Recommendations for Discipline-Specific FAIRness Evaluation Derived from Applying an Ensemble of Evaluation Tools

RESEARCH PAPER

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ubiquity press

ABSTRACT

From a research data repositories' perspective, offering research data management services in line with the FAIR principles is becoming increasingly important. However, there exists no globally established and trusted approach to evaluate FAIRness to date. Here, we apply five different available FAIRness evaluation approaches to selected data archived in the World Data Center for Climate (WDCC). Two approaches are purely automatic, two approaches are purely manual and one approach applies a hybrid method (manual and automatic combined).

The results of our evaluation show an overall mean FAIR score of WDCC-archived (meta) data of 0.67 of 1, with a range of 0.5 to 0.88. Manual approaches show higher scores than automated ones and the hybrid approach shows the highest score. Computed statistics indicate that the test approaches show an overall good agreement at the data collection level.

We find that while neither one of the five valuation approaches is fully fit-for-purpose to evaluate (discipline-specific) FAIRness, all have their individual strengths. Specifically, manual approaches capture contextual aspects of FAIRness relevant for reuse, whereas automated approaches focus on the strictly standardised aspects of machine actionability. Correspondingly, the hybrid method combines the advantages and eliminates the deficiencies of manual and automatic evaluation approaches.

Based on our results, we recommend future FAIRness evaluation tools to be based on a mature hybrid approach. Especially the design and adoption of the discipline-specific aspects of FAIRness will have to be conducted in concerted community efforts.

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KEYWORDS:

FAIR; FAIRness evaluation; climate science; long-term archive; data curation; reusability; WDCC

TO CITE THIS ARTICLE:

Peters-von Gehlen, K, Höck, H, Fast, A, Heydebreck, D, Lammert, A and Thiemann, H. 2022. Recommendations for Discipline-Specific FAIRness Evaluation Derived from Applying an Ensemble of Evaluation Tools. *Data Science Journal*, 21: 7, pp. 1–21. DOI: *https://doi.org/10.5334/dsj-2022-007*

2.4 ACHIEVING COMPARABILITY AMONG EVALUATION APPROACHES

The applied FAIRness evaluation tools all show a different number of maturity indicators, which are also differently distributed along the FAIR dimensions. In order to achieve comparability between the assessment approaches, we took a pragmatic approach and simply averaged the results over all maturity indicator tests per approach. We do so, because this approach is automatically applied for the two automatic assessment approaches (F-UJI and FMES). Where necessary, we normalised the results to yield a FAIR-score in the range between 0 and 1, indicating a low- or high-level of FAIRness, respectively.

We acknowledge the fact that this way of comparing the results of different FAIRness evaluation tools somewhat distorts the results, because the results per FAIR dimension are not equally weighted. However, we argue here that our study has the main focus of raising awareness for available FAIRness evaluation tools and highlighting the intricacies associated with applying them. In the end, the results of most tests compare well at the AIC-level (see next section).

3 RESULTS

3.1 MEAN SCORES OF FAIR ASSESSMENTS

We show the calculated scores obtained from the five FAIRness evaluation tools along with some general statistics in ***Table 4***. The calculated level of FAIRness strongly depends on the assessment method and the evaluated AIC. Overall, we obtain an ensemble mean FAIR score for the WDCC of 0.67, with individual results per applied FAIRness evaluation tool ranging from 0.5 to 0.88. The calculation of the mean FAIR score does not account for any weighting by data volume per AIC. Scores are mostly higher for the manual or hybrid approaches compared to the automated ones. This is mostly because the automatic FAIRness evaluation tools include checks on the actual data, which require the evaluated data to be openly accessible by the evaluation tool. Since almost all WDCC-archived data are open and free for use by anyone, but only accessible after authentication, the automatic tests requiring data access fail by design. The manual evaluation tools however allow for an evaluation of WDCC-archived datasets, as these can be accessed through *human intervention* (wording taken from Bahim et al., 2020). Metadata must be prepared accordingly for automated tools, for example, in the JSON-LD, so that it can also be evaluated. We discuss further aspects behind the differences in FAIRness scores between the applied methods in Section 4.

At the AIC-level (column "⌀ per project" in ***Table 4***), the spread around the ensemble mean is slightly smaller, ranging from 0.43 to 0.76. AICs with DOI obtain the highest FAIR scores, with an AIC associated with the project CMIP6_RCM_forcing_MPI-ESM1-2, which has a DOI assigned and is comprised of data produced within the framework of the CMIP6 initiative (Eyring et al., 2016), scoring highest.

Consequently, AICs having no DOI assigned, such as MILLENIUM_COSMOS, score lower. The lowest score is determined for one of the CliSAP AICs (CliSAP, no DOI and no data accessible). While that AIC does provide ample metadata on the corresponding WDCC landing pages (cf. Supplement for details to find the tested AICs), the data is not accessible because the status of the AIC was never set to 'completely archived' by WDCC staff. The lack of data accessibility can in this case only be pinpointed using the manual and hybrid approaches – the automatic ones fail to recognise this major shortcoming and therefore cannot be used to capture the actual data curation status. While such curation levels are rather the exception than the rule for the WDCC, we deliberately chose to include an AIC with no accessible data in our evaluation to analyse the entire spectrum of WDCC data curation levels and for checking whether the automated tools recognise this.

Summarising this part of our results, we find that all FAIRness evaluation tools can be used to reliably distinguish between various degrees of (meta)data curation of AICs preserved in the WDCC and that for the most part, AICs preserved in the WDCC satisfy the majority of the FAIR maturity indicators addressed by the applied evaluation approaches.

3.2 AGREEMENT BETWEEN EVALUATION APPROACHES

Our ensemble approach to FAIRness evaluation also offers the unique opportunity to analyse the consistency between the assessment approaches at the AIC-level. To illustrate this, we

automated test yield failed tests. While this result is fully explainable (FMES and F-UJI check for dataset URLs which are deliberately not included in the JSON-LDs for security reasons), it does reveal a central shortcoming of the automated evaluation approaches and highlights the intricacies of exactly matching the syntax of machine-actionable content required to pass automated tests.

- In cases when data are actually not available, the information on the availability status of the data is only provided on the landing page and not as part of the machine-readable metadata. Therefore, the automated approaches evaluate these AICs exactly as the other tested WDCC-entries (data is not accessible, test failed), resulting in too high FAIRness scores.
- Contextual information is practically impossible to evaluate using automated approaches. As the main goal behind providing FAIR data is to foster their reuse, providing adequate references, documentation and provenance information is essential. The machine-readable qualifiers ('subjectOf') included in the JSON-LDs lead to associated publications or reports. Once such a reference is detected by an automated evaluation approach, the corresponding test is passed. However, the actual content of the linked reference cannot be checked – it could therefore be completely irrelevant in the context of the evaluated (meta)data. In the context of this study, the AIC HDCP2-OBS represents such a case.
- By virtue of their intended application, the automated evaluation approaches do not take any information provided on the human-readable landing pages into account. At the WDCC, these often contain ample information about the data, like dataset size and file format. These parameters are not included in the JSON-LD because schema.org-requirements are vaguely defined.

All of the above points pose no problem to manual or hybrid tools. However, including the 'human factor' in the evaluation process may lead to inconsistencies. A further limitation of manual FAIRness evaluation tools is the obvious inability to check for machine-actionability. Since this is an essential component of FAIR data, checking just for the human-readable aspects of preserved (meta)data is just as impeding as only checking for the machine-actionable aspects. Or put in other words, automated FAIRness evaluation tools check for the technical FAIRness – or reusability – whereas manual approaches (can) check for the contextual/scientific reusability.

A further point worth discussing is the comparability of the different test results. As outlined in Section 2.1, the five FAIRness evaluation tools do not cover the four FAIR dimensions in a comparable manner: FMES puts little focus on R (2 of 22), FAIRshake is dominated by R (5 of 9), F-UJI is dominated by F and R (together 17 of 24) and our own self-assessment following Bahim et al. (2020) puts equal emphasis on all FAIR dimensions and is far more comprehensive than the other approaches (45 tests, compared to 20, 22, 9 and 24 for CFU, FMES, FAIRshake and F-UJI, respectively). Since there exist no recommendations regarding the importance of individual FAIR dimensions – apart from F, which is seen as the single most important principle of the FAIR spectrum to enable data reuse (Mons et al., 2017) – and their weighting in an evaluation, we provide simple arithmetic means of the test results. Similar to the ensemble approach applied in simulation based climate science, where the ensemble mean over multiple models is usually a better representation of reality than the simulation of an individual model (Tebaldi & Knutti, 2007), we see an added-value in presenting the mean over all FAIRness evaluation tools as 'WDCC-FAIRness' (***Table 4***) as compared to relying on just a single test. Of course, once FAIRness evaluation becomes standardised and an operational requirement for repositories and archives in order to be regarded as trusted in science, basing a certification on the results of an ensemble of tests is impractical. We therefore hope that the results we present here help the community converge towards standardised, broadly applicable and officially recommended FAIRness evaluation tools.

4.3 LESSONS LEARNED

The process of applying five different FAIRness evaluation tools has helped us judge the WDCC preservation practice, critically reflect on our internal workflow, indicate avenues for improving the FAIRness of our (meta)data holdings and develop a sound understanding for domain-specific FAIRness in climate science.

- Machine actionability of archived data need not be the priority for data collections in the climate sciences. The size of datasets archived at WDCC is often $\mathcal{O}(10^2)$TB and more. It is simply not practical to include URLs pointing to the actual datasets in the machine readable metadata, as this may incur both security and bandwidth issues. The WDCC is currently implementing a PID-system at the dataset level to increase Findability.
- Some of the automated tests could have been passed, if the information given in the machine-actionable metadata would have been as comprehensive as that supplied on the landing pages of archived datasets. One example would be the specification of the file format. At the moment, we do not provide this information in the JSON-LD, because in some cases, the actual file format is NetCDF, a standard open file format of the climate science community, but the files are packed as .zip or .tar archives for download. Note however, that these issues are rather minor and do not reduce the FAIRness of WDCC data holdings per se – including them would merely increase the FAIR score of the automated evaluation approaches.
- Archiving of climate science related data in data collections characterised by a strict top-down hierarchy which do not have PIDs assigned to every data file is a main characteristic of the discipline-specific standard procedure to make these data available to the community. Evaluating a collection in its entity is essential to fully characterise its FAIRness.
- Reaching out to the developers of the evaluation tools was essential to apply the tools correctly, comprehend the test results and even discover bugs in the tools' source code. Close communication and collaboration between the tool developers and those wishing to apply them cannot be overrated and we wish to contribute further to their development and testing in the future.
- In the process of defining the sample of AICs to be tested, we discovered several ones in which the data is not available due to shortcomings in the WDCC archival workflow. We are at the moment sieving through the WDCC data holdings to find and amend these AICs and make the data associated with them available to the community.
- Applying the manual evaluation approaches is far less straight forward compared to the automated ones. Even if domain and repository experts perform the evaluation, the results may differ because subjectivity cannot be ruled out. One example would be a maturity indicator demanding the provision of dataset and provenance documentation. While supplying links to a third-party online database containing this information would suffice for one evaluator, this might not be the case for another one. Therefore, evaluation results obtained by one evaluator should always be reviewed. In this context, the list of FAIR maturity indicators compiled by Bahim et al. (2020) helps to reduce the risk of unconscious bias because it provides very specific guidance for testing.
- For some AICs, documentation is provided in terms of README files or reports which are archived along with the data. However, these files are hard to find if a user is not familiar with the WDCC and does not know where to look. WDCC-efforts to improve the user experience in this regard are underway by providing more clear access to associated documents and by working towards a community-acceptance of the EASYDAB (EArth SYstem DAta Branding, Ganske et al., 2021) concept which allows users to clearly identify high-quality archived datasets.

4.4 RECOMMENDATIONS FOR FUTURE FAIRNESS EVALUATION TOOLS

In the course of our analysis, it became apparent that none of the five applied FAIRness evaluation approaches was entirely fit-for-purpose to evaluate the WDCC data-holdings (cf. Section 4.2 and 4.3), but all of them have their individual strengths on which to build future FAIRness evaluation tools. We provide an overview table summarising our experiences from applying the five different FAIRNess evaluation approaches in ***Table 6***.

For future FAIRness evaluation tools, we recommend the development of capable hybrid approaches to capture both the technical and contextual reusability of preserved research data.

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