Six Recommendations for Implementation of FAIR Practice

European Commission

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By FAIR in Practice Task Force of the European Open Science Cloud FAIR Working Group

Independent Expert Report

Research and Innovation

EOSC Executive Board
WG FAIR
October 2020

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European Commission
Directorate-General for Research and Innovation
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Manuscript completed in October 2020.

PDF ISBN 978-92-76-22779-3 doi: 10.2777/986252 KI-01-20-580-EN-N

Luxembourg: Publications Office of the European Union, 2020.

EUROPEAN COMMISSION

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Edited by: the EOSC Executive Board

October 2020

2020 Directorate-General for Research and Innovation

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EXECUTIVE SUMMARY

This report analyses the state of FAIR practices within diverse research communities and FAIR-related policies in different countries and offers six practical recommendations on how FAIR can be turned into practice. These recommendations are aimed primarily at decision making entities of the European Open Science Cloud (EOSC), as well as research funders:

1. Fund awareness-raising, training, education and community-specific support.
2. Fund development, adoption and maintenance of community standards, tools and infrastructure.
3. Incentivise development of community governance.
4. Translate FAIR guidelines for other digital objects.
5. Reward and recognise improvements of FAIR practice.
6. Develop and monitor adequate policies for FAIR data and research objects.

In order to ensure widespread benefits of the EOSC, improvements in FAIR practices are necessary. We believe that the timing of this report, which coincides with the fully-fledged launch of the EOSC, could help the EOSC, research funders and policymakers make crucial strategic decisions about investment needed to put FAIR principles into practice.

1. INTRODUCTION

The FAIR Practice Task Force was set up as one of the four task forces of the European Open Science Cloud Executive Board FAIR Working Group. Its goal was to support the Working Group with an oversight of FAIR practices: learning about the possibilities of future FAIR implementation from current experience.

Even though the Task Force was not assigned a deliverable, this report was written because the Task Group's research into FAIR practices provided useful insights on gaps, differences and commonalities between communities. We wrote this report to share our findings and highlight the risks of not addressing these gaps.

This report can be seen as a follow-up on the 2018 report "Turning FAIR into reality" from the European Commission Expert Group on FAIR Data[1]. Our primary aim was to translate our findings into actionable recommendations to the decision-making entities of the European Open Science Cloud (EOSC), as well as research funders and policymakers on how to turn FAIR into practice. In addition, this work should be seen as complementary to "Recommendations on practice to support FAIR data principles[2]" by the FAIRsFAIR project, which makes specific recommendations aimed primarily at research communities and research support personnel (including data stewards and research software engineers).

After a section describing our methodology and the limitations of our study, this report contains a disciplinary and a regional perspective on FAIR implementation. The disciplinary perspective summarises what we have been reading on FAIR practices split into 2x2 parts: *technical and social impediments* on one side, and *technical solutions and social enablers* on the other. The regional perspective shows trends in regional policies and how they have so far driven the development of FAIR practices, highlighting the differences and commonalities.

A separate section details FAIR practices for digital objects other than research data.

We close the report with two sections with insights. The first one describes where differences between disciplinary and regional implementations come from, what implications these differences have for policymakers turning FAIR into reality, and how these differences can and should be addressed. Finally, we close off with our recommendations for the EOSC, research funders and policymakers.

This report was written collaboratively in an interesting time, with all authors working from home in the time of the Covid-19 pandemic in 2020. Our observations of data handling in this time helped us reflect that existing FAIR practices are already paying off for the expedited research processes needed to fight this new disease, but also that more acceleration would have been possible if FAIR practices would already have been implemented more broadly. There is still a lot to gain.

1 https://ec.europa.eu/info/sites/info/files/turning_fair_into_reality_1.pdf

2 Molloy, L., Whyte, A., Davidson, J., Asmi, A., Grootveld, M., Herterich, P., Martin, I., Méndez, E., Nordling, J., Principe, P., van Horik, R., Vieira, A., (2020) D3.4 Recommendations on practice to support FAIR data principles, Zenodo: https://doi.org/10.5281/zenodo.3924132

2. METHODOLOGY

This section describes the methodology undertaken by the FAIR Practice Task Force of the FAIR Working Group in investigating FAIR practices, producing the body of knowledge document, writing this report and consulting communities.

The investigation into FAIR practices was started with literature research (lasting from July 2019 to June 2020). Literature was organised as a body of knowledge in a dedicated online spreadsheet[3], to which various team members contributed reading resources. Reading resources were arranged by academic discipline[4]. The spreadsheet was open for community consultation and additional reading resources were contributed by various experts outside of the task force[5].

Each reading resource was allocated to a team member who analysed it in detail. Key findings from each resource were then classified into four different types: technical solutions, social enablers, social impediments and technical impediments. The applicability of each finding was then further matched to individual FAIR principles. Filtering was applied on the types and applicability of the different findings to facilitate easy, interactive queries of the spreadsheet content.

On 16-18 June 2020, the FAIR Practice Task Force met online to summarise their findings in a written report with recommendations primarily intended for the EOSC, Research funders and Policymakers. The members of the Task Force have different disciplinary backgrounds, which allowed putting the different findings from the reading resources into perspective of FAIR data experts from the various fields, further increasing the depth of the analysis This written report thereby has become the symbiosis of conclusions from the reading list and members' own experience.

Stakeholder definitions used in this report are consistent with the terminology used in "Turning FAIR into reality" report[6], with the exception that a new stakeholder "EOSC" has been introduced and defined as "those in decision-making capacity within the EOSC".

A draft version of this report, as well as the body of knowledge spreadsheet, were open for public consultation between 9 July 2020 (a dedicated webinar[7] attended by 200+ participants launched the consultation period) and 31 August 2020. In addition to useful feedback received during the webinar[8], a lot of comments and suggestions have been shared with the Task Force during the consultation phase, either directly on the google document, or via emails (the names of contributors who made substantive changes are indicated in the contributors' list on page 1). Subsequently, both resources were revised accordingly and finalised.

3 Hooft, Rob; Beyan, Oya; Chue Hong, Neil; Cozzini, Stefano; Hoffman-Sommer, Marta; Lembinen, Liisi; … Teperek, Marta. (2020). FAIR in practice reference list (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.3898674

4 Outline of academic disciplines: https://en.wikipedia.org/wiki/Outline_of_academic_disciplines

5 How to move from FAIR principles to FAIR practice? https://eoscsecretariat.eu/news-opinion/how-move-fair-principles-fair-practice - blog post announcing the work of FAIR Practice Task Force and requesting community contributions

6 Turning FAIR into reality: https://doi.org/10.2777/1524

7 WEBINAR: How to move from FAIR principles to FAIR practice? Current practices and recommendations for the future: https://www.eoscsecretariat.eu/events/webinar-fair-principles-fair-practice-recommendations-future

8 How to move from FAIR principles to FAIR practice? Q&A from the FAIR WG Webinar: https://www.eoscsecretariat.eu/news-opinion/how-move-fair-principles-fair-practice-qa-fair-wg-webinar

2.1. Limitations

This study has some limitations.

1. The body of knowledge was composed of reading resources known to FAIR Practice Task Force members or recommended to them by external experts. Thus, the list of resources should not be perceived as an exhaustive information on FAIR practices.
2. Lack of data, or lack of information on practices should also be considered informative. Communities or subcommunities that are not aware of FAIR practices might be less likely to write publications analysing such practices, and also less likely to participate in surveys and research looking at FAIR practices.
3. The classification of findings by type and applicability was done as best-effort by the team member going through the resource, looking for the closest match. Therefore, there might be cases where a certain finding is classified as one type/applicability, but in fact could fit into more than one category.

Information on community practices is almost exclusively based on desk research and thus might not always be accurate, as it is based on (sometimes subjective) interpretations of the written text. In addition, attempts to engage with certain communities to verify information on their practices or get information about their practices were not always successful and/or are ongoing.

3. FAIR PRACTICES: A DISCIPLINARY PERSPECTIVE

An overwhelming majority of scientific references to the FAIR principles come from life and natural sciences[9]. Nevertheless, sufficient information is available about the practical implementation of FAIR practices across disciplines to make a general overview of what has been done already, and also to identify what stands in the way of a further deployment of FAIR within communities, both from technical as well as social perspectives.

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.[10]

3.1. Technical impediments

There are many generic and many data-type or discipline-specific repositories. Nevertheless, some fields note a **lack of specific repositories** (e.g. earth sciences) or **lack of repositories that can deal with complex outputs ("complex digital objects")** (humanities) or **insufficient infrastructure for transferring and archiving of large data** to/from repositories. Also reported is a **lack of sufficiently flexible and secure infrastructure for archiving sensitive data**. On the other hand, we also encountered the complaint that there are **too many different repositories** to search for data.

Interoperability principles are widely considered the hardest to adopt. It is sometimes observed that efforts to improve FAIRness tend to be more focused on findability instead of interoperability, because this is easier to start with. Even at the level of intra-disciplinary interoperability we see that it is hard to make **traditional text-based outputs like lexicons and bibliographies** FAIR. On the other hand, some communities choose standardisation on widely used formats like CSV or SPSS, not realising that **these formats by themselves do not sufficiently document the data for reuse**. It does not help when **different sub-fields of a discipline are using the same terms to mean different things** (e.g. social sciences and humanities) or when there is **no standardisation of the way variables are coded**. Inter-disciplinary interoperability brings its own challenges: different repositories are using **different semantics for resolving persistent identifiers**, which makes it hard for machines to access the data. Some interdisciplinary practices like e.g. the use of ORCID[11] identifiers are not **equally adopted in all disciplines**. In addition, solving findability and accessibility of data within a discipline by bringing the data together in a virtual research environment can result in a **larger silo** of data that no longer interoperates with other disciplines. Many of these interoperability impediments show the importance of community-specific solutions **[Recommendation 2]**.

FAIR for machines is recognised as important, but also seen as a very difficult goal to reach. Sometimes it is perceived as secondary to FAIR for humans. The option of tackling

9 Towards the Tipping Point for FAIR Implementation: https://doi.org/10.1162/dint_a_00049

10 This section does not separately reference the documents from our reference list (https://doi.org/10.5281/zenodo.3898673); as it is a summary of all findings. Please refer to the reference list to find the sources.

11 https://orcid.org/

this with Artificial Intelligence is also mentioned. Neither approach properly addresses the need to consider FAIR for machines with every implementation choice.[12]

Both findability and reusability require **metadata**. The widest reported technical problem with metadata is that there are **insufficient ways of automatically collecting, updating and preserving** it. Currently, electronic lab notebooks[13] **either impose too much of a fixed structure or they are giving lots of freedom but then are incapable to interface** with e.g. instrumentation that collects the data. While in one of the studies an overwhelming majority of researchers report that they will only consider reusing a data set if it is very well documented, a similarly large percentage will be **put off by the prospect of having to document** their own data manually. **Lack of discipline-specific metadata** schemas and standards is also reported.

We encountered two related financial issues. First, it is very **hard to find dedicated funding for community resources** over a longer period, covering e.g. changes in data standards. Second, many funders do **not allow researchers to budget long term service fees** that pay for data services beyond the lifetime of a project. Fundamentally, project-based funding makes for a difficult fit with long-term data stewardship and preservation.

3.2. Social impediments

In different disciplines different reasons are brought up why the **FAIR principles do not apply** to data. This is often caused by **confusing FAIR with fully open** and freely accessible. In some cases, the **high volume of data** (e.g. molecular sciences) is brought up. Elsewhere, the presence of **personal and sensitive data** (e.g. in the health sciences), which under FAIR requires a proper description of the conditions under which it *can* be used, has made some researchers think that FAIR does not apply to them. FAIR is also perceived to be unsuitable where **intellectual property protection** is essential due to the role of commercial parties (e.g. in engineering, health and plant sciences). Sometimes it is said that FAIR was made for quantitative data and not **qualitative data** (e.g. social sciences and humanities), or that it is not suitable for the study of **real world objects** because that is different from the study of digitised objects (e.g. humanities, but much less in natural history collections).

It is widely seen that researchers **do not see sufficient benefits** of FAIR data, and therefore are not willing to put in the efforts in implementing FAIR practices; this is sometimes phrased as **academic recognition coming primarily from publishing papers** (explicitly mentioned in earth sciences) and not from publishing data. In some cases, data is **not considered an autonomous research output**, but only supplementary to the paper at best, and very often not considered at all. A related issue is that there is an academic **benefit of proposing and publishing new standards** over re-using existing ones.

We also see that some researchers **do not think their data can be reused** for other research at all. In contrast, many feel that there would be **significant additional cost** incurred if data needs to become FAIR, because it is **hard to do** and a lot of **extra work is required**.

12 These conclusions were added here based on responses to the first public consultation on the SRIA for EOSC (https://www.eoscsecretariat.eu/open-consultation-eosc-strategic-research-and-innovation-agenda); this topic was not picked up from the reference list.

13 Laboratory notebooks are common in laboratory science, e.g. life sciences, chemistry, but also research that can lead to IP that is protected by a patent. For an opinion on Paper versus Electronic lab notebooks, see https://www.openaire.eu/blogs/electronic-lab-notebooks-should-you-go-e-1

It is also observed that researchers are afraid that their data is **exploited by others:** they **fear being 'scooped'** by others who run with the carefully collected data, or fear that the data will be misused by those who will **make commercial use** of it, who do **not understand** the data properly, or have **malicious intentions**.

In some fields, it is felt that it is **impossible to document data sufficiently** to allow other humans and machines to interpret it, and that human-human collaboration will therefore always be needed. We also observe that in different disciplines the **general resistance to change** in habitual processes is brought up.

Implementation of FAIR is sometimes impeded by **misunderstandings about copyright and licensing**. In life sciences researchers often think that data is **owned by the researcher**. In mathematics it is sometimes thought that putting something on a **website makes it public domain**.

Many of these arguments are caused by a widely observed **lack of sufficient knowledge and understanding of FAIR**: many researchers have never heard of the FAIR principles. It is also observed that **researchers do not have sufficient legal knowledge** to make data FAIR without proper legal support.

Many of these arguments against open or FAIR data are sufficiently addressed elsewhere; we will not repeat these here[14]. However, we want to make clear that FAIR is a journey that is taken step by step, and that the results of making data FAIR do not have to be perfect in order for them to be valuable **[Recommendation 1-2]**.

3.3. Technical solutions

When looking at the different disciplines it is important to recognise that some disciplines require different types of technical solutions to obtain the same benefits from FAIR data. For example, "Findability" of data associated with a specific high-energy physics experiment may be sufficiently addressed if major search engines can find the instrument by name, whereas health researchers interested in a rare disease will need a more advanced Findability infrastructure to assemble information independently collected in many locations.

Generally, we observe that it has become **easier to make data citable**; citing persistent identifiers has become mainstream and many **repositories make it very easy to get a persistent identifier**, e.g. a DOI or Handle, for a data set.

There is a significant effort to **support FAIR practice within the repositories community** as well. For example, the Core Trust Seal's[15] requirements map strongly against a number of the FAIR requirements, meaning that the effort to obtain the CTS marks a move towards supporting FAIR. Similarly, COAR[16] (the Coalition of Open Access Repositories) has reviewed the FAIR principles and includes many of them in their Community Framework for Good Practices in Repositories.

14 Concerns about opening up data, and responses which have proven effective:
https://docs.google.com/document/d/1nDtHpnIDTY_G32EMJniXaOGBufjHCCk4VC9WGOf7jK4/edit#

15 Mokrane, M., & Recker, J. (2019). CoreTrustSeal–certified repositories: Enabling Findable, Accessible, Interoperable, and Reusable (FAIR). 16th International Conference on Digital Preservation (iPRES 2019), Amsterdam, The Netherlands. https://doi.org/10.17605/OSF.IO/9DA2X

16 https://comments.coar-repositories.org/wp-content/uploads/2020/06/
COAR-community-framework-for-repositories-June-16-20201.pdf

In many fields there is **no shortage of data and metadata standards**; standards are becoming easily findable through resources like FAIRsharing[17]. Communities are getting together to **choose between different available standards,** e.g. guided by the GO-FAIR convergence matrix or FAIR implementation profiles[18].

The role of semantics in interoperability is broadly recognised and **facilities for semantic interoperability are developed**, allowing better machine actionability of data. Good practices for semantic resources are being developed[19].

Some research disciplines are further along than others in implementing FAIR practice. In some cases, this is due to a **long history of data sharing practice**, such as in astronomy and high-energy physics. Their large infrastructure, shared between researchers from many different institutes and countries, have been designed with **data standardisation processes in mind**. In such disciplines, concrete, innate demand for sharing and standardisation were decisive factors in their success stories. In these fields, the data is maintained by the infrastructure organisations who have been collecting it.

There are practices that started as an effort in one discipline but could be readily generalised. For example, life sciences started **collecting and documenting the use of data and metadata standards** in BIOsharing; the realisation that this solved a problem of findability of standards that is also faced in other disciplines led to the development of FAIRsharing.

Life sciences have many **data-type specific repositories** which can offer more functionality for data re-users than generic repositories. This is a good model, but it may be hard to replicate for research fields where data types are less standardised. Also, each of these repositories requires sustained funding **[Recommendation 2]**.

Bringing together data and facilities for analysis into **Virtual Research Environments** increases findability and accessibility of the data (earth sciences). Related to this is the effort of **bringing the analysis to the data** instead of migrating the data to the place where they are to be analysed (e.g. earth sciences and life sciences); this approach solves problems with large data transfer as well as legal difficulties with off-premise copies.

3.4. Social enablers

Both publishers and research funders are in a position to **push for FAIR data sharing**. For funders this can be through mandates, as well as by **allowing projects to budget** for data management and data publishing (note this requires a clear understanding of the costs of data management and data publishing). Funder's actions can be made effective by **monitoring** adherence **[Recommendation 6]**. Publishers can mandate data sharing and can also **require authors to cite data** instead of just mentioning it.

A balance of penalties and rewards is needed for optimum impact. Policy requirements and the consequence of not being able to get funding without complying (see later section on a regional perspective) can be seen as penalties, and should not be the only motivation to implement FAIR. There is also a fear of unjust decisions (not sufficiently taking context into account) based on (automated) FAIR indicators. Rewards for data sharing that are mentioned in different places are **co-authorships** for the originators of data or **being cited** as data authors. It is expected that the academic reward is in balance with the effort

17 https://fairsharing.org/

18 https://www.go-fair.org/today/fair-matrix/

19 D2.2 FAIR Semantics: First recommendations; https://doi.org/10.5281/zenodo.3707985

made in sharing the data (e.g. earth sciences). It is also suggested that data sharing should be incorporated into researcher's **performance evaluations [Recommendation 5]**.

The **disciplinary culture** is considered very important for data sharing: it is facilitated if **data sharing is the norm** in a discipline (e.g. astronomy), and tools to access and use data are collaboratively developed. It can also help when a community is **organised around a virtual research environment** (e.g. earth sciences). Also, a **culture of collaboration** pushes data sharing along. Data from complex fields also push for data sharing because of the **pressure for verifiability**. Copyright and licensing policies that favour sharing data can also bring FAIR implementation forward.

Data sharing can be boosted by **increasing awareness** and through **education**[20] **[Recommendation 1]**. It helps if researchers know of **success stories**. Broad awareness also leads to peer visibility and **peer pressure**. Awareness can also be raised by the **availability of Research Data Management support** or through **Data Management Plan templates** that stress the importance of FAIR data. Researchers need to know that **FAIR data is not the same as open data**[21] (many of these are mentioned in reports from social sciences and humanities).

Finally, it is easier to see the benefits of FAIR data when **collecting the data is either very expensive** or when there is only **a single chance of collecting an observation**.

It is important to note that the push for data sharing also results in a **push for better quality data in general**.

20 See also Recommendation 10, Action 10.4 in Turning FAIR into Reality

21 See section 2.3 in Turning FAIR into Reality

4. FAIR PRACTICES: A REGIONAL PERSPECTIVE

Regional FAIR Practices are strongly determined by national policies. In this section we give an overview of the commonalities and the regional differences observed. Overall, we found that within Europe, Western European countries, and in particular, the Netherlands, UK, France and Germany are in the lead when it comes to FAIR practice.

4.1. Main approaches in Europe

We observed eight main approaches towards introducing policies on FAIR practices in Europe, which we describe below with some representative examples. These approaches can be divided into three groups: national approach (National plan or policy (1a), expert or working groups developing policy usually on the request of the national government (1b)); funders' or infrastructure requirements (government-funded research (2a), funder's policy (2b), national research data infrastructure requirements (2c)), and community/local approach (multi-stakeholder or research groups collaboration (3a) or research institutions (3a1), research integrity policies (3b), regional working groups enabling FAIR (3c)).

1a) National plan or policy: The Netherlands is one of the leaders in implementing FAIR principles in Western Europe. The Dutch *National Plan Open Science*[22] has an ambition for a consistent system to allow FAIR access to research data. The Plan is implemented through National Platform Open Science. The Netherlands is one of the few countries who have paid attention to monitoring and rewarding data sharing in their Plan. Similar national level framework approach is taken in Ireland through the *National Framework on the Transition to an Open Research Environment*[23] and in Norway through the Ministry of Education and Research's *National Strategy on Access to and Sharing of Research Data*[24]. These national policies often do not mention FAIR, but the approach contains all elements of FAIR. For example, both Serbia[25] and Slovenia[26] describe in their strategies how and when research data should be made available, as well as which repositories and licences should be used.

1b) Policy recommendations of national level workgroups: such workgroups give recommendations and advice on principles for development of national open science policies. In Austria, the Open Science Network Austria (OANA) WG has developed recommendations for a national open science strategy[27], which includes FAIR recommendations. A similar approach has been taken also in Baltic and Eastern European countries (Estonia, Latvia, Slovakia).

22 van Wezenbeek, W.J.S.M., Touwen, H.J.J., Versteeg, A.M.C., and van Wesenbeeck, A. (2017). National Plan Open Science. Ministerie van Onderwijs, Cultuur en Wetenschap, 2017. https://doi.org/10.4233/uuid:9e9fa82e-06c1-4d0d-9e20-5620259a6c65.

23 National Open Research Forum (July, 2019). National Framework on the Transition to an Open Research Environment. http://norf-ireland.net/wp-content/uploads/2019/07/NORF_Framework_10_July_2019-2.pdf

24 Norwegian Ministry of Education and Research (2018). National Strategy on Access to and Sharing of Research Data. https://www.regjeringen.no/contentassets/3a0ceeaa1c9b4611a1b86fc5616abde7/en-gb/pdfs/national-strategy-on-access_summary.pdf

25Ministry of Education, Science and Technological Development of the Republic of Serbia. (July, 2018). Open Science Platform. http://open.ac.rs/svevesti/87328781babfe70aad60429fad8f4feb/Open-Science-Policy-Serbia.pdf

26 Government of the Republic of Slovenia. (3 September, 2015). National Strategy of Open Access to Scientific publications and research data in Slovenia 2015–2020. https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/ZNANOST/Strategije/National-strategy-of-open-access-to-scientific-publications-and-research-data-in-Slovenia-2015-2020.pdf

27 Open Science Network Austria OANA. (2020). Recommendations for a National Open Science Strategy in Austria of the Open Science Network Austria OANA written by the working group "Open Science Strategy". https://oana.at/fileadmin/user_upload/k_oana/dokumente/Entwurfv1.1-EmpfehlungenOS-OANA.pdf

2a) Compliance requirements for government-funded research: France has set as one of the goals in its National Plan for Open Science[28] to ensure that data produced by government-funded research become gradually compliant with the FAIR Data Principles and that they are preserved and, whenever possible, open to all. The same principle is applied in Norway - the Research Council of Norway Policy[29] for open access to research data has been based on the FAIR Principles.

2b) Funders' policy/requirements: Belgian federal funder's BELSPO Open Research Data policy is aligned with FAIR principles.[30] Similarly, non-profit funders are more often requiring sharing data opening as soon as possible (for example, Wellcome Trust encourages researchers to share their data through Wellcome Open Research[31]), in addition, European Commission's Horizon 2020 Funding requires projects to produce FAIR DMPs.[32]

2c) Requirements of national research data infrastructures: National Research Data Infrastructures[33] (NFDI) funded by Germany's federal and state governments require that all data preserved in NFDI is managed in accordance with FAIR principles.[34] A similar approach is taken also in Italy where the Italian Computing and Data Infrastructure (ICDI[35]) is leading in FAIR practices in order to establish a nationally coordinated strategy towards FAIR.

3a) Multi-stakeholder approach to requirements: In the UK, the Concordat on Open Research Data[36] has been developed by a multi-stakeholder group and has been signed by the higher education funding council, one private funder (Wellcome Trust), several national research funders, and the umbrella group of UK universities. The Concordat is not considered a government document but rather a community output. The Concordat does not focus specifically on FAIR but the content is aligned with the FAIR principles. In addition, the Open Research Data Task Force[37], which builds its recommendations on the principles set out in the Concordat, argues for adherence to FAIR principles for sharing data in the UK. A multi-stakeholder approach is taken in Finland's Declaration for Open Science and Research (Finland) 2020-2025.[38] All signed organisations and research

28 National plan for Open Science. (4 July, 2018). https://www.ouvrirlascience.fr/national-plan-for-open-science-4th-july-2018/

29 The Research Council of Norway (March, 2020). The Research Council Policy for Open Science. https://www.forskningsradet.no/siteassets/tall-og-statistikk-seksjonen/apen-forskning/nfr-policy-open-science-eng.pdf.

30 The Federal Science Policy Office (BELSPO). (3 December, 2019). Open Research Data mandate. https://www.belspo.be/belspo/openscience/doc/ORD_Policy_Dec2019.pdf

31 Wellcome Trust (April, 2018). Good research practice guideline. https://wellcome.ac.uk/grant-funding/guidance/good-research-practice-guidelines.

32 European Commission (2016). H2020 Programme Guidelines on FAIR Data Management in Horizon 2020. (26 July, 2016) https://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

33 German Research Foundation. National Research Data Infrastructures (website) https://www.dfg.de/en/research_funding/programmes/nfdi/index.html

34 German Research Foundation. (May, 2020). Guidelines for Consortia National Research Data Infrastructure (NFDI)https://www.dfg.de/formulare/nfdi100/nfdi100_en.pdf

35 Proudman, V., Sveinsdottir, T., & Davidson, J. (2020). An Analysis of Open Science Policies in Europe v5. Zenodo. https://doi.org/10.5281/zenodo.3689450

36 UK Research and Innovation. (28 July, 2016). Concordat on Open Research Data. https://www.ukri.org/files/legacy/documents/concordatonopenresearchdata-pdf

37 Open Research Data Task Force. (July, 2018). Realising the potential. (Final report). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/ 775006/Realising-the-potential-ORDTF-July-2018.pdf

38 Open Science Coordination in Finland, Federation of Finnish Learned Societies (2020). Declaration for Open Science and Research 2020–2025, 2nd edition. DOI https://doi.org/10.23847/isbn.9789525995213

communities in Finland accept that the management of research data is based on FAIR principles.

3a) Institutional approach: Individual research institutions (universities) across Europe are taking an approach requiring or at least recommending FAIR principles in research, in these cases universities also offer support or guidance for their researchers. For example, Utrecht University makes practical guidelines for each letter (F.A.I.R.) on how to make research data FAIR and offers assistance.[39] TU Delft Research Data Framework Policy sets responsibility for researchers, PhD supervisors and students to publish that data FAIR.[40] Similar approaches can be seen in other research institutions across Europe.

3b) Research integrity policies: FAIR data principles are sometimes referred to in national or institutional codes of conduct for research integrity as well. The European Code of Conduct for Research Integrity refers to FAIR principles suggesting that wherever possible researchers, research institutions and organisations should make sure that access to data is aligned with FAIR principles.[41] The Netherlands Code of Conduct for Research Integrity[42] asks researchers to contribute to FAIR data and tasks research institutions with ensuring that research data is open and accessible in accordance with the FAIR principles. Similar approaches are also used in countries or institutions without any official national policy on FAIR or Open Science, for example in Estonia[43].

3c) Regional approach - Nordic and Baltic countries have taken a collaborative approach to FAIRification of repositories through the EOSC Nordic project[44]. Goals of this project are to identify the region's research data repositories, evaluate and improve their FAIRness and to landscape Open Science policies in Nordic and Baltic countries. National Initiatives for Open Science in Europe – NI4OS Europe (funded by EC Horizon 2020) unites a large number of member states of the European Council (15 Member States and Associated Countries in the EOSC governance). One of its goals is to "instill the EOSC philosophy and FAIR principles in the community".[45] There are various other regional EOSC projects in Europe which aim to align with FAIR principles.

4.2. Outside Europe

Countries outside Europe are also actively involved in developing their open science and FAIR policies. The Australian Research Data Commons (ARDC[46]) supports and encourages initiatives that enable making data and other related research outputs FAIR, including policy development.[47] With the policy statement, a group of key stakeholders in the Australian research sector are advocating for government policy to support that all publicly

39 Utrecht University (2019). How to make your data FAIR. https://www.uu.nl/en/research/research-data-management/guides/how-to-make-your-data-fair

40 TU Delft (August, 2018). TU Delft Research Data Framework Policy.
https://d1rkab7tlqy5f1.cloudfront.net/Library/Themaportalen/RDM/researchdata-framework-policy.pdf

41 ALLEA - All European Academies (2017). The European Code of Conduct for Research Integrity. Revised Edition.
http://www.allea.org/wp-content/uploads/2017/03/ALLEA-European-Code-of-Conduct-for-Research-Integrity-2017-1.pdf

42 KNAW; NFU; NWO; TO2-federatie; Vereniging Hogescholen; VSNU. (2018). Netherland's Code of Conduct for Research Integrity. DANS. https://doi.org/10.17026/dans-2cj-nvwu

43 Centre for Ethics, University of Tartu (2017). Estonian Code of Conduct for Research Integrity.
https://www.eetika.ee/sites/default/files/www_ut/hea_teadustava_eng_trukis.pdf

44 EOSC-Nordic. (2020). European Commission Horizon 2020 project no. 857652. (website). https://www.eosc-nordic.eu/

45 National Initiatives for Open Science in Europe (2020). https://ni4os.eu/

46 Australian Research Data Commons. (website). https://ardc.edu.au/

47 Australian Research Data Commons (2020). FAIR principles. (website). https://ardc.edu.au/collaborations/fair-principles/

funded research outputs will be FAIR.[48] New Zealand's eResearch2020 is a nationally coordinated multi-stakeholder programme for developing a national strategic approach to research data in New Zealand.[49] The United States in a 2013 Directive from the White House Office of Science and Technology Policy (OSTP) required Public Access to Federally Funded Research Outputs.[50] This work is an ongoing federal effort to support the advancement of open science and to make federally funded research outputs available.[51] An open and overarching network - the GO FAIR Implementation Network Africa - IN-Africa - has been established. Their manifesto and activity plan aim, among other objectives, to implement FAIR-principles and connect African research with the global FAIR community.[52]

4.3. General commonalities, differences, and gaps in Europe

4.3.1. Commonalities

- It is usually funders, institutions and research groups that introduce FAIR policies rather than governments. In many countries, funding agencies are the main actors implementing open science strategies (this is noticeable all over Europe, with no major regional differences).
- FAIR is mainly part of communities' practice rather than of national policies. Various research groups and disciplines are doing FAIR and they also mention FAIR in their proceedings.
- FAIR is sometimes confused with open data.
- Most Open Science national policies or recommendations require managing and sharing research data. There is no difference in this between various regions of Europe.
- Most European countries have established National Infrastructure Roadmaps which often contain research data infrastructure and recommendations on data management, preservation and usability and may refer to FAIR.
- Various studies across Europe have shown that only few countries have an official Open Science policy that refers to FAIR data. Most Open Science and Access national policies have implications to FAIR principles without mentioning these explicitly. Policies cover preservation, accessibility, reusability, machine readability and other principles of FAIR. In Europe, at the beginning of 2020, only six countries had national Open Science policies where FAIR is mentioned. These included the policies from the Netherlands, France, the UK, Finland, Spain and Ireland. At the same time,

48 Australian FAIR access working group (2020). Policy Statement on F.A.I.R. Access to Australia's Research Outputs. https://www.fair-access.net.au/fair-statement

49 NeSI, REANNZ and NZGL. (March, 2016). eResearch 2020. National Research Data Programme. http://www.eresearch2020.org.nz/wp-content/uploads/2016/03/eResearch2020_National ResearchDataPrograme_S.pdf

50 Executive Office of the President. Office of Science and Technology Policy. (22 February, 2013). Increasing Access to the Results of Federally Funded Scientific Research. (Memorandum). https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf

51 Request for Information: Public Access to Peer-Reviewed Scholarly Publications, Data and Code Resulting From Federally Funded Research. (2020, February 19). Federal Register. https://www.federalregister.gov/documents/2020/02/19/2020-03189/request-for-information-public-access-to-peer-reviewed-scholarly-publications-data-and-code

52 Manifesto of the FAIR Implementation Network - Africa To establish the Africa connection of the Internet of Data and Services "Go FAIR in Africa 2019-2020." (August 1, 2019). https://www.go-fair.org/ wp-content/uploads/2019/08/Activity-Plan-with-the-Manifesto-of-the-GO-FAIR-in-AFRICA-Final-1-August-2019.pdf

more than 15 countries in Europe had Open Science national policies in place that focus on open access to publications.[53]

4.3.2. Differences

- Main FAIR implementers are Western European countries. More focus needs to be placed on Eastern Europe, specifically in the area of FAIR54, given that fewer national Open Science and FAIR policies have been adopted in the Eastern European and Baltic countries [Recommendation 6].
- FAIRsFAIR FAIR D3.1 FAIR Policy Landscape Analysis55 survey showed that Western European countries are more active in Open Science and are more advanced in implementing FAIR guidelines (majority of survey respondents are from Western European countries). However, a more detailed look into Eastern European Open Science recommendations (there are few policies) reveals that these countries also recommend research data to be open, available and reusable. These differences between Western and Eastern European countries might be explained with the EU funding of various specifically FAIR-related projects which are often led by Western European countries (GO FAIR, FAIRsFAIR), and in which Eastern European countries do not always participate.

4.3.3. Gaps

- Focusing only on the term FAIR is limiting the understanding of activities that are taking place in Europe that are advancing FAIR. Often FAIR is not mentioned, but activities are enabling implementation of FAIR principles in practice. It can be observed that countries are moving towards FAIR; however, the term FAIR is not widely spread yet.
- Studying FAIR and Open Science policies is not enough to landscape the work that is done. The mapping should be wider by including research integrity activities, teaching and training, and also by including actions taking place on institutional and discipline level, for instance in the Cluster projects [Recommendation 6].
- Having a national FAIR policy or roadmap in place does not equate to full compliance with that policy.

53 Proudman, V., Sveinsdottir, T., & Davidson, J. (2020)., ibid.

54 van Reisen, M., Stokmans, M., Basajja, M., Ong'ayo, A., Kirkpatrick, C. and Mons, B., 2020. Towards the Tipping Point for FAIR Implementation. Data Intelligence, 2(1-2), pp.264-275.
https://www.mitpressjournals.org/doi/full/10.1162/dint_a_00049

55 Davidson, J., Engelhardt, C., Proudman, V., Stoy, L., & Whyte, A. (2019). D3.1 FAIR Policy Landscape Analysis.
https://doi.org/10.5281/zenodo.3558173

5. FAIR PRACTICES FOR OTHER RESEARCH OBJECTS

In the original FAIR principles paper[56] the authors state:

> *"...it is our intent that the principles apply not only to 'data' in the conventional sense, but also to the algorithms, tools, and workflows that led to that data. All scholarly digital research objects—from data to analytical pipelines—benefit from application of these principles, since all components of the research process must be available to ensure transparency, reproducibility, and reusability."*

The majority of reports and studies on FAIR practice focus on research data; when other digital research objects are mentioned, it is in the role of supporting FAIR data, e.g. tools to enable FAIRification[57], such as the use of Data Management Plans (DMPs) and software to improve the data processing steps required before publication. This section of the report looks at the published practice and work to define better guidance to make other research objects FAIR in their own right.

5.1. FAIR Digital Objects used in research

For the purposes of this report, we consider FAIR Digital Objects used in research to include anything which is a direct component of the research process, e.g. software, workflows, executable notebooks, DMPs. This might also include research objects which are originally either physical (e.g. samples) or conceptual (e.g. protocols[58,59]) but have a directly referenceable digital form; but we do not focus on these in this report due to a current lack of published evaluation of / reflection on practice. We note that there is an urgent need for more studies to be commissioned to identify the impact of work being done in this area, such as DiSSCo[60] for natural sciences collections. Many research objects are discipline-specific, which means that FAIR guidance and practice will also be discipline-specific.

We are excluding indirect components of the research process, such as teaching and training materials, from this report but note that significant progress has been made under the banner of "Open Educational Resources" (OER) that is complementary to the adoption of FAIR. The EOSCpilot project considered how standards developed for OER may be applied towards making training materials more FAIR.[61] Initiatives to catalogue these materials as FAIR resources are being led by e.g. ELIXIR,[62] ENVRI-FAIR,[63] and the EOSC Executive Board WG Training and Skills.[64]

56 Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., … Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data, 3(1). https://doi.org/10.1038/sdata.2016.18

57 Thompson, M., Burger, K., Kaliyaperumal, R., Roos, M., & da Silva Santos, L. O. B. (2020). Making FAIR Easy with FAIR Tools: From Creolization to Convergence. Data Intelligence, 2(1–2), 87–95. https://doi.org/10.1162/dint_a_00031

58 https://www.protocols.io/

59 https://protocols.scienceexchange.com/

60 https://www.dissco.eu/

61 Whyte, A., Leenarts, E., de Vries, J. et al. (2019) Strategy for Sustainable Development of Skills and Capabilities, EOSCpilot D7.5 https://eoscpilot.eu/content/d75-strategy-sustainable-development-skills-and-capabilities

62 Garcia L, Batut B, Burke ML, Kuzak M, Psomopoulos F, Arcila R, et al. (2020) Ten simple rules for making training materials FAIR. PLoS Comput Biol 16(5): e1007854. https://doi.org/10.1371/journal.pcbi.1007854

63 https://trainingcatalogue.envri.eu/

64 Kuchman, I. 'Building competence and capabilities for EOSC' (blog article, 30/032020) https://www.eoscsecretariat.eu/news-opinion/competence-capabilities-eosc-skills-training

5.2. Current Practice

It is clear that adoption of FAIR practice for other research objects lags behind research data, yet evidence from the number of software deposits in repositories[65] and registries[66] with associated metadata and identifiers suggests that many research objects should be more findable and accessible. There is some evidence[67] of how different ESFRIs are making other types of outputs more findable and accessible as part of a broader aim of making their catalogues and repositories FAIRer, including EPOS aggregating information of about 400 elements (data, data product, software and services) to improve findability and CLARIN developing distributed workflow frameworks with harmonised metadata descriptions to improve interoperability and reusability.

The Turning FAIR into Reality report advocates that DMPs should be FAIR outputs in their own right. Making DMPs 'machine-actionable' means making their content findable and accessible, exchanging that content with other systems in standardised, interoperable ways, and potentially reusing that content. A standard for exchanging DMP content[68] has demonstrated the effective exchange of DMP data across several connected platforms[69].

However, most of the published practice, guidance and policy on other research objects concerns software, workflows and computational (executable) notebooks.

5.2.1. Software

Historically, there has been a wide spectrum of practice in publishing and sharing research software (including applications, scripts, tools, libraries, APIs and services). A previous lack of formalisation and standards means that even within disciplines, practices may vary considerably. However more recently the RDA COVID-19 working group has published Recommendations and Guidelines on data sharing[70] which puts forward some key practices for the development and (re)use of research software, including making source code publicly available under an open license to improve accessibility, as doing so facilitates sharing and accelerates the production of results.

The open source software community aims to allow anyone to inspect, modify and enhance software. They have developed practices and recommendations that align with FAIR principles, and which are increasingly used by researchers as open source licensing of research software becomes more common. For example, by following simple recommendations for making research software open[71,72] (make code public, add to registries, use open source license) it is possible to make software more findable, accessible and reusable. The practice of depositing software in an archive (for instance, when publishing a paper) is increasing due to changes in journal policies[73]. However,

65 Fenner, M. (2019). Jupyter Notebook FREYA PID Graph Key Performance Indicators (KPIs) (Version 1.1.0). DataCite. https://doi.org/10.14454/3BPW-W381

66 E.g. Astrophysics Source Code Library https://ascl.net/ and DOE Code https://www.osti.gov/doecode/

67 Wittenburg, P., de Jong, F., van Uytvanck, D., Cocco, M., Jeffery, K., Lautenschlager, M., Thiemann, H., Hellström, M., Asmi, A., & Holub, P. (2020). State of FAIRness in ESFRI Projects. Data Intelligence, 2(1–2), 230–237. https://doi.org/10.1162/dint_a_00045

68 Walk, P., Miksa, T., & Neish, P. (2019). RDA DMP Common Standard for Machine-actionable Data Management Plans. Research Data Alliance. https://doi.org/10.15497/RDA00039

69 https://rda-dmp-common.github.io/hackathon-2020/

70 RDA COVID-19 Working Group. (2020). Recommendations and Guidelines on data sharing. Research Data Alliance. https://doi.org/10.15497/rda00052

71 Jiménez, R. C., Kuzak, M., Alhamdoosh, M., Barker, M., Batut, B., Borg, M., … Crouch, S. (2017). Four simple recommendations to encourage best practices in research software. F1000Research, 6, 876. https://doi.org/10.12688/f1000research.11407.1

72 Five Recommendations for FAIR Software: https://fair-software.eu/

73 E.g. BMC policy: https://www.biomedcentral.com/getpublished/writing-resources/ structuring-your-data-materials-and-software

despite availability of guidance on publishing software[74], this is still not commonplace. In Zenodo, for instance, only 3.24% of all software DOIs registered are traceably cited at least once, and most are self-citations[75]. A study on GitHub repositories referenced in publications show clear differences in the reusability of the software[76] with 23.6% not having a license and readme - two basic indicators of reusability.

Most of the published work[77,78,79,80] on FAIR suggests that whilst the FAIR foundational principles can apply to software, the guiding principles require translation for software; though how much is still unclear. The paper "Towards FAIR principles for research software"[81] reviews previous work on applying the FAIR principles to software and suggests ways of adapting the principles to a software context. They argue that software is different from data: it is a tool to do something (executable); it is built by using other software (implements multi-step process, coordinates multiple tasks), it has complex dependencies and has a short life cycle with frequent need of versioning (including dependencies). Some of these characteristics also apply to data. However, the variety of software and its publishing and distribution channels, and the necessity to document dependencies and describe data formats, poses a challenge when adapting the current FAIR principles.

Recent recommendations for FAIR software[82] note that "at present research software is typically not published and archived using the same practices as FAIR data, with a common vocabulary to describe the artefacts with metadata and in a citable way with a persistent identifier". The majority of software is effectively "self-published", through project websites or code repositories such as GitHub and Bitbucket, rather than going through a deposit and curation step, as is the case with publishing data in a digital repository. The use of discipline-specific, community-maintained catalogues and registries (e.g. in astronomy[83], biosciences[84], geosciences[85]) can make software more findable and accessible if software is registered in them. Increasing incentives for publishing software with good metadata, such as improved acceptance of software citation[86] and the ability to make software more

74 Jackson, M. (2018). Software Deposit: Guidance For Researchers. Zenodo. https://doi.org/10.5281/ZENODO.1327310

75 van de Sandt, S., Nielsen, L., Ioannidis, A., Muench, A., Henneken, E., Accomazzi, A., Bigarella, C., Lopez, J. and Dallmeier-Tiessen, S., 2019. Practice Meets Principle: Tracking Software And Data Citations To Zenodo Dois. [online] arXiv.org. Available at: https://arxiv.org/abs/1911.00295 [Accessed 18 June 2020].

76 Whitaker, K., O'Reilly, M., , Isla, & Hong, N. C. (2018). Softwaresaved/Code-Cite: Sn-Hackday Version. Zenodo. https://doi.org/10.5281/ZENODO.1209095

77 Chue Hong, N., & Katz, D. S. (2018). FAIR enough? Can we (already) benefit from applying the FAIR data principles to software? https://doi.org/10.6084/M9.FIGSHARE.7449239.V2

78 Erdmann, C., Simons, N., Otsuji, R., Labou, S., Johnson, R., Castelao, G., Boas, B. V., Lamprecht, A.-L., Ortiz, C. M., Garcia, L., Kuzak, M., Martinez, P. A., Stokes, L., Honeyman, T., Wise, S., Quan, J., Peterson, S., Neeser, A., Karvovskaya, L., … Dennis, T. (2019). Top 10 FAIR Data & Software Things. Zenodo. https://doi.org/10.5281/ZENODO.2555498

79 Aerts, P. J. C. (2017). Sustainable Software Sustainability - Workshop report. Data Archiving and Networked Services (DANS). https://doi.org/10.17026/DANS-XFE-RN2W

80 Doorn, P. (2017). Does it make sense to apply the FAIR Data Principles to Software? https://indico.cern.ch/event/588219/contributions/2384979/attachments/1426152/2189855/FAIR_Software_Principles_CERN_March_2017.pdf

81 Lamprecht, A.-L., Garcia, L., Kuzak, M., Martinez, C., Arcila, R., Martin Del Pico, E., Dominguez Del Angel, V., van de Sandt, S., Ison, J., Martinez, P. A., McQuilton, P., Valencia, A., Harrow, J., Psomopoulos, F., Gelpi, J. L., Chue Hong, N., Goble, C., & Capella-Gutierrez, S. (2020). Towards FAIR principles for research software. Data Science, 3(1), 37–59. https://doi.org/10.3233/DS-190026

82 Hasselbring, W., Carr, L., Hettrick, S., Packer, H., & Tiropanis, T. (2020). From FAIR research data toward FAIR and open research software. It - Information Technology, 62(1), 39–47. https://doi.org/10.1515/itit-2019-0040

83 ASCL: https://ascl.net/

84 BioTools: https://bio.tools/

85 OntoSoft: https://www.ontosoft.org/

86 Smith, A. M., Katz, D. S., & Niemeyer, K. E. (2016). Software citation principles. PeerJ Computer Science, 2, e86. https://doi.org/10.7717/peerj-cs.86

discoverable through search engines through improved annotation will help to increase the findability and accessibility of software. However, this does not address the issue of information loss in the scholarly publishing system[87], where the metadata provided by software authors is removed or incorrectly passed on, which hinders the ability of infrastructure and tools used by research to help make software FAIR by degrading citations, credit and discoverability.

As reported in the work of FAIRsFAIR[88], "FAIR software and the application of FAIR principles to software is important, and sometimes neglected. [...] The way in which FAIR is applied to software, and the development of any related guidelines and metrics, needs further work and clear recommendations." Suggestions for this work are summarised as part of the Commonalities and Gaps at the end of this section.

5.2.2. Services

Software is often used to provide web services to process or analyse data. These services are typically domain-specific and some communities have identified the need for FAIR services. In the marine sciences, properly structured metadata to aid findability, along with provision of services via uniform and compatible encodings using community-adopted standards to aid accessibility, will be required to support machine-based processing of data flows[89]. In biodiversity, a digital object architecture has been proposed as an approach, building on the use of community-specific metadata registries[90]. GO-FAIR suggests using the 'hourglass model' to support 'The Internet of FAIR Data and Services'[91], where (similar to the architecture of the internet which has network protocols, e.g. IP, at the "neck" in the middle of the hourglass as an abstraction / spanning layer between the proliferation of applications above and physical networks below) a small set of core pieces - persistent identifiers and mapping tables - are agreed to support FAIR data, tools and services. In all cases, these approaches are still on the path to adoption and maturity.

The FAIRsFAIR Assessment report on 'FAIRness of services'[92] identified that "mapping of the 15 FAIR principles [...] to data services would [...] probably not deliver actionable insights of real and lasting value" and that "there is limited tangible guidance on how to 'make services FAIR'". It also noted the distinction between services which help enable FAIRness and services being FAIR themselves. Nevertheless, certification and other forms of assessment of FAIR services are important and extend beyond repositories. Ongoing work in FAIRsFAIR will be developing a Data Services Assessment Framework that will include actionable recommendations that service providers need to make incremental improvements to their services to support the emergence of a FAIR ecosystem. This could include a priority list of services which would benefit from such assessment. The Metrics and Certification Task Force of the EOSC FAIR Working Group will also make recommendations on the certification of services in the FAIR ecosystem.

87 Nielsen, L. H., & Van De Sandt, S. (2019). Tracking citations to research software via PIDs. ETH Zurich. https://doi.org/10.3929/ETHZ-B-000365763

88 Dillo, I., Grootveld, M., Hodson, S., & Gaiarin, S. P. (2020). Second Report of the FAIRsFAIR Synchronisation Force (D5.5). https://doi.org/10.5281/ZENODO.3953979

89 Tanhua, T., Pouliquen, S., Hausman, J., O'Brien, K., Bricher, P., de Bruin, T., … Zhao, Z. (2019). Ocean FAIR Data Services. Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00440

90 Lannom, L., Koureas, D., & Hardisty, A. R. (2020). FAIR Data and Services in Biodiversity Science and Geoscience. Data Intelligence, 2(1–2), 122–130. https://doi.org/10.1162/dint_a_00034

91 https://www.go-fair.org/resources/internet-fair-data-services/

92 Koers, H., Gruenpeter, M., Herterich, P., Hooft, R., Jones, S., Parland-von Essen, J., & Staiger, C. (2020). Assessment report on 'FAIRness of services'. https://doi.org/10.5281/ZENODO.3688762

5.2.3. Workflows

The history of sharing workflows dates back to before the publishing of the FAIR principles. Initiatives such as the Galaxy Toolshed[93] and myExperiment[94] in the life sciences and ArcGIS Catalog[95] in geosciences have made computational and data processing workflows more findable, accessible and reusable, before the FAIR principles were conceived.

Most current publications on FAIR workflows suggest policies and processes to improve the FAIRness of workflows. These include the use of persistent identifiers (PIDs) and machine learning to improve classification[96]; and better conventions for naming workflows alongside registration in specialised repositories[97]. A common theme is that the same challenges faced when attempting to apply the FAIR guiding principles to software apply to workflows and executable notebooks; their characteristics mean that they are similar to software artefacts. Another challenge for workflows is that automated annotation and description strategies and tools are required because the burden of creating and maintaining metadata for workflows is much higher than for data.

Workflows also have an important role in promoting the FAIR vision by supporting the FAIRness of other objects. While it is important that research workflows are FAIR themselves, any workflows used in research should be designed in a way to support the application of the FAIR principles to the objects used in the workflows.

5.2.4. Executable notebooks

A significant cultural change has occurred in the last five years, with more research[98] being disseminated through executable notebooks (most commonly Jupyter Notebooks). In the geosciences, domain-specific software repositories and better specification of software location, license and citation are suggested as ways of making research software findable and accessible, along with using containers to make software easier to reuse, to create "Geoscience papers of the future" combining data, code and narrative[99].

Considerable progress has been made on tooling and services to help make executable notebooks findable, accessible and reusable, by providing DOIs to identify them, reproducible environments to run them (Binder[100], CodeOcean[101]) or to export them to other publishing formats. This has been supported by documentation and training that has aided adoption. One study has analysed the FAIRness of Jupyter notebooks in the Astrophysics Data System, with 37 of 91 papers publishing openly accessible Jupyter notebooks containing detailed research procedures, associated code, analytical methods,

93 https://galaxyproject.org/toolshed/workflow-sharing/

94 https://www.myexperiment.org/

95 https://pro.arcgis.com/en/pro-app/help/analysis/geoprocessing/share-analysis/ create-a-geoprocessing-package.htm

96 Weigel, T., Schwardmann, U., Klump, J., Bendoukha, S., & Quick, R. (2020). Making Data and Workflows Findable for Machines. Data Intelligence, 2(1–2), 40–46. https://doi.org/10.1162/dint_a_00026

97 Goble, C., Cohen-Boulakia, S., Soiland-Reyes, S., Garijo, D., Gil, Y., Crusoe, M. R., … Schober, D. (2020). FAIR Computational Workflows. Data Intelligence, 2(1–2), 108–121. https://doi.org/10.1162/dint_a_00033

98 E.g. the LIGO Project: https://losc.ligo.org/tutorials/

99 Gil, Y., David, C. H., Demir, I., Essawy, B. T., Fulweiler, R. W., Goodall, J. L., Karlstrom, L., Lee, H., Mills, H. J., Oh, J., Pierce, S. A., Pope, A., Tzeng, M. W., Villamizar, S. R., & Yu, X. (2016). Toward the Geoscience Paper of the Future: Best practices for documenting and sharing research from data to software to provenance. Earth and Space Science, 3(10), 388–415. https://doi.org/10.1002/2015ea000136

100 https://mybinder.org/

101 https://codeocean.com/

and results. However, practices for mentioning, storing, and providing access to the notebooks varied greatly across papers[102].

5.3. Commonalities and Gaps

Analysis of existing practice and guidance reveals a number of commonalities shared across software, workflows and executable notebooks in relation to improving adoption of the FAIR principles - these should continue to be addressed:

- **Identifiers** are seen as a key requirement to making research objects findable and accessible. However, uptake of suitable persistent identifiers with associated metadata, though increasing, is still relatively low. This can be addressed through the development of better policies and guidance, along with appropriate funding and incentives. **[Recommendation 2, 5]**
- **Specialist repositories and catalogues** are often suggested to improve the FAIRness of software and workflows. These improve the quality of the metadata associated with other research objects for users but require additional effort from developers and curators to create and maintain the metadata, as automated transfer of metadata between systems is not yet common. The adoption of these infrastructures is often related to their use for other research objects in particular domains. **[Recommendation 1, 2, 3, 4, 5]**
- **Publishing of software** is different from publishing of data. Because the community norms of distributing software do not currently include the use of FAIR repositories, there is less cohesion around metadata. Making the metadata curation part of the process of assigning identifiers may help. Changes in code repository infrastructure, such as support for keywords/topics[103], will make it easier to automatically harvest and collate such information, which will make it easier to implement "metasearch" engines to improve the findability of software, workflow and services without them needing to be deposited in repositories. **[Recommendation 2, 4, 5]**
- **Enabling FAIRness** - the focus on FAIR digital objects is often on the FAIRness of the object itself. However, an important role in promoting the FAIR vision is recognising the role of some objects (e.g. services, workflows, software) in enabling the FAIRness of other objects through the way that they interact with them. **[Recommendation 1, 2, 4, 5]**
- **Authorship** - including citation and credit policies - is often mentioned as a method of providing incentives to improve FAIRness. Publishers, journals and conferences have shown a willingness to provide better support for this. **[Recommendation 1, 2, 3, 4, 5]**

- There are also some key gaps, where work is only just beginning:

- **Executable papers** combine elements of data, software, workflow and paper. It is still unclear how practice around making executable papers FAIR might proceed, though there is a proposed RDA effort to examine this. **[Recommendation 2, 4]**

102 Randles, B. M., Pasquetto, I. V., Golshan, M. S., & Borgman, C. L. (2017). Using the Jupyter Notebook as a Tool for Open Science: An Empirical Study. 2017 ACM/IEEE Joint Conference on Digital Libraries (JCDL). Presented at the 2017 ACM/IEEE Joint Conference on Digital Libraries (JCDL). https://doi.org/10.1109/jcdl.2017.7991618

103 https://help.github.com/en/github/administering-a-repository/classifying-your-repository-with-topics

- **Metrics for FAIR software,** as currently proposed, combine metrics based on FAIR data metrics with metrics based on software quality metrics. This will need to be clarified, in particular to identify which metrics will best help adoption of FAIR for software, and new work building on the previously published metrics is taking place in the FAIR4RS working group on FAIR software metrics and FAIRsFAIR. **[Recommendation 4, 5, 6]**
- **Studies on the adoption of FAIR** for other research objects are rare. Most published work looks at limited case studies, or proposes recommendations on how to apply FAIR principles, rather than measuring the success of these recommendations. **[Recommendation 6]**

Applying FAIR principles to the context of specific communities requires adoption/translation. This need is more obvious in the case of other digital research objects such as software. The relative importance of the FAIR foundational principles will depend on the goals, priorities and open science / open research culture of the community. Funder and publisher mandates will also have a key role in improving FAIR practice, as most of what has been identified in this section has resulted in requirements to share code as a prerequisite for publication.

In 2020, a joint RDA/FORCE11/ReSA working group has been setup on FAIR for Research Software (FAIR4RS)[104], which has begun the work of reviewing and, if necessary, redefining FAIR guiding principles for software and related computational code-based research objects. We expect this to be the community forum for taking forward the FAIR principles for software, services and workflows.

104 https://www.rd-alliance.org/groups/fair-4-research-software-fair4rs-wg

6. ADDRESSING DIFFERENCES IN FAIR MATURITY BETWEEN COMMUNITIES

The adoption of FAIR principles is increasing, but for policymakers and research funders it is important to acknowledge that in reality researchers know little about FAIR. In 2018, 60% of surveyed researchers had never heard of FAIR and only a fraction understood what the FAIR principles meant. Even awareness of an usually powerful tool, funders' expectations, was only 30%.105 Reality is even more harsh: among the respondents of such surveys there is usually a bias towards disciplines, countries and groups that already have better awareness. For example, bio- and natural sciences are significantly overrepresented, constituting almost the whole sample of disciplines where FAIR Guiding Principles have been properly implemented. There are also considerable differences even inside specific fields between early career and established researchers - their abilities, possibilities, awareness and vulnerabilities differ greatly. This all has also other implications: recommendations, standards and, more importantly, expectations regarding FAIR are based largely on experiences and expertise from these most successful and engaged communities.106 This section will discuss how differences in maturity between different research communities affect FAIR practices and why they should be taken into account when policymakers and research funders make decisions on research data, on the possible adoption of FAIR practices, and on the allocation of funding to support these activities.

It is very important to understand the reasons for the large differences between research communities and groups that are advanced in practising FAIR data and those that are not, as this has strong implications for the EOSC. Why do some communities already now practise FAIR data and why do others not? Why simply demanding that communities work harder to implement FAIR practices won't suffice? We need to understand this in order to enable all researchers from all communities to participate in the EOSC, and to implement FAIR data and benefit from it

6.1. Importance of internal drivers

Our observations support a conclusion that the successful implementation of FAIR practices in a particular community is usually a result of bottom-up initiatives. These initiatives typically arise from concrete demands for each other's data. Development of awareness inside the group on what data is important and should be shared is a crucial step here. In communities where there is internally a high level of reuse, researchers are intrinsically motivated to share their data. This motivation is crucial, but it is not sufficient for a community to establish FAIR data routines. Effective data sharing requires certain standards for findability, availability and interoperability and some thought on reusability. There are thus many factors involved, such as the type of data in question (How easy is it to standardise? Are there any legal challenges such as GDPR, copyright, or IPR issues?), the degree of organisation and international cooperation a community represents (Are there any community governance structures? Is there a forum where such things can be discussed and decided?), the financial resources of the community (Does the community routinely practice international collaboration? Who will pay for any necessary infrastructure? Who will lead and sustain these efforts?), etc. The availability of standards, methodologies and infrastructure for FAIR data in a given community will depend on all of these, as well as on the hard work of community members to develop these.

As a result, the divides between more and less advanced groups do not strictly follow discipline boundaries, but they also exist inside disciplines and subdisciplines, depending

105 TU Delft survey 2019, https://openworking.wordpress.com/2019/12/02/research-data-management- survey-2019-the-results-are-here/; State of Open Data Report, 2018, https://doi.org/10.6084/m9.figshare.7195058.v2

106 https://www.mitpressjournals.org/doi/full/10.1162/dint_a_00049

on types of data collected, country or region where a researcher is based, or even age groups among researchers. In the end these different factors boil down to whether there is genuine demand for FAIR practices and whether the effort required to achieve them is reasonable; if yes, then a culture that embraces those practices may develop. But if a community lacks strong internal motivation, then often the barriers to FAIR data are considered too high and no cultural change will occur.

6.2. Top-down approaches need to take into account community needs

As mentioned above, expectations regarding FAIR practices are based on the experiences of communities which have successfully embraced the FAIR principles. Funders and policymakers tend to take these experiences and then transform them into expectations and solutions applicable to all research communities. At this point, the bottom-up success stories are transformed into top-down endeavours which have drastically lower success rates. For communities that are not familiar with FAIR, such demands increase the feeling of alienation, in particular if these communities/groups haven't yet found their innate demand for FAIR data. Tools that are recommended for use are often developed to different needs in different communities and may feel unfamiliar in different fields and their use inconsequential. In addition, if there is no internal awareness on what data should be FAIR, demands might be interpreted so that everything should be made FAIR, which is both a daunting and likely impossible (if not undesirable) task to begin with. When faced with demands from research funders and policymakers, some might adopt these principles and demands, but only superficially, and, without proper support, they might end up publishing data that is not FAIR.[107]

The change of direction from bottom-up to top-down also has other implications. When systems have been built from the bottom-up, they have evolved naturally, building up infrastructure, services and expertise that are truly necessary for the successful implementation of FAIR practices in the particular community. When applied from top-down, these communities might only have the most general level of support from general data experts, if any support is available at all, and not from field-specific data stewards that are essential for successful implementation of FAIR and take-up by researchers [**Recommendation 1**]. If the group as a whole doesn't yet have a shared understanding for issues related to FAIR, it direly needs specialists who have such an understanding and can support the rest of its members on their specific field of research.

It is a natural conclusion that we cannot simply wait for all the disciplines and groups to find FAIR on their own. While translating bottom-up experiences and success stories into top-down policies and expectations is necessary, it is essential that such policies and expectations truly reflect community needs and practices in order to be successfully implemented. They also need to take into account what made bottom-up success possible and why the top-down approach faces difficulties. Here policymakers and especially research funders and institutions are seen as crucial contributors to change as their demands have the power to influence how researchers behave.108 But in driving these changes it is recommended that funders and research institutions take into consideration how much work has to be done on grassroot level to engage those researchers who are not yet familiar with FAIR and that they enable allocation of time and resources for implementing them - especially for early career researchers whose position and funding are often volatile. **[Recommendation 1-2]**. To succeed, the audience as a whole has to be understood and serviced **[Recommendation 1-3]**. Researchers have to be incentivised **[Recommendation 3-5]** in such a way that they would not feel their careers endangered by the investment of time and resources into making data FAIR (this is particularly relevant

107 https://datascience.codata.org/articles/10.5334/dsj-2017-016/

108 State of Open Data Report, 2019. https://doi.org/10.6084/m9.figshare.9980783.v1

to Early Career Researchers). It means investing also in research support services and raising awareness of their pivotal role, not only giving demands and recommendations **[Recommendation 1, 6]**. It is also crucial to always bear in mind that FAIR is not binary: FAIR/unFAIR, but a wide spectrum. If we expect to project practices from well developed communities and success stories suddenly on everybody, many will be overwhelmed as they have not had time to follow the long path towards it. It is a path where every step is valuable and every step needs support, services and training **[Recommendation 1-3]**.

7. RECOMMENDATIONS FOR IMPROVING FAIR PRACTICES

In order to ensure widespread benefits of the EOSC, improvements in FAIR practices are necessary. The first essential step to achieve this is for the communities to develop a shared understanding of their internal needs for FAIR practices. Shared understanding could in turn motivate the development of agreed methodologies, standards, tools, policies and infrastructures. FAIR data is a goal that cannot be achieved in one leap. Rather, it is a journey and each step, even a small one, is essential and valuable.

Therefore, to facilitate widespread adoption of FAIR practices, all these steps need to be incentivised and we make the following six key recommendations:

Table 1. Overview of recommendations and stakeholder groups they apply to.

	EOSC	Research funders	Institutions	Policy-makers	Coordination fora	Standards bodies	Data service providers	Publishers
1. Fund awareness-raising, training, education and community-specific support	√	√	√					
2. Fund development, adoption and maintenance of community standards, tools and infrastructure	√	√			√	√	√	
3. Incentivise development of community governance	√	√			√			
4. Translate FAIR guidelines for other digital objects	√	√		√	√	√		
5. Reward and recognise improvements of FAIR practice	√	√	√	√				
6. Develop and monitor adequate policies for FAIR data and research objects	√	√	√	√				√

These recommendations are explained below, indicating the key stakeholder groups tasked with applying these recommendations, and providing a short rationale and practical examples.

Recommendation 1: Fund awareness-raising, training, education and community-specific support.

Stakeholders: EOSC, Research funders, Institutions
Rationale: Community-specific actions are needed because arguments and solutions which works for one community might not be the key drivers for another. Raising awareness is needed at all levels – from individual researchers through heads of institutions to policymakers – but in order to be meaningful it must be based on adequate, community-specific arguments. Awareness raising, training, education and providing dedicated community-specific support take time and effort and thus such actions need to be financially supported. Funding pilot projects might be a useful mechanism to facilitate this.
Example: An initial pilot at TU Delft to fund data stewards with disciplinary knowledge helped communities realise the importance of FAIR practices, foster best practices and prompted them to appoint their data stewards as

permanent member of staff[109]. Funding similar pilots could help other communities see the value of FAIR practices and drive the internal need for improvement.

Recommendation 2: Fund development, adoption, and maintenance of community standards, tools and infrastructure.

Stakeholders: EOSC, Research funders, Coordination fora, Standards bodies, Data services providers

Rationale: It is difficult for communities to work without funds, on a best effort basis. The development of standards, methodologies and tools takes commitment and time[110]. However, this phase is essential for putting FAIR principles into practice. While it is important that community members actively contribute to standard development, leading such work requires dedicated resources. Funding of adoption efforts is also crucial, in order to avoid unnecessary over-proliferation of standards and to facilitate alignment and interoperability between various communities. Implementation of standards also requires appropriate methodologies, tools and infrastructure (e.g. databases, repositories), tailored to community needs, and the development of these also needs to be funded. Standards, tools and infrastructure also have to be sustainably maintained and regularly revised to avoid depreciation, and this can only happen if communities see the value of such standardisation, are incentivised to do such work, and receive the necessary funding for this.

In addition, it is crucial that communities, especially those less experienced in FAIR practices, have access to people with expertise (for example, data stewards or ontology experts), who can help with development and adoption of standards and methodologies, provide best practice recommendations or case study example, and offer tailored training. Such efforts have to be appropriately and sustainably funded and research institutions should be encouraged to take long-term responsibility for the availability of such support roles.

Example: The Joint Programme on Wind Energy of the European Energy Research Alliance (EERA JPWind) received funding from the European Commission which allowed it to lead concentrated efforts which culminated in successful development of taxonomy and metadata for the wind energy sector[111].

Initiatives such as the Wellcome Trust's Open Research Fund[112], or the EOSC Co-Creation[113] provide, amongst others, financial support for activities which aims at improving FAIRness of community practices.

109 Cite: Plomp, Esther, Nicolas Dintzner, Marta Teperek, and Alastair Dunning. 2019. "Cultural Obstacles to Research Data Management and Sharing at TU Delft". Insights 32 (1): 29. DOI: http://doi.org/10.1629/uksg.484

110 Those who successfully developed standards often cite years to ensure sufficient community consultation and co-development

111 Sempreviva Anna Maria, Vesth Allan, Bak Christian, Verelst David Robert, Giebel Gregor, Danielsen Hilmar Kjartansson, … Hermans Koen W. (2017, December 12). Taxonomy and metadata for wind energy Research & Development. Zenodo. http://doi.org/10.5281/zenodo.1199489

112 Sempreviva Anna Maria, Vesth Allan, Bak Christian, Verelst David Robert, Giebel Gregor, Danielsen Hilmar Kjartansson, … Hermans Koen W. (2017, December 12). Taxonomy and metadata for wind energy Research & Development. Zenodo. http://doi.org/10.5281/zenodo.1199489

113 EOSC Co-Creation fund: https://www.eoscsecretariat.eu/funding-opportunities/co-creation-requests

Research Data Alliance (RDA)[114] is an example of an overarching coordination forum which plays an important role by offering a framework for communities who wish to work together, outputs to support standards development (e.g. FAIRsharing[115], which is a curated resource on data and metadata standards), or providing recommendations on best practices from various communities[116].

Recommendation 3: Incentivise development of community governance.

Stakeholders: EOSC, Research funders, Coordination fora
Rationale: Standards need to be developed by/with the community for them to be accepted and successfully implemented. For this to happen, clear community governance is essential to determine responsibilities and oversight of the different processes and to ensure a structured way of communicating feedback. Such efforts should be incentivised financially (e.g. the costs and time required to organise community consultation.
Example: Astronomy is a discipline with strong community governance. The standard data format for astronomy has been developed in 1981 and maintained by the International Astronomical Union[117]. The International Virtual Observatory Alliance (IVOA) develops and maintains the technical interoperability standards for astronomy. The IVOA does not have any formal funding, but benefits from in-kind contributions of community members[118], which highlights the importance of advocacy and bottom-up level buy-in for such initiatives to be sustainable. The wheat research community is an example of a community which used the framework offered by the Research Data Alliance and created a dedicated Wheat Data Interoperability Working Group to facilitate development of best practices standards in a structured manner (clear leadership of the group, clear ways of working and of providing community input, clear timelines and goals)[119]. The agriculture community set up an Interest group at the early stages of the RDA which coordinates the discussion on future developments and Working Groups and liaises with disciplinary international organisations such as the Food and Agriculture Organisation of the United Nations (FAO)[120] and Global Open Data for Agriculture and Nutrition (GODAN)[121].

114 https://www.rd-alliance.org/

115 https://fairsharing.org/

116 https://www.rd-alliance.org/recommendations-and-outputs/all-recommendations-and-outputs

117 https://fits.gsfc.nasa.gov/

118 Genova, F., Arviset, C., Almas, B.M., Bartolo, L., Broeder, D., Law, E. and McMahon, B., 2017. Building a Disciplinary, World-Wide Data Infrastructure. Data Science Journal, 16, p.16. DOI: http://doi.org/10.5334/dsj-2017-016

119 Dzale Yeumo E, Alaux M, Arnaud E et al. Developing data interoperability using standards: A wheat community use case [version 2; peer review: 2 approved]. F1000Research 2017, 6:1843 (https://doi.org/10.12688/f1000research.12234.2)

120 Food and Agriculture Organization of the United Nations: http://www.fao.org/home/en/

121 Global Open Data for Agriculture and Nutrition: https://www.godan.info/

Recommendation 4: Translate FAIR guidelines for other digital objects.

Stakeholders: EOSC, Research funders, Policymakers, Standards bodies
Rationale: Applying FAIR principles to the context of specific communities requires adoption/translation. This need is more obvious in case of other (non-data) digital research objects where direct mapping of the FAIR guiding principles may not be appropriate. The importance of each principle may defend on the priorities and maturity of the community in their use of certain research objects. This translation will need to be agreed in appropriate community fora, and such efforts should be incentivised financially (e.g. the costs and time required to organise community consultations).
Example: As part of the AGU's 'Make Data Fair' project[122] to enable FAIR Data across the earth and space sciences, town hall meetings[123] and panels[124,125] have addressed the challenges of making other research objects FAIR, including software, samples and workflows. This is beginning to lead to community-specific guidance around metadata and citation practices to improve software and services findability, accessibility and reusability[126].

Recommendation 5: Reward and recognise improvements of FAIR practice.

Stakeholders: EOSC, Research funders, Policymakers, Institutions
Rationale: Efforts aiming at improvement of community FAIR practices are usually time-consuming and require a lot of dedication. Nevertheless, such efforts tend to be unnoticed in the current academic rewards system, unless linked to journal publications. To incentivise such work and to highlight its importance, it is essential that it is appropriately recognised and taken into account in evaluation, promotion and hiring criteria. This is shared responsibility that needs a concerted approach between institutions, Research funders and Policymakers at various levels. In addition, it is crucial that the needs of the most vulnerable communities, such as Early Career Researchers, are emphasised in the process. The EOSC should play a supporting role. This should go beyond merely recognising the time and efforts needed to make individual research outputs FAIR. Efforts aimed at greater community engagement, such as development of shared standards for FAIR practices and of the infrastructure, are crucial and need to be recognised as well. Furthermore, incentivising and rewarding FAIR practices should not be pursued in isolation, but rather be embedded in the broader discussion on responsible academic assessment and its role in improving the academic culture by, among other things, making room for the transition to Open Science, strengthening research ethics and integrity, and promoting a broad range of academic activities that goes well beyond the current focus on journal publications.

122 Enabling FAIR Data project: https://osf.io/jy4d9/

123 Data Fair: Sharing Your Software — What Is FAIR?: https://agu.confex.com/agu/fm18/meetingapp.cgi/Session/56228

124 How Safe and Persistent Is Your Research? https://agu.confex.com/agu/fm17/meetingapp.cgi/Session/25700

125 FAIR Data Is Not Enough: Communicating Data Quality and Making Analytical Code FAIR I: https://agu.confex.com/agu/fm18/meetingapp.cgi/Session/60523

126 Hausman, J., Stall, S., Gallagher, J., & Mingfang Wu. (2019). Software and Services Citation Guidelines and Examples. Figshare. https://doi.org/10.6084/M9.FIGSHARE.7640426

Example: There are multiple efforts undertaken by Research funders, Policymakers and Institutions towards better rewarding and recognising researchers for making individual research outputs more FAIR. The final report of the Open Science Policy Platform[127] offers a comprehensive set of recommendations for various stakeholder groups, reflecting the broader discussion on responsible academic assessment of which it is part. The Open Research Funders group developed the Incentivization Blueprint[128] which provides concrete recommendations with a template specifically for research funders.
FAIRsharing is a resource which gathers community standards and credits record maintainers. However, we were not able to identify concrete examples where efforts aiming at improving FAIRness of community practices (thus, at a higher level than just making individual outputs FAIR) were explicitly mentioned in academic rewards and recognition policies. Interestingly, recommendations that such activities should be rewarded have been already articulated in Turning FAIR into Reality Report (Rec. 4, Action 4.1 and Rec. 6 Action 6.2) published in November 2018[129], suggesting that implementation of these recommendations did not happen and should be prioritised.

Recommendation 6: Develop and monitor adequate policies for FAIR data and research objects.

Stakeholders: EOSC, Research funders, Policymakers, Publishers

Rationale: Policies can be important drivers for FAIR data[130] and other research objects (software, workflows, models, protocols, etc.). Therefore, it is essential that bottom-up, community-based efforts are coupled with top-down, policy-driven approaches. Policies should be developed collaboratively (ensuring that all relevant stakeholders are included[131]), they need to be explicit (e.g. clear roles and responsibilities, FAIR vs open data, purpose and effects of FAIR metrics[132]), aligned with each other, aligned with community practices and other relevant policies and regulations (e.g. research integrity). This applies to policies of research funders, publishers and institutions. Proper implementation, monitoring and suitable incentives are also essential for effectiveness of such policies. Implementation should be coordinated with institutional actors so that demand are not coming into effect without appropriate support and common understanding of means and goals.
Western European countries and Institutions have taken the lead in developing and implementing policies on FAIR. Therefor, dedicated efforts need to be focused on less advanced countries.
Example: Finnish policies are highly coherent which was achieved through coordination between the developments at a global level (OECD), European level (EOSC and the European Union), national level (Ministry of Education

127 "Progress on Open Science: Towards a Shared Research Knowledge System" - final report of the Open Science Policy Platform https://doi.org/10.2777/00139

128 Incentivization Blueprint: http://www.orfg.org/incentivization-blueprint

129 Turning FAIR Into Reality: https://ec.europa.eu/info/sites/info/files/turning_fair_into_reality_1.pdf

130 Science, Digital; Fane, Briony; Ayris, Paul; Hahnel, Mark; Hrynaszkiewicz, Iain; Baynes, Grace; et al. (2019): The State of Open Data Report 2019. Digital Science. Report. https://doi.org/10.6084/m9.figshare.9980783.v1

131 131 Stoy, Lennart, Saenen, Bregt, Davidson, Joy, Engelhardt, Claudia, & Gaillard, Vinciane. (2020). D7.1 FAIR in European Higher Education (Version Version v1.0_draft). Zenodo. https://doi.org/10.5281/zenodo.3629682

132 Ingrid Dillo, Marjan Grootveld, Simon Hodson, & Sara Pittonet Gaiarin. (2020). Second Report of the FAIRsFAIR Synchronisation Force (D5.5) (Version 1.0). Zenodo. https://doi.org/10.5281/zenodo.3953978

and Culture together with Academy of Finland) and community-level (where both researchers and institutions are present)[133]. National open science working groups[134] comment on policies and ensure that national policy recommendations are taken into account in institutional policies. As a result, the national policy[135] is developed by the community itself (through open science groups), but is at the same time in-line with national and international requirements and funders' demands.

The data policy of the Economic and Social Research Council (ESRC)[136] in the UK offers an example of a policy with consequences for non-compliance. It mentions that the ESRC has the right to apply sanctions, such as withholding the final payment of a grant, if data has not been archived within three months of the end of the grant.

We were not able to identify published examples of FAIR data policies being thoroughly and transparently monitored.

133 https://avointiede.fi/en/coordination

134 https://avointiede.fi/en/open-science-expert-panels/open-data

135 Declaration for Open Science and Research 2020–2025 https://doi.org/10.23847/isbn.9789525995251

136 ESRC Data Policy: https://esrc.ukri.org/files/about-us/policies-and-standards/esrc-research-data-policy/

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The FAIR Practice Task Force was set up as one of the four task forces of the EOSC Executive Board FAIR Working Group. Its goal was to support the Working Group with an oversight of FAIR practices: learning about the possibilities of future FAIR implementation from current experience.

This report analyses the state of FAIR practices within diverse research communities and FAIR-related policies in different countries and offers sic practical recommendations on how FAIR can be turned into practice.

In order to ensure widespread benefits of the EOSC, improvements in FAIR practices are necessary. This report could help the EOSC, research funders and policymakers make crucial strategic decisions about investment needed to put FAIR principles into practice.

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