an assessment of a defined set of metrics, which would require a very flexible approach to the tool interface, many shared tests to select from and skill on the part of the user in selecting the correct set of tests. This is an approach being developed in the OSTrails project[8]. Each approach to harmonisation has its advantages and disadvantages and how these will be viewed by different disciplines and communities of users will define which approach is chosen.

The first approach assumes that there is already a high degree of standardisation within a well-networked community and that the number of FAIR-supporting methods is relatively small. In recent decades, for example, the communities in the social sciences or the biosciences and earth sciences have already agreed on discipline-specific standards that are developed and monitored by authorities. For such communities, FAIR metrics, which only require the application of this small number of standards, should be sufficient.

Initiation and creation of FAIR metrics

Our initial approach was to develop customised metrics which only consider the standards relevant to the respective communities. We have initially selected two communities as use cases: the social sciences and humanities and the earth and environmental sciences.

The aim was to focus on those FAIR implementing practices for which a certain degree of specificity can be expected. That is, the use of specific interfaces, metadata standards, vocabularies, data formats, identifiers or at the content level, the use of specific metadata properties (for example, for spatial reference) or license types.

Our approach was to initially draw on existing publications and other documents from the communities that either already described FAIR requirements and interpretations or contained the specifications for the implementation of community-specific standards. Furthermore, we tried to identify those standards that are already used in existing infrastructures and networks (e.g. CESSDA[9] for SSH) of the communities and to draw conclusions about the vocabularies used and the metadata standards currently offered via their interfaces.

[8] https://ostrails.eu/fair-assessments
[9] https://www.cessda.eu/

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In addition, we approached representatives of data archives of these communities and asked them to fill in FAIR Implementation Profiles (FIP)[10] via the FIP wizard tool[11], which maps FAIR practices in a structured way. We also used existing FIPs previously collected by other projects (e.g. ENVRI, WorldFAIR) to complete the picture.

However, it very quickly became clear that these use case communities were too broad, as FAIR practices differed greatly and sub-communities could easily be identified, for example at infrastructure and sub-discipline level. For the SSH use case, we therefore concentrated solely on the social sciences and were able to identify specific FAIR practices with the help of FIPs and the available documentation, for example the use of DDI[12] as a metadata format or the specification of the language in the metadata properties. Based on this, we then defined specific metrics and requested community feedback.
At the same time, we enabled the F-UJI tool[13] to be individually configurable and thus able to support community-specific metrics. This allowed representatives of the social science community to test and evaluate these metrics in practice.

Validation of FAIR metrics

Extensive tests were carried out by representatives of the social sciences community, in particular DANS and UKDS, who themselves manage large social science collections. Using several reference datasets, FAIR assessments were performed using both the domain-independent metric and the newly developed discipline-specific metrics.

However, it soon became apparent that the outcomes differed. For domain-independent and discipline-specific FAIR metrics being applied, scores were often reduced for disciplinary metrics. This caused considerable confusion and required a very detailed consideration and analysis of metrics, implemented tests and, in particular, the reference data sets, and the methods used to expose metadata. It appears that compliance with very narrowly defined specific metrics is particularly difficult for disciplinary repositories that use community-agnostic software. For example, metrics that specify discipline-specific metadata formats, depend on this information being supplied with a dataset on a landing page. This must be implemented technically and repositories that use third-party software are dependent on

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[10] Schultes, E., Magagna, B., Hettne, K.M., Pergl, R., Suchánek, M., Kuhn, T. (2020). Reusable FAIR Implementation Profiles as Accelerators of FAIR Convergence. In: Grossmann, G., Ram, S. (eds) Advances in Conceptual Modeling. ER 2020. Lecture Notes in Computer Science(), vol 12584. Springer, Cham. https://doi.org/10.1007/978-3-030-65847-2_13

[11] https://fip-wizard.ds-wizard.org/wizard/

[12] "The Data Documentation Initiative (DDI) is a suite of products that describes metadata about both quantitative and qualitative research data in the social, behavioral, economic, and health sciences." https://ddialliance.org/overview-of-current-products

[13] https://www.f-uji.net/

the manufacturer's release cycles, whereas in-house developments can be adapted quickly. On the other hand, generalist software is often already optimized for web and search engines, which thus can provide very good results when using domain-independent metrics.

It appears that community-specific metrics are more difficult to fulfil, simply because the possible intersection between required and existing tested properties is much smaller. It appears much easier to meet a 'one size fits all' set of metrics and tests than to meet one or two very specific ones. However, this is also an advantage of community-specific metrics, as they enable very strict tests that are necessary when it comes to achieving the greatest possible standardisation and thus interoperability.

Community survey

In order to gather insights and opinions on discipline specific metrics, the FAIR-IMPACT project conducted a survey from November 2024 to January 2025, which gathered 29 responses[14]. Respondents included IT specialists, data experts, and researchers with varying experience levels. Most were familiar with FAIR principles and even applying them in their work and using FAIR assessment tools.

However, only one third had encountered discipline-specific FAIR metrics, primarily within social sciences and humanities. Respondents favoured a bottom-up approach for developing these metrics, led by researchers and support staff, preferring organic adoption over mandates.

Research support staff and large research clusters were identified as primary stakeholders for implementing these metrics, which should be applicable across various organisational levels. Limited capacity, including time and financial constraints, and a lack of relevant skills were significant barriers to consensus on these metrics.

Preferences for FAIR metrics varied, with some favouring large discipline-specific metrics, others focusing on data types or research methods, and a smaller group supporting detailed metrics for sub-disciplines. The findings emphasise strong engagement with FAIR principles but highlight resource challenges in developing and implementing discipline-specific metrics. Recommendations include fostering collaborative metric development and increasing resource allocation.

A more detailed description of the results can be found in the form of a blogpost on the FAIR-Impact webpage.[15]

[14] Mihai, H., Verburg, M., & Huber, R. (2025). Questionnaire on discipline specific metrics - questions and responses [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15081652

[15] https://fair-impact.eu/articles-and-blogs/survey-results-discipline-specific-metrics

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Discipline-specific metrics for software

FAIR-IMPACT expanded FAIR assessment to cover object types beyond data. Work was done to create metrics relevant for the FAIR assessment of research software, and to implement those in an assessment tool. For this object type, it was also explored how metrics could be defined specifically for a discipline or community. This section depicts the creation of the different metrics, their implementation, and the community feedback received.

Creation of the metrics

We developed 17 FAIR metrics for Research Software[16], which build upon the outputs of past working groups and existing guidelines related to FAIRness, particularly the Research Software Metadata Guidelines[17], also developed in FAIR-IMPACT. For testing the metrics with an automated assessment tool, we concentrated on metrics that could be implemented as practical tests and used the concept of distinct levels of FAIRness that could be measured automatically, though in some cases this was dependent on additional subjective analysis encoded into the test. We developed both the most general, domain-agnostic metrics as well as using the existing guidelines from CESSDA[18] as an exemplar for a more specific implementation within a Social Sciences disciplinary community based on their characteristic community standards. This was done in a rapid iterative process with CESSDA. Having the precise and detailed CESSDA technical guidelines helped to speed-up the implementation process.

Testing of the metrics

We choose the existing automated assessment tool for data, F-UJI, as the basis for extending its usage to assess adherence to the FAIR4RS principles for research software[19] provided in GitHub software repositories. We decided on extending F-UJI after an investigation into currently available and suitable tools for the purpose[20]. For a proof-of-concept, two of the FAIR metrics from *D5.2 - Metrics for automated FAIR software assessment in a disciplinary context (D5.2)*[6] were implemented fully and skeletons for many of the remaining metrics were

[16] Chue Hong, N., Breitmoser, E., Antonioletti, M., Davidson, J., Garijo, D., Gonzalez-Beltran, A., Gruenpeter, M., Huber, R., Jonquet, C., Priddy, M., Shepeherdson, J., Verburg, M., & Wood, C. (2023). D5.2 - Metrics for automated FAIR software assessment in a disciplinary context (1.0). Zenodo. https://doi.org/10.5281/zenodo.10047401

[17] Gruenpeter, M., Granger, S., Monteil, A., Chue Hong, N., Breitmoser, E., Antonioletti, M., Garijo, D., González Guardia, E., Gonzalez Beltran, A., Goble, C., Soiland-Reyes, S., Juty, N., & Mejias, G. (2024). D4.4 - Guidelines for recommended metadata standard for research software within EOSC (V1.0). Zenodo. https://doi.org/10.5281/zenodo.10786147

[18] CESSDA technical guidelines: https://docs.tech.cessda.eu

[19] Chue Hong, N. P., Katz, D. S., Barker, M., Lamprecht, A.-L., Martinez, C., Psomopoulos, F. E., Harrow, J., Castro, L. J., Gruenpeter, M., Martinez, P. A., Honeyman, T., Struck, A., Lee, A., Loewe, A., van Werkhoven, B., Jones, C., Garijo, D., Plomp, E., Genova, F., … RDA FAIR4RS WG. (2022). FAIR Principles for Research Software (FAIR4RS Principles) (1.0). Zenodo. https://doi.org/10.15497/RDA00068

[20] Antonioletti, M., Wood, C., Chue Hong, N., Breitmoser, E., Moraw, K., & Verburg, M. (2024). Comparison of tools for automated FAIR software assessment (1.0). Zenodo. https://doi.org/10.5281/zenodo.13268685

provided; these were also tested against a selection of repositories provided by CESSDA and FAIR-EASE (see *M5.6 - Practical tests for automated FAIR software assessment in a disciplinary context (M5.6)*[21]).

The FAIR-IMPACT Support Action Open Call on "Assessment and improvement of Research Software" gave us the opportunity to have both the metrics from D5.2 and their implementation into F-UJI from M5.6 tested by owners of real-life and actively used research software held in software repositories, such as GitHub[22]. Eleven groups participated in the Open Call, plus one additional observer. The participants came from a variety of scientific backgrounds from diverse roles, career stages and institutions. Their task was to assess and improve some of their own existing research software by using the extension of the automated F-UJI tool for research software, to improve their initial score for FAIRness, to learn more about all the 17 metrics and investigate them with respect to their software. In some cases, this included investigation of implementation of other metrics.

We organised a total of three workshops between May and October 2024 (two of which jointly with T4.3) to support all groups during this activity, in addition to a mailing list and a Slack[23] channel that were available for questions, discussions or extra information during the whole duration of the Open Call. A summary of each group's findings is published as their FAIR Implementation Story[24] on Zenodo.

From the Open Call we identify three categories of findings:

1. First, the Open Call allows us to see if there are any issues with the way a metric is implemented or defined and hence if there are suggestions for changes and revisions for any given metric.
2. Second, how useful each metric is for improving the participants' software. This translates into recommendations for practices, which help to improve FAIRNess of research software in general.
3. Third, how easy or challenging is it to use the extended version of the F-UJI tool for automated software assessment.

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[21] Moraw, K., Antonioletti, M., Breitmoser, E., Chue Hong, N., & Priddy, M. (2024). M5.6 - Practical tests for automated FAIR software assessment in a disciplinary context (1.0). Zenodo. https://doi.org/10.5281/zenodo.10890043

[22] GitHub is a platform that allows developers to create, store, manage, and share their code and is widely used for research software development and as a repository. https://github.com/

[23] https://slack.com/intl/en-gb/

[24] All FAIR-IMPACT FAIR Implementation Stories https://fair-impact.eu/search/node?keys=implementation%20story. Examples that are available on Zenodo include:
Fouilloux, A., & Coca-Castro, A. (2024, November 25). Journey Towards FAIR Metrics for Research Software: Experiences from Simula Research Laboratory. Zenodo. https://doi.org/10.5281/zenodo.14589450,
Ravinder, R., Quinones, N., & Castro, L. J. (2024, October 31). FAIRness assessment using F-UJI for selected research software repositories in the SemTec team at ZB MED. Zenodo. https://doi.org/10.5281/zenodo.14446501
Perbix, M., & Löbe, M. (2024, November 1). Evaluating the FAIRness of Health Research Software at Leipzig University Using an Automated FAIR Assessment Tool. Zenodo. https://doi.org/10.5281/zenodo.14394188

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We received direct feedback and comments on all the 17 metrics for the FAIRness of Research Software from the participating Open Call groups. We identified that researchers would benefit from more clarification and specific recommendations, specifically for some of the metrics (e.g., to understand the best choice of identifier - SWHID[25] or DOI[26] - to include in research software metadata). Many software developers would find the provision of actual examples very helpful. This could potentially be provided through domain-specific exemplary repositories. Several participants are also planning to use the repository they focused on during the Open Call as a template for future or other repositories they work with and share their newly gained insights with colleagues and within their institution. Another issue raised is that of potential duplication or overlap, because some information can be provided in several locations instead of just one, which makes consistent maintenance more challenging: E.g., information that can typically be found in the README, the CodeMeta file and the CITATION file.
In addition, when the number of contributors is relatively high (60 or over in the cases we encountered), the on-going need of keeping the contributor/author list up to date would turn out to be very cumbersome very quickly, for example if this list is kept directly in the README file.
One group also participated in the ReSA Authorship and Contributor Task Force[27]. As one of the outputs, they devised a set of guidelines to clarify when an open-source contributor is deemed an author of the software, and therefore added to the CITATION.cff file.

When asked via anonymous feedback poll which metrics seem less useful or important, FRSM-02 ("Do the different components of the software have their own identifiers") came up several times, but also once as one of the more useful metrics but there was no opportunity to follow this up with the participants. As most useful/important, the following metrics were highlighted: FRSM-01 ("Does the software have a globally unique and persistent identifier"), FRSM-04 ("Does the software include descriptive metadata which helps define its purpose"), FRSM-07 ("Does the software metadata include the identifier for the software"), FRSM-08 ("Does the software have a publicly available, openly accessible and persistent metadata record"), FRSM-15-R1.1 ("Software is given a clear and accessible licence"), FRSM-17-R1.2 ("software is associated with detailed provenance").

Regarding the promotion of FAIRness, it would be very useful to raise awareness of certain tools and practices that often allow covering FAIRness with relatively little effort for software developers and researchers. For this purpose, it is important to have standardized approaches and make them known throughout the research communities as well as making metadata machine-readable. This will minimize the effort needed by the developers to make their software FAIRer.

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[25] SWHIDs (from "SoftWare Hash IDentifiers") are persistent, intrinsic identifiers for software source code artifacts such as source code files, source trees, commits, and other objects typically found in version control systems. https://www.swhid.org/

[26] Digital Object Identifier https://www.doi.org

[27] Research Software Alliance (ReSA) Authorship and Contributor Task Force https://www.researchsoft.org/tf-authorship-contribution/. See also The Research Software Alliance (ReSA), by Daniel S. Katz and Michelle Barker, 2023, doi.org/10.54900/zwm7q-vet94.

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Many participants emphasized that over 50% of the metrics can be satisfied just by using the general-purpose open repository Zenodo (ideally with GitHub[28] integration, which also allows authors to be credited more easily) - which adds a DOI - by using machine-readable files, improving the README and adding a codemeta file.

The provision of a list of the main available, hands-on tools that help to generate metadata files or badges automatically (e.g., to create a codemeta.json file, a CITATION.cff file, a development status badge, etc.) would support researchers in easily improving their repositories' FAIRness. It is also worthwhile to make specific features of repositories, such as GitHub, more widely known, that already have tools in place that generate for example a list of authors, code contributors, coding languages used, etc., and to make users aware of the typical places or files/file names where valuable information can be found, such as a pyproject.toml file for dependencies and requirements to build and install python code.

Furthermore, the need to increase the currently scarce support for AI/ML model developers with respect to the implementation of FAIR practices was identified.

It was obviously a limiting factor that at the time of the Open Call only a few out of the total of 17 metrics for Research Software, both domain-agnostic and domain-specific, were implemented into the F-UJI tool. Participants had the option to extend the tool themselves if they felt technically able to but raised the lack of detailed documentation to do so. One of the outcomes of the Open Call are many suggestions of what F-UJI could exactly test to meet the metrics' requirements, and these suggestions could also be applied to similar automated assessment tools. There is obvious interest for a complete, working version for the F-UJI tool for research software with all metrics being implemented and maintained. At the same time, the users of such tools should be able to see what exactly the specific tool measures and is looking for to avoid both confusion and a clear insight into why a test might be failing. Future tool developers should be aware that field naming conventions used, as well as their comprehensiveness, might not follow the same standards across communities, and hence discrepancies might be encountered easily.

Any automated assessment tool does not replace the need for ensuring that the provided information remains human-readable.

All participating groups noted that the Open Call helped them to increase the FAIRness of their research software by becoming more aware of FAIR4RS, familiarizing with the metrics and looking into and using tools to increase the amount of useful metadata to improve their software repositories' FAIRness.

Participants recognised the importance of early and continuous integration of the FAIR principles in the software development lifecycle to enhance the long-term sustainability and usability of research output with minimum effort. Most developers have limited time and resources to devote to the maintenance and improvement of their software. The provision of guidelines, processes and tools can act as a blueprint for their projects with easy-to-

[28] https://github.com/

implement actions that will enhance the FAIRness of their software and, in turn, increase the user base, scientific citations and available funding. Once a basic FAIR structure has been decided upon (for example, which files are needed at the root of the repository and what minimal information must they contain) it is easy to replicate and extend to other software projects.

During the presentations and discussions in the final workshop participants noticed that they had taken similar approaches during the Open Call, which should be an indicator that there is a good amount of agreement on how to interpret and implement most of the metrics.

Often, developers are more aware of FAIRness for data than for other digital objects, such as research software. This is not unexpected since the FAIR principles were first developed for data and much of the promotion of FAIRness has been around data and only relatively recently have the principles been applied to other digital objects.

Overall, users must be aware that some metric tests can be evaluated more easily than others, and some criteria are more challenging to qualify than others.

It is very important for (re)users of the tool that they understand why a given repository receives a certain score, also compared to other, rather similar looking, repositories.

It can be confusing for new adopters that the automated tools provide a score while being told simultaneously that the score is not meant for comparing two independent repositories with each other and its purpose is solely for the progressing improvement of a given repository. The provision of more precise guidelines on what needs to be done to improve this initial score is also needed. Additionally, it may be that paper-based or checklist-based approaches could also be useful for improving FAIRness of software as they can cover elements that are hard to automatically assess, but easier for adopters to discuss.

Activities making new FAIR-adopters aware that FAIRness does not guarantee the scientific quality of the software, and that accessibility is not to be confused with being Open Source, should be continued.

Research Software Metadata adoption in practice (OSCARS investigation)

In collaboration with the OSCARS[29] CodeMetaSoft project[30], we set out to assess how different scientific communities describe Research Software with metadata to support FAIR, how do they adopt existing good practices regarding citation, documentation or versioning, and what is the current adoption of archival services for long-term preservation, based on the

[29] Fostering the uptake of Open Science in Europe (OSCARS) https://oscars-project.eu

[30] The CODEMETASOFT project aims to develop a comprehensive framework to streamline the management, enrichment, and propagation of research software metadata, thereby enhancing interoperability and supporting the scientific community's efforts to leverage software in research effectively. https://oscars-project.eu/projects/codemetasoft

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Research Software MetaData (RSMD) guidelines[31]. Our goal was 1) to gather some insights into how well the good practices are promoted in FAIR-IMPACT being adopted by different communities, and 2) to identify what are the main points of improvement in each scientific discipline. The results of our analysis are reported in El Hounsri and Garijo (2025)[32] and briefly summarized here.

Research Questions

To assess the adoption of the RSMD guidelines, we set out to answer the following research questions:

- RQ1: How do communities describe Research Software metadata in their code repositories?
- RQ2: What is the adoption of archival infrastructures across disciplines?
- RQ3: How do software projects adopt versioning?
- RQ4: How comprehensive is the metadata provided in code repositories? Specifically:
  - What is the adoption of open licenses?
  - Do research projects include a description?
  - How well documented are research projects? (i.e., in terms of installation instructions, requirements, and documentation availability)
- RQ5: What are the most common citation practices among communities?

These questions are selected based on RSMD, in particular on the need for projects to be properly identified with persistent ids, described with metadata and properly archived in existing repositories, using consistent versioning schemes and with a public license.

European Science Clusters

We carried out our analysis on over 9000 software repositories from the following Open Science clusters:

- **The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures (ESCAPE)**, a collection of various research infrastructures in astronomy, particle physics, and nuclear physics to create solutions for managing large-scale scientific data.
- **The Environmental Research Infrastructure (ENVRI)**, is a scientific hub which offers many notebooks to explore data and has a search service where users can find software such as notebooks and their corresponding GitHub repositories.
- **The Life Science Research Infrastructure bio.tools (LS-RI)**, a directory dedicated to bioinformatics tools and resources that support life sciences research, facilitating data sharing, analysis, and software reuse. bio.tools provides metadata driven descriptions for tools across bioinformatics, genomics, proteomics, and related fields.
- The **Photon and Neutron Open Science Cloud Software Catalog** (PaNOSC), a project that focuses on creating a software catalogue for photon and neutron research

[31] https://fair-impact.github.io/RSMD-guidelines/

[32] El Hounsri, Anas and Garijo, Daniel (2025), "Good practice versus reality: A landscape analysis of Research Software metadata adoption in European Open Science Clusters". To appear in Proceedings of the Mining Software Repositories Conference, 2025). Association for Computing Machinery. MSR '25. 2025. https://dgarijo.com/papers/El_Hounsri_MSR_2025_landscape_analysis_CR.pdf.

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facilities, providing accessible tools and services tailored to data-intensive scientific research.

We also included the Research Software Directory (RSD), a software catalogue that does not represent a science cluster but has gained momentum as a software registry from multiple science domains, with contributions from more than 20 different organizations.

A summary of results

Our analysis revealed the following insights, the methodology and quantitative results of our analysis, can be found in *El Hounsri and Garijo 2025*[33].

Regarding the first question: "*how communities describe RS metadata?*" researchers consistently dedicate effort in adding some metadata in their code repositories (LICENSE and README files are widely adopted, and package files are commonly used, although ENVRI and LSRI have low adoption of packages). However, the way in which metadata is adopted is inconsistent. The adoption of community standards for metadata (CodeMeta) and citation (CFF) is low (below 2% for CodeMeta, below 10% for CFF), although they are present in some science communities (ESCAPE and RSD respectively with 80% and 60% presence respectively). The continuous support from the community to help create these files (e.g., the CodeMeta generator[34], cffinit[35]) may increase their adoption. Attribution-specific files like AUTHORS and CONTRIBUTORS are for the most part absent in code repositories, indicating that authors do not yet consider key to acknowledge contributor roles. The increasing demand for recognizing contributions may see a rise in the adoption of these files. Zenodo.json files, used in the metadata integration with the platform are not widely adopted yet.

When it comes to the question *"what is the adoption of archival infrastructures across disciplines?"* results show a varied commitment to long term preservation. Software Heritage (SWH)[36] is notably used in ENVRI, PANOSC, LSRI and RSD while ESCAPE shows low adoption with 20%, suggesting potential reliance on alternative systems or low prioritisation of preservation practices. While many repositories use archival services, the results show that not many of them acknowledge their use. For example, the ESCAPE software registry is in Zenodo as a community, yet only 41.18% of their repositories include a badge with a DOI to the platform. RSD follows with (28%). The results highlight a significant variation in archival infrastructure adoption across disciplines, indicating that while some communities prioritise long-term software preservation, others may lack the necessary practices or awareness.

Next, for the question "*how research software projects adopt versioning*?" practices in research software show major variations in the adoption of releases and consistent version naming schemes. ESCAPE and RSD exhibit the highest adoption rates with 88.2% and 85.9% of projects having releases and 80% and 76.5% using consistent naming conventions, while

[33] El Hounsri, Anas and Garijo, Daniel. Good practice versus reality: A landscape analysis of Research Software metadata adoption in European Open Science Clusters. To appear in Proceedings of the Mining Software Repositories Conference, 2025). Association for Computing Machinery. MSR '25. 2025. https://dgarijo.com/papers/El_Hounsri_MSR_2025_landscape_analysis_CR.pdf.

[34] https://codemeta.github.io/codemeta-generator/

[35] https://citation-file-format.github.io/cff-initializer-javascript/#/

[36] https://www.softwareheritage.org

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ENVRI shows much lower adoption, with only 16% including releases. Overall, the results show us that there is a need for an easy way to keep consistent versioning.

Regarding the question *"How comprehensive is the metadata provided in code repositories?"* we analysed different metadata adoption for description, licenses and documentation associated with code repositories. Overall, all communities tend to include both short and long descriptions of their projects. When it comes to providing known licenses, we see a positive adoption rate, except for ENVRI, with an alarming number of repositories with no license. As for documentation and installation instructions, we notice a peculiar pattern in instructions, where only installation has positive adoption (around 60% in the existing repositories), with documentation slightly falling behind. Software requirements are missing in many repositories. Here we believe there is an opportunity for registries to warn researchers when key metadata is missing from their repositories (e.g., license, which highly affects their reusability).

Finally, regarding the question "*what are the citation practices among the communities?"*, we see that the adoption of structured citation formats, such as .bib and .cff, is limited across most communities, with the only notable exception in RSD (60.6% for .cff). The use of README.md for citation across communities is frequent, at least more notably than .bib and .cff (except for RSD with 5.78%). This gap of citation practices indicates a reliance on README files to communicate citation details more than using .bib and .cff, possibly due to their flexibility and ease of use, compared to generating citation using .bib and .cff. However, while README files are easy to read, they lack a standard method of citing, which limits their effectiveness in automated citation systems. This gap is important for raising awareness in developing an easier and automated way to adopt novel citation formats such as CFF.

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Lessons learned on discipline-specific metrics

The development and implementation of good FAIR assessment metrics is costly in terms of resources. Defining metrics in a way that is unambiguous, clearly testable, understandable, and transparently motivated is an immense and continuous challenge. Furthermore, it is difficult to define the discipline that a set of discipline-specific metrics should cover, as these can range from broad fields, such as the social sciences and humanities, which include many branches of knowledge, to a subdiscipline, for example psychology or even a speciality e.g. clinical neuropsychology, or a community such as CESSDA. Focus can also be put on data types or use other classifications to identify shared FAIRness qualities. Identifying for whom and respectively, which purpose, metrics should be defined and how such metrics cover everything that the 'discipline' specification covers can be a tricky process and can lead to an incredibly large number of new metrics and associated tests requiring development and continuous care. With increased specificity of a metric and associated tests it becomes harder to satisfy the metric test with a result, either positive or negative, rather than 'not found'. This generally means that community-specific metrics will result in lower scores and will only fit those who implement all the agreed community standards for their digital objects. This observation makes it even more important that the outcome or score of any FAIR assessment tool is de-emphasised and the focus is put on the explanations around the metrics and how to make improvements to the digital object and its associated metadata.

What happens if a set of discipline-specific metrics are no longer supported and maintained by the discipline or a community supporting the discipline? Should a discipline have an agreed policy whereby another community takes over the maintenance and, if so, how is this governed?

Examples of good practices and opportunities for conversation are the best ways to support and increase understanding of FAIR and its implementations. Having a specific implementation reference to work towards, or an overview of the different ways to reach the same end goal, lowers the barrier to work on improving FAIRness of digital objects. Different object types have their own specific challenges when it comes to implementing and evaluating FAIR, which must be addressed by uniquely tailored metrics and assessment processes. For example, the metrics for automated FAIR software assessment are based upon the FAIR Principles for Research Software (FAIR4RS) which are not a derivation of the original FAIR Guiding Principles[37] but a wholly new set of FAIR principles.

To lower the barrier of satisfying the FAIR principles, it is important to work towards (community) standardisation, harmonisation, and providing infrastructure that automates as much of the process as possible. Such tools could then be suggested in the results of FAIR assessment tools to help advance the FAIRness of an object as easily as possible.

[37] Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

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3. Harmonisation of FAIR assessment tools

An overarching theme from the FAIR-IMPACT Synchronisation Force workshop sessions on metrics and tools, has been that FAIR should not be seen as the end goal but should instead be a means to reach other goals[38]. A recommendation from the first FAIR-IMPACT Synchronisation Force session emphasised that assessments should encourage enhancement of the FAIRness, rather than merely achieving an overall score for FAIRness of a digital object[39]. Moreover, it is important that users of FAIR assessment tools receive more assistance in navigating the landscape of available tools to select which tool(s) to use for their purpose.

Assessment tools utilising discipline-specific may be more accurate, but also may appear to produce a lower FAIRness score generated by the tool due to their strictness in interpreting test results for a specific metric. Without further investigation and explanation this can cause frustration and possibly a preference for the generic tools that may present higher scores, for example, when a multi-disciplinary data repository sees different scores for data objects which are managed and maintained in the same fashion. Moreover, the FAIR Guiding Principles[40] doesn't refer to disciplines, instead using the term 'domain' in a very general sense. Many different ontologies of disciplines exist, at different levels of granularity, making it difficult to apply a unique value to any research or publication. As noted above, FAIR practices differ greatly between disciplines, sub-discipline and communities of practice. Reducing the focus of FAIR testing from the social sciences and humanities to just the social sciences provide a tighter focus, but even within this narrower area differing qualitative and quantitative methodologies exist, which imply different best practices for a wider range of dissimilar data formats, metadata schema and ontologies, which are difficult to meet with an automated assessment tool. A related issue is that of authority. Working with CESSDA provides a valuable social science perspective on FAIR assessment, but the adoption of a set of FAIR tests by CESSDA does not imply their authority to set criteria globally.

As noted above, assessment results will differ if domain-independent or community-specific FAIR metrics are used, thus in real world use this could lead to a defensive decision by repositories to select the tests that deliver the most positive score, rather than deliver their fairest outcome for their disciplinary community of users. Discipline-specific standards may be agreed upon but might not be actually adhered to in practice. FAIR assessments should encourage enhancement to the FAIRness of a digital object rather than merely achieving a score for FAIRness. Therefore, there should be a shift towards facilitating the practical application of FAIR principles rather than solely focussing on their measurement. Assessment

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[38] Everhardt, M., Fink, A. S., Jonquet, C., Gonzalez, E., Dillo, I., Nordling, J., Davidson, J., Horton, L., Marjamaa-Mankinen, L., Verburg, M., Priddy, M., GRAU, N., Rouchon, O., & Pittonet Gaiarin, S. (2024). M1.9 Third Synchronisation Workshop Report - 20241218 1.0 (v1.0)., Zenodo. p.10. https://doi.org/10.5281/zenodo.14537952.

[39] Grootveld, M., Pittonet Gaiarin, S., Davidson, J., Dillo, I., O'Connor, R., Marjamaa-Mankinen, L., Verburg, M., & Jonquet, C. (2023). M1.7 - First synchronisation workshop. Zenodo. p.9. https://doi.org/10.5281/zenodo.7692063

[40] Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

and measurement are still essential to evaluate if improvements in FAIRness have been accomplished but this goes hand-in-hand with advice on how to make further improvements. There have been many tools for FAIR assessment developed, both manual and automated, applying different sets of metrics and tests, each with their own interpretation of the FAIR principles. There are discipline specific examples, such as FAIR-Checker[41,42] created for the life sciences domain[43], as well as those which operate with only one data repository, for example FAIR EVA for DIGITAL.CSI[44]. Although it may be possible to evaluate if an automated tool is actively being developed, in many cases it is difficult to ascertain if the tool is being managed, maintained and actively used, with examples only available as an installable set of files in a GitHub repository with no active version which can be tested. Thus, the landscape of FAIR assessment tools can, at first sight, appear to be chaotic and confusing. For those automated FAIR assessment tools such as F-UJI, FOOPS![45,46], FAIR-Champion[47] and others, which remain in development, both individually and through the alignment of tests between them, there may be rapid changes to metrics and tests, with consequences for scores[48]. This instability, and any lack of clarity about whether tools and tests are under development or in production can make it hard for repositories to adopt tools and keep up with the development in their daily active workflows.

The challenges are not only on the side of assessment tools. Repositories are being asked to enrich existing metadata to demonstrate FAIRness and to expose that metadata in ways that are actionable by FAIR tools. With variation in how tests are performed by automated assessment tools it becomes challenging for repositories to meet the possible competing needs. The automated creation and curation of an overview of the tool landscape could also be more easily facilitated if such information is similarly presented across tools thus supporting these repository needs. FAIRassist[49] is a list resource of available tools based upon manual registration of the tool. An important drawback is that recent updates to the tools, as well as their continued management or maintenance are not recorded. This information, in addition to stories about usage, as well as technical details about the metrics used and the tests performed helps to inform choice, although much of this should also be available through the tool's own interface and documentation.

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[41] https://fair-checker.france-bioinformatique.fr/check

[42] Gaignard, A., Rosnet, T., De Lamotte, F. et al. FAIR-Checker: supporting digital resource findability and reuse with Knowledge Graphs and Semantic Web standards. J Biomed Semant 14, 7 (2023). https://doi.org/10.1186/s13326-023-00289-5

[43] Although FAIR-Checker has been built for use in the biosciences it is capable of assessing data objects from other domains.

[44] https://fair.csic.es/en

[45] FOOPS! is a tool for assessing the FAIRness of ontologies and vocabularies. https://foops.linkeddata.es/FAIR_validator.html

[46] FAIR Implementation Framework of resources: FOOPS! Ontology Pitfall Scanner for FAIR https://catalogue.fair-impact.eu/resources/foops

[47] https://github.com/markwilkinson/FAIR-Champion

[48] It should be noted that F-UJI will allow an assessment for a data object be performed with different sets of metrics and tests

[49] https://fairassist.org/#!/

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As a natural result of research, curation actions and active preservation over time, objects change. Alongside this, the technical and semantic expectations of (re)user communities change. This evolution means that an object assessed as FAIR cannot be guaranteed to remain FAIR over time, and the drivers and timing of FAIR reassessment alongside other appraisal and reappraisal decisions still need to be explored. However, the assessment of digital objects and the repositories that care for them, both from FAIRness and from wider perspectives (repository trustworthiness, data quality etc), remains essential for evaluating and improving research infrastructures.

The intended user group(s) of an assessment tool should be clearly indicated, and the outcomes of the assessment should match the level of expertise and the intended follow-up actions of those users. Different users of FAIR assessment tools need different assistance in the understanding and implementing of the outcome of the assessments. Therefore, it is important for assessment tools to use metadata in a clear, transparent, and in a similar fashion across different metrics and tests, but at the same time disciplinary requirements must be respected. This contributes to the metrics and tools themselves becoming increasingly FAIR. Moreover, guidance about how to interpret the results from a FAIR assessment tool, metrics and tests is important for both those who are involved in improving the FAIRness of a digital object and for those wishing to reuse it. Having such information about metrics and tools can showcase the biases that are part of them and can allow users to then make their own informed decision about trusting and using each metric and tool. Should researchers reusing or depositing digital objects be required to understand in detail the FAIR principles, metrics and assessment methodologies? For a researcher planning to reuse a digital object their needs revolve around the questions ‘will it work’ and ‘is the quality good enough’. FAIR does not directly measure digital object quality (such as noting changes in collection methods, or reproducibility, or completeness of metadata) and nor should it, but the first question requires the researcher to dig behind the FAIRness score or trust the source, for example is it in a trustworthy repository which sets and meets transparent FAIRness criteria. For those depositing digital objects in a repository, ensuringing FAIRness requires a collaboration between the depositor (object owner) and the curator (repository manager), imposing overheads on both. This is why guidance on improving FAIRness should lead the process and not a simplistic FAIRness score that can change over time.

Guidance can come from different quarters. By taking advantage of the successes of the implementation of FAIR digital objects and the FAIRification processes as a means to increase the importance and prioritisation of research data management and other research outputs in science it is possible for communities to support each other through sharing stories. Such stories could include experiences shared by researchers on the advantages of good data management, the perspective of institutions or communities that choose to invest in this, but also examples of digital objects that follow good practices without being improved or overhauled to be FAIR, or stories from outside of the EOSC or academic research context, to highlight the common advantages.

The primary objective of FAIR assessment must shift towards facilitating the practical application of FAIR principles rather than solely focussing on their measurement of FAIRness.

To do this the tools must change their focus from scoring to specific advice and guidance which will benefit all those using the tools. Currently only two automated tools, FAIR-Checker and FAIR EVA, give guidance beyond debug text, with FAIR EVA being specific to the repository it supports. Disciplines can help to ensure the guidance meets their community needs along with discipline-specific repositories supporting their designated communities. Tools such as FAIR-Aware[50,51] can help in providing basic knowledge and can be adapted to specific needs of disciplines and digital object types, however, guidance built into the FAIR assessment process and results is far more useful as part of the deposit pipeline. Improving the FAIRness of digital objects already deposited in a repository presents different challenges to the repository managers, however FAIR guidance can still be valuable for researchers wishing to reuse older digital objects in a repository to ascertain what they may additionally need to do to make the digital object reusable for their purposes. Turning debug information into detailed meaningful guidance is not easy and will take time. A solution which allows more than just the tool creators to provide guidance is important, especially for discipline-specific needs and this could include community created stories and examples of best practice.

[50] https://fairaware.dans.knaw.nl/

[51] Vesa Akerman, Linas Cepinskas, Maaike Verburg, & Mokrane Mustapha. (2021). FAIR-Aware: Assess Your Knowledge of FAIR (v1.0.1). Zenodo. https://doi.org/10.5281/zenodo.5084861

4. Conclusions and suggestions for the future

Despite the rapid proliferation and dissemination of the FAIR principles over the last almost 10 years with take-up across digital object types and disciplines we are still in the early development phase of FAIRness. This is especially evident with the development of a plethora of metrics and tools which use the metrics for both automated as well as manual assessment. We are still in an initial, ad hoc maturity phase in the development of FAIR metrics and tools which is evident with the development of discipline-specific metrics and tests. Our initial work in this area suggests that, although possible, discipline-specificity raises additional challenges in gaining acceptance and use across the discipline communities, especially when discipline-specific metrics for discipline created data objects result in lower assessment scores compared to generic assessments. It is important that work in this area of FAIR assessment continues to provide a broad picture of the advantages and challenges of discipline-specific metrics and at what scale of discipline or defined sub-discipline that assessment works for the community. In Europe the ERICs could pick up this effort as they are best placed in understanding and evaluating the needs of their communities. However, care must be taken to ensure that the FAIR principles do not inadvertently support community-specific silos rather than its aim to bust the silos.

It may be a simple task to run an automated assessment for a digital object, obtain a score and finish the FAIR assessment by posting the score on the landing page, however it is clear, for researchers and support staff depositing a digital object in a repository or making it available elsewhere, FAIRness is a process of improvement. Therefore, FAIR assessment must be supported as a process with guidance, governance, and information.

The broad understanding of the need for data objects to be FAIR is clear, but will this be matched for other research digital objects such as software, semantic artefacts, data management plans and other research outputs? Where the (re)user communities start to request it, and the creators start to value FAIRness then it may not seem to be an additional chore. Additionally, it is essential that the FAIRness of digital objects is seen to be on a par with peer reviewed literature by funders and academia.