



HAL
open science

FAIREST: A Framework for Assessing Research Repositories

Mathieu d'Aquin, Fabian Kirstein, Daniela Oliveira, Sonja Schimmler,
Sebastian Urbanek

► **To cite this version:**

Mathieu d'Aquin, Fabian Kirstein, Daniela Oliveira, Sonja Schimmler, Sebastian Urbanek. FAIREST: A Framework for Assessing Research Repositories. *Journal of Data Intelligence*, In press, 5 (1), pp.202-241. 10.1162/dint_a_00159 . hal-03921682

HAL Id: hal-03921682

<https://inria.hal.science/hal-03921682v1>

Submitted on 4 Jan 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

FAIREST: A Framework for Assessing Research Repositories

Mathieu d'Aquin¹ Fabian Kirstein² Daniela Oliveira³
Sonja Schimmler² Sebastian Urbanek²

¹ LORIA, Université de Lorraine, CNRS, INRIA
54506, Vandœuvre-lès-Nancy, France
`mathieu.daquin@loria.fr`

²Fraunhofer FOKUS and Weizenbaum Institute for the Networked Society
10623 Berlin, Germany
`firstname.lastname@fokus.fraunhofer.de`

³LaSIGE, Faculdade de Ciências, Universidade de Lisboa
1749-016 Lisboa, Portugal
`dpoliveira@fc.ul.pt`

Abstract

The open science movement has gained significant momentum within the last few years. This comes along with the need to store and share research artefacts, such as publications and research data. For this purpose, research repositories need to be established. A variety of solutions exist for implementing such repositories, covering diverse features, ranging from custom depositing workflows to social media-like functions.

In this article, we introduce the FAIREST principles, a framework inspired by the well-known FAIR principles, but designed to provide a set of metrics for assessing and selecting solutions for creating digital repositories for research artefacts. The goal is to support decision makers in choosing such a solution when planning for a repository, especially at an institutional level. The metrics included are therefore based on two pillars: (1) an analysis of established features and functionalities, drawn from existing dedicated, general purpose and commonly used solutions, and (2) a literature review on general requirements

27 for digital repositories for research artefacts and related systems. We further describe an
28 assessment of 11 widespread solutions, with the goal to provide an overview of the current
29 landscape of research data repository solutions, identifying gaps and research challenges
30 to be addressed.

31 **Keywords:** research repositories, FAIR principles, open access, research data

32 1 Introduction

33 The transparency of the research process and the accessibility of its outputs are core concerns
34 for the open science movement, specifically as it seeks to ensure the reproducibility of research.
35 The European Open Science Cloud (EOSC)¹ and, globally, funders' increasing requirements for
36 open access to publications and research data² exemplify this change.

37 Consequently, there is a need to help institutions in their effort to provide support for re-
38 searchers to deposit, store and make available research artefacts, including not only publications
39 but also data and other resources [1]. In particular, we consider here support in the form of
40 software solutions for research repositories, defined as systems enabling researchers to register
41 and access such research artefacts.

42 There exists a multitude of solutions, software or services, that can contribute to this need for
43 research repositories. Here, we specifically focus on solutions enabling the creation of general-
44 purpose repositories where research artefacts (publications, data, or other) can be deposited,
45 made accessible and reused independently from the research domain. However, in contrast with
46 the pressing need for clear information regarding the advantages and disadvantages of those
47 different solutions, we could not find a systematic overview that discusses their features and
48 the aspects that would enable research performing organisations to select the most appropriate
49 solution.

50 In this article, our aim is to provide such an overview, supporting decision makers who are in
51 the process of establishing a research repository, and developers who are extending and enhanc-
52 ing the underlying solutions. To achieve that, we establish an assessment framework inspired
53 by the FAIR principles [2]. In order to support a broad range of technical prerequisites, our

¹<https://www.eosc.eu/>

²See for example https://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-data-management/open-access_en.htm

54 selection is independent of the deployment mechanism. Therefore, we include on-premise/self-
55 hosted solutions as well as online services in our selection.

56 The FAIR principles of findability, accessibility, interoperability and reusability for data
57 publication and release are widely accepted as core to enabling transparent research. Therefore,
58 these principles form a good starting point for a structured comparison of existing solutions.
59 However, in order to create a framework comparing solutions for research repositories, a specific
60 set of principles, inspired and redesigned from FAIR, need to be considered: First, we need to
61 reconsider them so to be appropriate for assessing software and service solutions in relation
62 not only to research data, as well as to include aspects of human interactions and the social
63 context in which research artefacts are created and shared.³ Second, they need to be adapted
64 to the assessment of software and services making such artefacts available especially through a
65 set of concrete metrics attached to each of the principles, enabling a structured assessment of
66 how specific solutions (i.e. research data platforms) contribute to the practical achievement of
67 those.

68 We therefore adapted the FAIR principles and added three additional principles that relate
69 to the way the solutions should enable engagement, social connections and trust, forming the
70 FAIREST principles. Engagement encompasses usability aspects and interaction mechanisms
71 provided. Social connections spans the social context of research artefacts and social connec-
72 tions of researchers. Trust focuses on the reliability of the solution and of the artefacts included.
73 In this article, we define a set of metrics to assess specific solutions with respect to the way the
74 features they provide enable each of the FAIREST principles.

75 As a way of validation and illustration, but also to provide an overview of the current field,
76 we also performed an assessment of 11 general-purpose solutions, as described below.

77 We conducted our research in 6 steps in order to cover a broad variety of sources, receive
78 iterative feedback, and sharpen our findings:

79 1. First, we conducted a literature review to explore existing research on research repositories
80 and related topics. We put a focus on comparative articles, solution overviews, and
81 evaluation frameworks. The result is presented in Section 2.

82 2. Based on and inspired by these findings we derived a framework for evaluating and com-

³The need to include such social features in research repositories has been identified for example in [3].

83 paring features and functionalities of research repositories. The framework consists of
84 a structured set of metrics and corresponding assessment criteria, inspired by, adapting
85 and adding to the FAIR principles, as presented in Section 3 about the details of the
86 FAIREST principles.

- 87 3. We applied our framework on a selection of 11 popular solutions for research repositories
88 (see Section 4 for an overview of the solutions), covering both online and on-premise
89 solutions. Those solutions were selected on the basis of being general (i.e. not dedicated
90 to a specific research domain) and active (i.e. currently significantly used by various
91 organisations). We used official documentations, online sources, concrete installations,
92 source code and other literature as basis for the assessment of individual systems.
- 93 4. In order to validate our preliminary findings, we requested direct feedback from the de-
94 velopers and/or operators of each solution. Although we did not receive responses for
95 all the solutions, this step helped refining some of the assessments and ensured that the
96 proposed framework could be meaningfully understood and applied outside the co-author
97 group.
- 98 5. We finalised our assessments by incorporating the responses and reviews, thus concluding
99 with valid and approved statements. Section 4 includes a comprehensive overview of the
100 results and presents selected highlights.
- 101 6. Finally, as presented in Section 5, we analysed our assessments to identify common gaps
102 and recommendations for future developments and enhancements in the domain of re-
103 search repositories. We conclude our work in Section 6.

104 **2 Related Work**

105 This article focuses on research repositories, their purpose and characteristics and practical im-
106 plementations. The review in this section relies on the definition of digital research repositories
107 encompassing any repository to store research publications (articles), research data, and other
108 digital artefacts produced during research processes. It also spans other related systems such
109 as academic social networks and social bookmarking systems. This definition will be narrowed

110 down later, when it comes to assessing specific research repository solutions, to focus only on
111 generic, domain-independent and widely used systems.

112

113 **2.1 Reviewing research repositories**

114 Thanks to the growing popularity of research repositories, some research exists that aims to
115 classify and assess solutions for building research repositories.

116 Nicholas et al. [4] categorise repositories into institutional, subject and format repositories.
117 Institutional repositories store research artefacts generated by an academic institution. Subject
118 repositories specialise in a specific domain, such as computer science. Format repositories store
119 outputs of a particular type such as electronic theses.

120 Amorim et al. [5] further introduce a deployment classification as an important aspect,
121 distinguishing between installation packages (on-premise) and services (online).

122 Besides digital research repositories, other solutions gathered attention in the past, too.
123 This includes preprint servers, such as arXiv⁴, which aim to make publications available as
124 early as possible. Furthermore, this also comprises academic social networks [6], including
125 ResearchGate⁵ and Academia.edu⁶, whose main purpose is to connect researchers. Finally,
126 there are also social bookmarking systems [7] such as Bibsonomy⁷, whose aim is to share and
127 link to scientific publications.

128 These systems mainly target preservation and access within the lifecycle of research arte-
129 facts. However, there are other systems targeting other phases of the research process. One
130 of them is the Open Science Framework (OSF)⁸, a generic tool that spans the whole research
131 data lifecycle.

132 In terms of uptake, the number of research repositories has been steadily growing over the
133 years. Due to the variety and fragmentation of existing systems, exact numbers can only be
134 estimated by looking into topic- or system-specific repository listings [8].

135 OpenDOAR⁹, a curated directory of open access repositories, reported 78 open repositories

⁴<https://arxiv.org>

⁵<https://www.researchgate.net>

⁶<https://www.academia.edu>

⁷<https://www.bibsonomy.org>

⁸<https://osf.io>

⁹<https://v2.sherpa.ac.uk/opensoar>

136 in 2005 and, as of May 2021, includes 5,663 repositories. Among these repositories, Dataverse is
137 the most popular solution with an adoption by 39% of the repositories in OpenDOAR, followed
138 by EPrints (11%), and WEKO (9%). Approximately 76% of these repositories host written
139 research outputs such as articles, reports, and book chapters, and the remaining 24% include
140 other research outputs such as bibliographic references, software, and more. Data is the main
141 focus of only $\approx 2.3\%$ of the repositories.

142 re3data¹⁰ is another registry of research repositories, focusing on data depositing platforms.
143 As of May 2021, it indexes 2,686 research data repositories, where $\approx 80\%$ use unknown or
144 “other” as their underlying software. The majority of the remaining repositories use Dataverse¹¹
145 ($\approx 23\%$), followed by DSpace¹² ($\approx 21\%$), MySQL¹³ and CKAN¹⁴. Most of the research artefacts
146 published in these repositories are in scientific and statistical data formats, followed by textual
147 formats, images, and then raw data [9].

148 Deeper insights can be gained from several surveys and comparisons of research repositories,
149 which target generic repositories, and which mainly focus on the FAIR principles (see Section 2.2
150 below on FAIR and other principles). Some representative examples will be described in the
151 following.

152 Andro et al. [10] examined a mix of 10 open and proprietary software solutions, including
153 ePrints, Invenio¹⁵, and DSpace. The authors devised a questionnaire of 160 questions divided in
154 6 categories, spanning document management, metadata, engine, interoperability, user manage-
155 ment, and Web 2.0. The main conclusion of this survey is that the criteria to choose a solution
156 depends on the types of documents to be uploaded (contemporary or old), on the licensing of
157 the software (open or proprietary), or on any other aspect of the 160 questions of the survey.
158 The design of the questions follows a similar methodology to our approach. However, since the
159 survey is close to 10 years old, an update to current needs and developments is required.

160 Amorim et al. [5] created a compact comparison of six established repository solutions,
161 namely DSpace, CKAN, figshare¹⁶, Zenodo¹⁷, ePrints¹⁸, and the services of EUDAT (B2DROP,

¹⁰<https://www.re3data.org>

¹¹<https://dataverse.org>

¹²<http://dspace.org>

¹³<https://www.mysql.com>

¹⁴<https://ckan.org>

¹⁵<https://inveniosoftware.org/>

¹⁶<https://figshare.com>

¹⁷<https://zenodo.org>

¹⁸<https://www.eprints.org>

162 B2SAFE, B2SHARE), regarding architectural and metadata characteristics. The authors de-
163 rive key advantages for each solution and conclude that an extensive requirement analysis is
164 indispensable.

165 Assante et al. [11] focused on analysing five scientific data repositories, namely 3TU.Datacentrum¹⁹,
166 CSIRO DAP²⁰, Dryad²¹, figshare, and Zenodo. Their analysis focused on formatting, document-
167 ing, licensing, publication costs, validation, availability, discoverability and access, and citation.
168 The authors present a thorough discussion of shortcomings and prospects for the future at the
169 time of publishing.

170 Austin et al. [12] assessed 32 online data platforms, including CKAN, Dataverse, figshare,
171 and Zenodo. Their survey covered the categories hardware and infrastructure, description,
172 preservation, privacy and security, archiving, submission, accessing and sharing, collaboration,
173 policy, administration, tabular data, and certification status.

174 Further surveys and comparisons of research repository solutions can be found in [12, 13,
175 14, 15]. Most of these overlap in the metrics and features used in their assessments. We
176 conclude that there is a growing need for standard principles to assess research repositories
177 against different requirements of repository managers in an organised way, which incorporates
178 the metrics and features mentioned in the related work.

179 Besides these evaluations, several publications specifically analyse the usability of research
180 repositories. Joo et al. [16] propose a method to evaluate the usability of digital libraries.
181 Their method is based on the ISO 9241-11 standard, spanning efficiency, effectiveness, and
182 satisfaction, extended with learnability as inspired by Nielsen’s usability model [17].

183 Machova et al. [18] conducted a usability evaluation of governmental data portals and pro-
184 vided a list of best practices for improving the ability to discover, access, and reuse these online
185 information sources.

186 2.2 Principles guiding research repositories

187 As already mentioned, a widely recognised and endorsed concept regarding the publication of
188 research data and metadata are the FAIR principles. These principles were originally intro-

¹⁹<http://datacentrum.3tu.nl/>

²⁰<https://data.csiro.au/>

²¹<https://datadryad.org/>

189 duced in 2016 by Wilkinson et al. [2] to improve the feasibility of reusing scholarly data by
190 both machines and humans. The four high-level principles are: Findability, Accessibility, In-
191 teroperability, and Reusability, where each principle is refined into three to four sub-guidelines.
192 For instance data and/or metadata needs to be assigned a unique and persistent identifier and
193 a standard protocol is to be used for accessing the data. It is important to note that the FAIR
194 principles are only universal guidelines and do not define practical implementations and techno-
195 logical decisions. In practice, this can cause inconsistent implementations and interoperability
196 issues [19]. However, the principles have been widely adopted as guidance for data publishing
197 and substantiated in various forms.

198 In addition, the scope of FAIR has been expanded beyond mere research data, e.g. to-
199 wards research software [20, 21]. A 2017 analysis of the repositories indexed by re3data [9]
200 recommends that, since several repositories started to operate before the publication of the
201 FAIR principles, managers of these repositories look at these principles and update features
202 and policies accordingly.

203 The FAIRsFAIR Horizon 2020 project²² addresses the development of procedures, stan-
204 dards, and metrics based on the FAIR principles. Recently, the project team proposed a series
205 of metrics to assess the extent of the FAIRness of a research artefact [22]. However, these
206 metrics focus on adapting the principles to general research objects and are supposed to work
207 in conjunction with the CoreTrustSeal principles. The authors mention two use cases that align
208 with the CoreTrustSeal stakeholders: Using these modified principles for self-assessment and
209 for guiding development. However, they still fail to provide a framework to categorise platforms
210 as a way to facilitate their selection by institutions.

211 The Research Data Alliance (RDA)²³ is a research community organization whose mission
212 is to build the social and technical bridges to enable open sharing of data. It’s working groups
213 and publications are of high relevance for our paper. One highlight is a paper of the FAIR
214 Data Maturity Model Working Group [23], which describes their FAIR data maturity model,
215 spanning a broad set of indicators to assess “FAIRness” of concrete research data. These
216 indicators form a profound consolidation of the FAIR principles, still leaving a lot of space for
217 interpretation.

²²<https://www.fairsfair.eu/>

²³<https://www.rd-alliance.org>

218 The European Open Science Cloud (EOSC) (EOSC)¹ is an initiative of the European Com-
219 mission aiming at developing an infrastructure providing its users with services promoting open
220 science practices. It’s services, task forces and publications are also of high relevance for our pa-
221 per. One highlight is a paper of the European Commission Expert Group [24], which describes
222 the broad range of changes required to “turn FAIR data into reality”. This especially includes
223 the establishment of FAIR ecosystems, covering policies, data management plans, identifiers,
224 standards and repositories.

225 Several stakeholders of the digital repository community developed the TRUST Princi-
226 ples [25]: Transparency, Responsibility, User Focus, Sustainability, and Technology. These
227 principles guide the development and maintenance of digital repositories that are sustainable,
228 reliable, and support comprehensive policies based on community practices. These principles
229 have a strong focus on providing a reliable service for users.

230 In parallel with these principles, the CoreTrustSeal²⁴ is a community-based non-profit or-
231 ganisation that promotes the trustworthiness of research repositories after a platform fulfils a
232 series of requirements regarding transparency, integrity, security, and privacy of the data. These
233 requirements are grouped in three categories: organizational infrastructure (6 requirements),
234 digital object management (8 requirements) and technology (2 requirements). Applicants use
235 these requirements to perform a self-assessment of their platform that must be accompanied
236 by evidence of compliance with each requirement. The application is then peer-reviewed before
237 being awarded a level of certification. The CoreTrustSeal certification is intended as a first step
238 for the creation of a global framework for repository certification that increases transparency,
239 therefore, building stakeholder confidence by demonstrating, with evidence, that a repository
240 follows good practices. However, the uptake of the certificate is very low²⁵ and repository
241 providers need to pay an administration fee to be certified.

242 Several stakeholders of the digital repository community also came up recently with the
243 CARE principles for indigenous data [26]: collective benefit, authority to control, responsibility,
244 and ethics. The principles are meant to complement the FAIR principles, considering both
245 people and purpose in their advocacy and pursuits.

246 In summary, research repositories have been under a lot of scrutiny in the last decade with

²⁴<https://www.coretrustseal.org/>

²⁵Out of the 172 repositories listed on the CoreTrustSeal website, less than 20 have an active certification at the time of writing.

247 multiple attempts to categorise and compare them. The FAIR principles provide a basis to
248 formalise and standardise such assessments, but they need to be extended, especially with
249 respect to engagement, the social context of research, and the trustability of solutions and
250 artefacts. For this reason, we propose below the FAIREST principles that extend FAIR in this
251 direction, and a set of clearly defined metrics, the FAIREST framework, to assess how much a
252 given solution enables the realisation of each principle.

253 **3 The FAIREST Principles**

254 As described in Section 2.2, the FAIR principles aim to ensure that, from a technical point of
255 view, research data and metadata is “optimised for reuse”²⁶. In other words, those principles
256 are seen as requirements in the way research data and its metadata must be represented and
257 made available formally. Our aim here is to assess solutions that make available such data,
258 the publications emanating from research, and possibly other kinds of research artefacts. For
259 this purpose, we first extended the FAIR principles to add engagement, social connections, and
260 trust. Engagement and social connections are inspired by functionalities subsumed as Web 2.0,
261 Science 2.0, or Library 2.0 in the literature [27, 28], and by functionalities specifically provided
262 by academic social networks [29] and academic bookmarking systems [7]. Trust is based on the
263 TRUST principles mentioned in the previous section (2.2).

264 Those additional principles aim to address the human point of view of research repositories,
265 including how to interact with them, how they account for the social context in which research
266 is carried out, and the important aspect of the trustability of both the system itself and the
267 artefacts it includes. Of course, the principles in themselves are not sufficient. Therefore,
268 we additionally identified a set of metrics through which each solution can be assessed with
269 respect to the way they enable each of the FAIREST principles. These measurable properties
270 were identified, as described in the introduction of this article, through inspecting the literature
271 and existing systems, as well as through interacting with the research repository development
272 community. They constitute the foundation for determining comparable characteristics for
273 individual research repository solutions. They are described, together with the principles to
274 which they relate, in the remainder of this section.

²⁶<https://www.go-fair.org/fair-principles/>

275 **3.1 Findability**

276 In the objective of optimising data for reuse, the first principle borrowed from FAIR is that data
277 first needs to be findable. Findability is seen here in a broad sense, which includes the notions
278 of data discovery as well as mechanisms that can enable both human users and machines to
279 search for data according to specific needs and criteria. Indeed, as in FAIR, the definition of
280 this principle starts with the idea that, to be findable, research artefacts should be clearly and
281 globally identifiable, and that an identifier should be provided with a mechanism to locate and
282 access the artefact’s description or content. Going a step further in the direction of engagement,
283 we consider here also the search functions research repositories can include, which might apply
284 to different aspects of research artefacts and which can enable more or less precise queries.

285 Table 1 shows the metrics to assess how much a research repository enables findability for
286 the research artefacts it contains. In accordance with the requirements described above, the
287 first metric relates to whether the repository automatically assigns a persistent identifier for all
288 artefacts it contains (FCS1). This metric is assessed as “yes” (y) if the system automatically
289 creates a stable, persistent way to address a research artefact it contains, and as “no“ (n) if
290 not. FCS4 adds to this, as another binary yes/no metric, the idea that those identifiers can be
291 dereferenceable, i.e. that using this identifier as a web link will point the user to the location of
292 the artefact in the system. In order to ensure that those identifiers are universally comprehen-
293 sible and interpretable, some repositories can generate DOIs²⁷ (Digital Object Identifiers [30])
294 or other handles, as assessed by FCS2 (yes/no). Other kinds of external identifiers might also
295 be imported by the repository to support findability, as assessed by FCS3 (yes/no).

296 The metrics above are considered within the category of content support as they relate to
297 finding artefacts directly based on their identifiers. In the content access category, we also take
298 into consideration functions that allow users to find artefacts without knowing their identifiers.
299 The following three binary (i.e. yes/no) metrics look at different aspects of how repositories
300 might index and enable users to search for artefacts based on criteria relating to the description
301 (metadata) of artefacts (FCA1), to the content of artefacts (FCA2), and/or using advanced
302 filtering and ranking mechanisms (FCA3).

²⁷<https://doi.org>

Table 1: Findability metrics.

Type	Metric	ID	Values	Description
Content support	Persistent identifiers	FCS1	y/n	A system is assessed yes (y) if it automatically assigns a persistent identifier to a research artefact.
	Generates DOIs	FCS2	y/n	A system is assessed yes (y) if, in addition to a possible unique identifier local to the system, it also supports the generation of a DOI for a research artefact.
	External identifiers	FCS3	y/n	A system is assessed yes (y) if it allows the import of identifiers of the research artefact, external to itself.
	Dereferenceable identifiers	FCS4	y/n	A system is assessed yes (y) if it provides a unique identifier for research artefacts that is dereferenceable to the artefact's location in the system.
Content access	Indexes and searches metadata	FCA1	y/n	A system is assessed yes (y) if it enables search over the metadata of the research artefacts.
	Indexes and searches content	FCA2	y/n	A system is assessed yes (y) if it enables search over the content of the research artefact.
	Advanced search features	FCA3	y/n	A system is assessed yes (y) if it provides advanced search features.

3.2 Accessibility

One of the central aims of research repositories is to give access to research artefacts. Access thereby entails different actors and scopes, especially since users of the system are not only humans but also machines. For human users, access becomes easier through standardised language support. In order to enable access for machines, repositories must provide machine readable interfaces and protocols that apply domain standards. Besides accessibility for actors, repositories also need to consider the dimensions of time and availability and the degree of openness of research artefacts. Constant access to data, offered through a high availability of the service and reliable long-time preservation, are core aspects of open science, to enable new forms of research. Access control at first seems to be contradicting the open idea of research repositories. Nevertheless, many research artefacts are not meant to be open by default.

With regard to metrics for accessibility, Table 2 divides them into functionalities concerning content language and content availability. Language support (ACL1) is measured via a yes/no variable, assessing whether the functionality exists (or not). We also evaluate the availability of protocols and APIs (ACL2) for data exchange with a yes/no metric only, as we do not intend to evaluate the individual protocols. Long-term preservation (ACA1) relates to whether artefacts are processed to be available over a long period of time in the future. There are many ways to

320 achieve long-term preservation, so this aspect is also assessed through a yes/no value, indicating
 321 whether any mechanism exists to enable this feature. Availability (ACA2) is measured by high,
 322 medium, or low, depending on the up-time of the system being higher than 99.9%, between
 323 99.9% and 99%, or lower than 99%. This metrics is only assessed for online solutions as
 324 the availability of instances of on-premise solutions depends upon the characteristics of their
 325 deployment. The last variable, access control (ACA3), describes the possibility to restrict access
 326 to data. There are three different cases: “Closed access” means that the design of the system
 327 makes artefacts private by default or more straightforwardly. “Open” means the opposite, i.e.
 328 that the artefacts are, by default or in most cases, publicly accessible. When, in a system,
 329 the common case is for access to be enabled through a request to the provider, the value “on
 330 request” is used. The variable access control may simultaneously take on multiple values.

Table 2: Accessibility metrics.

Type	Metric	ID	Values	Description
Content language	Language support	ACL1	y/n	A system is assessed as providing language support (y) if its interface is available in more than one language.
	Protocols and APIs supported	ACL2	y/n	A system is assessed as providing protocols and APIs (y) if it makes available at least one protocol and/or API for access to research artefacts.
Content availability	Long-term preservation	ACA1	y/n	A system is assessed yes (y) if it offers a convenient mechanism to perform long-term preservation beyond a simple database backup.
	Availability	ACA2	h/m/l	A system is assessed high (h) if the uptime is $\geq 99,9\%$, it is assessed medium (m) if the uptime is between 99,9% and 99% and low (l) if it is below 99% .
	Access control	ACA3	open, closed, on-request	A system is assessed open, if it makes research artefacts public by default. It is assessed as closed if it is primary designed for closed repositories. It is assessed on-request if it offers an on-request feature.

331 3.3 Interoperability

332 Research data repositories should foster interoperability: the ability to easily share data with
 333 other systems. Therefore, it is essential that research artefacts are available in formats that
 334 are portable, open, and widely supported by other systems and platforms. To further enhance
 335 interoperability, certain data federation features are of high value. It is also important that
 336 artefacts are clearly identifiable via unique and persistent identifiers (as for findability). The

337 associated metadata should follow commonly accepted metadata specifications, such as Dublin
338 Core²⁸ or MARC 21²⁹. Furthermore, data exchange should be supported by well-defined and
339 established protocols, such as OAI-PMH³⁰. The possibility to customise metadata and to (au-
340 tomatically) link other resources are two features that can further improve interoperability.
341 To smoothly integrate with research processes, the repository should support manual and au-
342 tomatic data upload and import, as well as data download and export. In this context, the
343 support for custom submission processes are another beneficial add-on.

344 Table 3 lists metrics that we used to assess interoperability. We distinguish between two
345 types of metrics here: interoperability in content and interoperability in the interaction with
346 content. The metrics related to interoperability of content include whether standard formats
347 for metadata (IC1) and content (IC2) are applied, the possibility to assign persistent identifiers
348 to the artefacts (IC3), the ability to create custom metadata schemes (IC4), and support for
349 semantic linking between artefacts (IC5). With standards we associate any official, publicly
350 available and established specification. Especially, this includes standards published by stan-
351 dardisation bodies, such as IANA or W3C. These metrics are assessed through yes/no values,
352 depending on whether the corresponding features are available in a given solution. Regard-
353 ing content interaction, metadata/data upload and import (ICI1), as well as metadata/data
354 download and export (ICI2) are important criteria. The assessment of those metrics is based
355 on whether those functions are available, and are considered only partial if a user has to go
356 through a web user interface to carry them out (i.e. no API function is available). Finally,
357 the availability of a custom submission processes (ICI3) and data federation features (ICI4) are
358 assessed via yes/no metrics.

359 **3.4 Reusability**

360 Research data repositories should support and encourage the reuse of their hosted artefacts.
361 This is especially true for artefacts other than publications, such as research data or supple-
362 mentary material. Typical reuse scenarios are the distribution, aggregation, conversion, or
363 enrichment of research data. The creation of derived and adapted work is an inherent element

²⁸<https://dublincore.org/>

²⁹<https://www.marc21.ca/>

³⁰<https://www.openarchives.org/>

Table 3: Interoperability metrics.

Type	Metric	ID	Values	Description
Content	Standard format for metadata	IC1	y/n	A system is assessed yes (y) if it employs a standardised and established format for providing the metadata.
	Standard formats for content	IC2	y/n	A system is assessed yes (y) if it supports the provision of data in common and standard file formats.
	Persistent identifiers	IC3	y/n	A system is assessed yes (y) if it assigns a persistent identifier (e.g. a stable URL) to the research artefacts.
	Custom metadata	IC4	y/n	A system is assessed yes (y) if it allows to customise, extend and limit the metadata schema/format.
	Linking of metadata and content	IC5	y/n	A system is assessed yes (y) if it supports the creation and publication of semantic links between different metadata and/or research artefacts.
Content interaction	Import and upload of metadata and content	ICI1	y/p/n	A system is assessed yes (y) if it supports the import and upload of metadata and data via multiple means, e.g. a web frontend or a standard API. It is assessed partially (p) if it only supports the provision via a web interface.
	Export and download of metadata and content	ICI2	y/p/n	A system is assessed yes (y) if it supports the export and download of metadata and data via multiple means, e.g. a web frontend or a standard API. It is assessed partially (p) if it only supports the download via a web interface.
	Custom submission process	ICI3	y/n	A system is assessed yes (y) if it supports the creation and maintenance of a customised submission process, including fine-grain access control and role assignment.
	Data federation	ICI4	y/n	A system is assessed yes (y) if it provides a built-in mechanism to make (part of) the metadata and data in other repositories (running the same system) available.

364 of many research processes. Reusability therefore needs to be supported on the technical and
365 legal level. The application of well-defined and standardised metadata schemes, protocols, and
366 interfaces lowers the barriers for further processing, especially the integration into third-party
367 tools. Furthermore, the repository solution should support and encourage the use of structured,
368 open and machine-readable formats for research data. This facilitates the provision of data in a
369 raw and immediate manner, attracting additional reuse scenarios. As important as the techni-
370 cal access is assurance about the legal conditions of reuse. Hence, a repository solution should
371 support the provision and publication of comprehensive licence information. This includes the

possibility to assign different rights and licences to different components of an artefact and a support for a wide range of established and common licences. Ideally, the users receive assistance in choosing and understanding the licence information. For instance legal wording might be translated into understandable and clear attributes, since explicit communication about reuse conditions fosters reusability.

Table 4 shows the metrics to assess the support for reusability of a repository solution. It is assessed based on three distinct metrics, which cover content depositing, access, and support aspects. First, the support for providing detailed licence information (RCD1) during the depositing process is assessed. A solution can have no support for licence information at all, hence no dedicated metadata property is provided. A research repository can offer basic support for licence information, if it facilitates the provision of licences attached to specific artefacts in any way, either as a free input field or based on a controlled vocabulary. Full support can be achieved if the solution supports a highly standardised and advanced method of providing the information, e.g. by applying a user-friendly provision mechanism and reusing existing licence vocabularies. Secondly, the same applies for accessing the licence information (RCA1). There may be no information at all, at least some basic information (e.g. a link to licence), or highly understandable and structured information is provided. Finally, the support for structured data access (RCS1) is assessed as “yes” if the actual research artefact can be accessed in a structured and machine-readable manner.

Table 4: Reusability metrics.

Type	Metric	ID	Values	Description
Content depositing	Licence support	RCD1	y/l/n	A system is assessed high (h) if it provides a highly usable and easy-to-understand mechanism to select a fitting licence for an artefact. It is assessed limited (l), if it at least provides a customizable controlled list of licences.
Content access	Licence support	RCA1	y/l/n	A system is assessed high (h) if it provides an easy-to-understand and human-readable description of the terms of use. It is assessed limited (l), if it at least provides a link to the applied licence.
Content support	Data	RCS1	y/n	A system is assessed as possessing the feature (y) if it allows users to access the content in a structured and machine-readable manner.

391 **3.5 Engagement**

392 Research artefacts should be provided through systems that are not only accessible, but that
393 are also highly usable and that implement interaction mechanisms fitting and matching the
394 workflow and culture of the research community. Specifically going beyond the FAIR principles,
395 we consider here that research repositories are built for use also by human beings. In other
396 words, to be successful, those repositories should be engaging. This principle looks primarily
397 at the usability of the repository system from the point of view of the intended user: It should
398 be simple, visible, integrated, and practical. It should, in particular, follow modern usability
399 standards, and minimise the effort required by both the publishers and the consumers of research
400 artefacts in accomplishing their tasks. In addition, those repositories should aim to facilitate
401 the work of their administrators by minimising the effort required for their maintenance.

402 Table 5 lists metrics used to measure how engagement is enabled by research repositories.
403 Those metrics follow two general categories assessing, on the one hand, the usability of the
404 system, evaluated as high, medium or low through relevant methodologies (EUA2) and through
405 the availability of support and documentation (EUA1). On the other hand, we look through
406 yes/no metrics, at the availability of features that are designed to support engagement. Those
407 include in particular features targeted mostly at publishers of research artefacts through which
408 the user is notified of a potential need for engagement (EES1) and supported through the
409 workflow of publishing research artefacts (EES2). The availability of visualisation (EES3) and
410 analysis (EES4) tools enabling consumers to interact with the content of the published research
411 artefacts is also considered an important aspect in assessing how engaging a repository is.

412 **3.6 Social connections**

413 Research artefacts are not created in isolation. They are the result of a social process involving
414 many different stakeholders, institutions, and collaborations. As such, it is important that they
415 are published, made available, and consumed in a way that also takes into account this social
416 context, not as isolated artefacts. As for engagement, this is an additional principle on top of
417 the FAIR principles that takes into account the human dimension of research repositories and
418 research artefacts. It considers two main categories of features that a research repository should
419 enable: The ability to reflect the social context in which a research artefact was created, and

Table 5: Engagement metrics.

Type	Metric	ID	Values	Description
Usability and ease of use	Support and documenta- tion	EUA1	h/m/l	A system is assessed high (h) if the documentation and support are of high quality and reachability.
	Usability	EUA2	h/m/l	A system is assessed according to this metrics based on usability testing carried out.
Engagement support	Push notifi- cations	EES1	y/n	A system is assessed as possessing the feature (y) if it includes mechanisms to notify users through mobile apps, email, or other mechanisms.
	Publication workflow support	EES2	y/n	A system is assessed as possessing the feature (y) if it provides a way to customise and manage the publication/deposit workflow.
	Visualisation tools	EES3	y/n	A system is assessed as possessing the feature (y) if it includes ways to visualise the content of publications or datasets, at least for some formats.
	Analysis tools	EES4	y/n	A system is assessed as possessing the feature (y) if it includes mechanisms to analyse the data in deposited research artefacts, including basic statistical analysis or more advanced methods.

420 facilitating the creation of new social connections between researchers based on the available
421 research artefacts.

422 Table 6 lists metrics used to assess how repositories enable social connections. Consistently
423 with the definition of the principle above, metrics to assess how research repositories enable
424 social engagement consider two main categories: Usability and ease of use, and engagement
425 support. Related to the first dimension, this includes being able to create collections of related
426 artefacts (SRT1), brand those collections or the whole repository (SRT3), and present research
427 artefacts under researcher profiles that reflect their ownership and origin (SRT3).

428 The second dimension mostly looks at the existence of features borrowed from social net-
429 working platforms: liking (SCN1), following (SCN4), sharing (SCN3), commenting (SCN2),
430 and forums (SCN5). While traditional social networks might enable users to follow only other
431 users, we consider here that being also able to follow an artefact, a collection, a topic, or an
432 institution is desirable.

433 In addition, a particular metric of interest is the one related to the existence of a develop-
434 ment community (SCN6), which is of importance to the administrator of the platform, as this
435 community and its level of activity are indicative of whether support and extensions for the
436 platform are likely to be available. While other metrics for this principle are assessed through
437 yes/no values, this one is assessed based on whether the development (community) is open or

Table 6: Social connections metrics.

Type	Metric	ID	Values	Description
Reflecting the social context	Theming / branding	SRT1	y/n	A system is assessed as possessing the feature (y) if it enables the publisher or administrator to change the aspect of pages on the system to reflect institutional affiliation.
	Creation of collections	SRT2	y/n	A system is assessed as possessing the feature (y) if it includes ways for users to create, name, and publish arbitrary sets of research artefacts.
	Individual researcher profiles	SRT3	y/n	A system is assessed as possessing the feature (y) if it provides pages for individual researchers, including at least the research artefacts they have authored/published.
Creating new social connections	Like button	SCN1	y/n	A system is assessed as possessing the feature (y) if it gives the ability to users to provide simple positive feedback (likes) on research artefacts.
	Comments	SCN2	y/n	A system is assessed as possessing the feature (y) if it enables users to comment on individual research artefacts.
	Sharing	SCN3	y/n	A system is assessed as possessing the feature (y) if it provides ways to share research artefacts with other users, on the system or other platforms (e.g. social media).
	Following	SCN4	y/n	A system is assessed as possessing the feature (y) if it enables users to follow, and receive updates from, other users, research artefacts, collections, institutions, etc.
	Discussion forums	SCN5	y/n	A system is assessed as possessing the feature (y) if it includes discussion forums for users and/or for communication with/from the administrators.
	Development community	SCN6	h/m/l/c	For a proprietary, closed system, the assessment should be closed (c). For an open system, assessment is based on the frequency of activities in the development community (daily/weekly updates: high, monthly/quarterly updates: medium, less: low).

438 closed. If it is open, we consider the level of activities in the development community according
439 to the following guidelines: High if there are at least weekly updates, medium if updates come
440 on a monthly basis, and low if they occur less frequently.

441 3.7 Trust

442 Trust in research repositories means that a user can rely on the provided system and informa-
443 tion. This is enabled by demonstrating the validity, robustness, and significance of scientific
444 artefacts. These principles are based on good scientific practice as well as the practices asso-
445 ciated with open science [31, 32]. Another important aspect is the long-term preservation of

446 data, i.e. that providers and consumers of research artefacts can trust that the relevant data
447 will remain available. This aspect is therefore shared with the accessibility principle.

448 In addition to those, it is useful to assess how repositories include features that are explic-
449 itly designed to ensure the trustability of available artefacts, such as reviewing features, gate
450 keeping, and authentication.

451 On the system level, mechanisms and techniques for long-term preservation are features
452 that we grouped together under trust, including backup systems that prevent loss of data. The
453 use of open source software or libraries is also part of this, since the openness of a system
454 enables transparency, which goes hand-in-hand with trust. Adoption and the size of the user
455 community can also be used, indirectly, as indicators of the trustability of the system.

456 Finally, how well personal data is protected in the research repository can play a crucial
457 role in the trust users will have in sharing their information with it. Here, we rely on high
458 level requirements from the European General Data Protection Regulation (GDPR³¹) to assess
459 this aspect, such as whether the system provides ‘out-of-the-box’ features for personal data
460 portability, deletion, and security.

461 Table 7 shows the metrics used to assess those different aspects of trust. Most metrics
462 take simple yes/no values that indicate whether a feature is present (yes) or not (no). The
463 metric indicator (TCS1), on the other hand, is more complex. A simple indicator represents
464 simple usage statistics that can be quickly calculated by the application. Advanced indicators
465 represent more sophisticated indicators, such as h-index or Altmetrics.

466 Long-term preservation (TCS2) can also be assessed with yes/no values, but information
467 about the time during which artefacts have been available in a given system gives a slightly
468 richer perspective, complementing the corresponding metrics in the accessibility principle.

469 The metric open source software and libraries (TS1) is also assessed with a binary classi-
470 fication, considering the underlying system and if it is mostly based on open source software.
471 Uptake (TS2) can be hard to assess precisely and is therefore considered on a high/medium/low
472 scale, where high means that the system is used by at least several thousands of users every
473 month. Right of information (TG2) and data deletion (TG3) represent the availability of a
474 function that can output or delete all personal data. For agreement per data management
475 process (TG4), the user should have the option to decide which personal data are processed

³¹<https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016R0679&from=EN>

Table 7: Trust metrics.

Type	Metric	ID	Values	Description
Content	Authentica- tion	TC1	y/n	A system is assessed as possessing the feature (y) if it includes an authentication mechanism for users.
	Gate keeping	TC2	y/n	A system is assessed as possessing the feature (y) if it provides a review functionality during submission by data stewards or other permitted organizational users.
	Review fea- ture	TC3	y/n	A system is assessed as possessing the feature (y) if it includes a functionality for writing reviews on specific research artefacts.
Content support	Indicator	TCS1	n/s/a	A system is assessed as possessing the feature (s) if it records usage statistics and (a) if it provides advanced research indicators like h-Index or AltMetrics.
	Long-term preservation	TCS2	date	Date at which the first available artefact was deposited on the platform.
System	Open Source software and libraries	TS1	y/n	A system is assessed as possessing the feature (y) if the underlying system is open source.
	Uptake	TS2	h/m/l	A system is assessed as having high uptake (h) if it is used by a thousands of active users each month, medium uptake (m) with hundreds of active users, and low uptake (l) with lower numbers of active users.
GDPR	System backup	TG1	y/n	A system is assessed as possessing the feature (y) if it includes automated backups in a constant time interval.
	Right of in- formation	TG2	y/n	A system is assessed as possessing the feature (y) if it provides a function to get all data about one user.
	Data dele- tion	TG3	y/n	A system is assessed as possessing the feature (y) if it provides a function to delete all data about one user.
	Agreement per data management process	TG4	y/n	A system is assessed as possessing the feature (y) if it allows the user to opt-in, agreeing to single personal data management processes individually.
	Portable and secure data exchange format	TG5	y/n	A system is assessed as possessing the feature (y) if it provides all personal data in an open standard format (e.g. HTML, TXT, PDF).
	Protection against data leaks	TG6	y/n	A system is assessed as possessing the feature (y) if it includes security tests for personal data.

476 and how. The online solutions should offer for example a control panel with checkboxes and on
477 premise solutions need a configuration possibility for this reason. Protection against data leaks
478 (TG6) and portable and secure data exchange format (TG5) are additional important points.
479 All those metrics are assessed with yes/no values, where yes indicates that the repository system
480 provides functions specifically dedicated to handling the corresponding requirement.

481 4 Assessment of Solutions

482 In order to evaluate and assess our framework, we applied it to a variety of existing and
483 established solutions for managing research publications and data. The main objective of our

484 selection was to cover a variety of solutions, while restricting the sample to a manageable number
485 of comparable and highly relevant solutions. In selecting a solution to assess, we essentially
486 applied three criteria:

- 487 1. Eligible solutions had to be a systems/services specifically dedicated to and used for
488 providing repositories of research artefacts.
- 489 2. They had to be a general-purpose solution and not focused on a particular domain or
490 sector.
- 491 3. Relevant solutions had to be currently used by a significant number of research organisa-
492 tions and researchers.

493 Our selection is divided into two categories of solutions: on-premise solutions and online
494 services. The first category includes solutions that can, or must be self-hosted on the adminis-
495 trator’s own server. The second category covers solutions that are provided as a service by a
496 operator. These categories are a selection criteria by themselves, but are treated neutrally in
497 our framework.

498 Below, we provide a short description of the systems assessed, discussing first online services
499 and second the systems that have to be deployed on-premise.

500 **Academia.edu** emphasises social network functionalities such as the ability to follow other
501 researchers, as well as “metrics” that are supposedly measuring reputation and impact. In
502 practice, it is more used as a way to publicise one’s research, i.e. as a service to deposit papers
503 to make them more accessible and visible.⁶ Assessment of Academia.edu was carried out on
504 the free version, but references to the paid version are included where relevant.

505 **arXiv** is most commonly used as a platform to publish non-peer reviewed papers. There is no
506 limitation on the content published other than that it has to contribute to a scientific discipline.
507 The arXiv platform is managed by moderators who check and validate the content.⁴

508 **Bibsonomy** is an online social bookmarking system created by research groups in Germany,
509 designed to support Web 2.0 research. While the system is generic and enables bookmarking
510 of any kind of web resources, it includes a specific section to share, comment on, and review
511 publications.⁷

512 **figshare** is a service for the publication of generic research data, aiming to cater for the
513 needs of institutions, publishers, and individual researchers. figshare for institutions focuses on
514 managing research artefacts and measuring the impact of these outputs. figshare for publishers
515 focuses on the publication of citable supplementary material. Finally, figshare for researchers
516 relies on the public web implementation of figshare, which allows individual researchers to
517 deposit and share their research artefacts.¹⁶ The assessment of figshare was performed over the
518 figshare for institutions solution as this is the most feature-complete version of the platform.
519 However, where relevant we refer to the public version of figshare.

520 **ResearchGate** presents itself as a social network for scientists of all disciplines. Familiar
521 social functions, such as those from Facebook or Twitter, have been adapted or newly imple-
522 mented with a focus on the needs of the academic community. Users can share papers, search
523 for collaborators, or follow specific research interests. One of the core features of ResearchGate
524 is the RG Score, a specific indicator of the impact of a researcher.⁵

525 **Zenodo** is an open access repository that focuses on sharing data with the wider community.
526 Datasets can be published with no restriction on the format, i.e. software, papers, measurement
527 series, databases, and other digital artefacts can be published through this service.¹⁷

528 **CKAN** is a data management solution for building on-premise data repositories and is the
529 de-facto standard for publishing public sector datasets, i.e. Open Government Data. It is
530 maintained with support from the Open Knowledge Foundation. A vanilla installation offers
531 basic features to publish, manage, and search for metadata with a organisation-based rights
532 management system. It focuses on metadata, but also includes a data storage feature for binary
533 and tabular data. A broad and vivid extension ecosystem has evolved, enabling use case-specific
534 customisation, but those are not included in our assessments.¹⁴

535 **Dataverse** is an open source research data repository software. It is a web application meant
536 to share, preserve, cite, explore, and analyse research data. A Dataverse repository corresponds
537 to the whole installed platform, which then can host multiple virtual archives called Dataverse
538 collections. Each Dataverse collection contains datasets, and each dataset contains descriptive
539 metadata and data files.¹¹

540 **DSpace** is an open source repository solution for digital research and educational artefacts
541 published by an organisation or institution. Its data model reflects the structure of research
542 organisations: Communities, collections, and items. The core data schema of an item is based
543 on Dublin Core.²⁸ DSpace offers extensive support for representing the publishing workflow
544 and its involved actors.¹²

545 **EPrints** is an open source repository solution developed at the University of Southampton
546 to support institutions in providing open access services for their publications, with recent
547 extensions to support educational software and research data.¹⁸

548 **Invenio** is an open source software framework which provides tools to implement custom
549 institutional repositories for research data management systems. The main features are the
550 scalability of this solution together with its components and the long-term preservation option.
551 The Zenodo online service has been built using the Invenio v3 framework.¹⁵

552 **4.1 Overview of Assessments: FAIREST Principles**

553 In this section, we provide a detailed assessment of each system, as structured by the seven
554 principles of the FAIREST framework. For each principle, we provide a table showing the
555 values for each of the metrics presented in Section 3 and highlights of interesting aspects of the
556 way the systems, on the whole, score with respect to those metrics. This will be complemented
557 in Section 4.2 with highlights from each of the assessed systems.

558 **4.1.1 Findability**

559 An overview of the assessments of each solution with respect to the metrics related to the
560 findability principle is provided in Table 8. All solutions provide some form of persistent
561 identifier for the research artefacts they hold (FCS1) and those identifiers are always used to
562 create dereferenceable web links to the artefact's representation in the system (FCS4). In all
563 but Academia.edu, external identifiers can also be imported (FCS3), which in some cases have
564 to be standard identifiers (e.g. DOIs), and in some cases can be any identifier. A subset of the
565 systems also have the ability to generate DOIs for the research artefacts they hold (FCS2).

Table 8: Overview of assessments of solutions for findability. In this table, as well as in the six following ones, the double line separates systems operating as online services, from systems that are deployed on-premise.

	FCS1	FCS2	FCS3	FCS4	FCA1	FCA2	FCA3
Academia.edu	y	n	y	y	y	n	n
arXiv	y	n	y	y	y	n	y
Bibsonomy	y	n	y	y	y	y	y
figshare	y	y	n	y	y	n	y
ResearchGate	y	y	y	y	y	n	y
Zenodo	y	y	y	y	y	n	y
CKAN	y	n	y	y	y	n	y
Dataverse	y	y	y	y	y	n	y
DSpace	y	y	y	y	y	y	y
EPrints	y	n	y	y	y	y	n
Invenio	y	y	y	y	y	n	y

566 All solutions provide a search feature that is based on the metadata of research artefacts
567 (FCA1). In most cases (all but EPrints and Academia.edu), this search feature can be con-
568 sidered ‘advanced’ as it enables the use of optional parameters and filters (FCA3). Only three
569 solutions (EPrints, DSpace, and Bibsonomy) enable searching in the content of the research
570 artefacts under specific conditions and configurations (FCA2).

571 4.1.2 Accessibility

572 The overview of the assessments of solutions with respect to metrics related to the accessibility
573 principle is provided in Table 9. Here, the implementations differ greatly: While some solutions
574 (e.g. DSpace) appear to have been developed to be highly accessible, others (e.g. Academia.edu)
575 appear less concerned with these aspects. Interestingly, only a few solutions provide interfaces
576 in other languages than English out-of-the-box (ACL1). Only few solutions do not provide any
577 form of API or programmatic access protocols (ACL2). As the assessment of ACA3 makes clear,
578 there are mostly two types of systems: The ones that are meant to support open access, and the
579 ones with a lesser focus on this aspect. This difference, in combination with whether the solution
580 is deployed as a cloud service or as a ‘commercially supported’ on-premise solution, partially
581 explains the variable support for long-term preservation (ACA1) and lack of information about
582 system availability (ACA2).

Table 9: Overview of assessments of solutions for accessibility. Here and in subsequent tables, - means that the information required to assess the metric is not available, while n/a means that the metric does not apply.

	ACL1	ACL2	ACA1	ACA2	ACA3
Academia.edu	n	n	-	-	open
arXiv	n	y	n	h	open
Bibsonomy	y	y	n	m	open
figshare	n	y	n	h	open
ResearchGate	n	n	n	-	open, on-request
Zenodo	n	y	y	m	open, closed, on-request
CKAN	y	y	n	n/a	open
Dataverse	y	y	n	n/a	open, closed
DSpace	y	y	y	n/a	open
EPrints	n	y	y	n/a	open, closed, on-request
Invenio	y	y	y	n/a	open, closed

583 4.1.3 Interoperability

584 The overview of the assessment of solutions with respect to metrics related to interoperability
585 is provided in Table 10. All solutions support standard formats for the content (IC2) and
586 persistent identifiers (IC3). Only half of the systems employ a standard and established format
587 for the metadata (IC1), most of them being on-premise solutions. The ability to customise
588 metadata (IC4) is also a feature provided by all on-premise solutions, while only the online
589 solutions EPrints and figshare offer this functionality. The linking of metadata and content
590 (IC5) is available in a few solutions with very different characteristics. Almost all solutions
591 support the import of metadata and data (ICI1), whereas only Academia.edu offers a web
592 interface but no API. The download of metadata and data is possible with almost all solutions
593 via frontend and API (ICI2). Only ResearchGate and Academia.edu do not offer an API. A
594 rare feature is the support for a custom submission process (ICI3), which is only offered by
595 EPrints, figshare, and DSpace. Furthermore, only three solutions allow the setup of federated
596 repositories (ICI4): DSpace, Dataverse, and CKAN, although, the implementations are limited
597 to harvesting mechanisms.

598 4.1.4 Reusability

599 The overview of the assessments of solutions with respect to metrics related to reusability is
600 provided in Table 11. The solutions tend to cover reusability in different ways with a focus on

Table 10: Overview of assessment of solutions for interoperability.

	IC1	IC2	IC3	IC4	IC5	ICI1	ICI2	ICI3	ICI4
Academia.edu	n	y	y	n	y	p	p	n	n
arXiv	n	y	y	n	n	y	y	n	n
Bibsonomy	n	y	y	n	y	y	y	n	n
figshare	y	y	y	y	n	y	y	y	n
ResearchGate	n	y	y	n	y	y	p	n	n
Zenodo	y	y	y	n	n	y	y	n	n
CKAN	y	y	y	y	n	y	y	n	y
Dataverse	y	y	y	y	y	y	y	n	y
DSpace	y	y	y	y	n	y	y	y	y
EPrints	n	y	y	y	n	y	y	y	n
Invenio	y	y	y	y	y	y	y	n	n

601 different aspects. For example, while most systems have some form of description of the licences
602 attached to research artefacts, very few appear to focus on making the aspect of licensing
603 prominent through clear and well documented descriptions of the available options (RCD1),
604 and even fewer support users in understanding the impact of licences on the consumption of
605 research artefacts (RCA1).

Table 11: Overview of assessments of solutions for reusability.

	RCD1	RCA1	RCS1
Academia.edu	n	n	n
arXiv	l	l	n
Bibsonomy	n	n	n
figshare	y	l	n
ResearchGate	l	l	y
Zenodo	y	l	n
CKAN	l	l	y
Dataverse	l	l	n
DSpace	l	l	n
EPrints	n	n	y
Invenio	l	l	n

606 RCS1 relates to whether the content of research artefacts is accessible in a programmatic
607 way. As such, it relates to similar metrics to the ones mentioned in relation to the accessibility
608 and interoperability principles. However, while APIs and access protocols might be available to
609 access the metadata of the research artefacts, only few systems really enhance the reusability
610 of research artefact by providing machine-readable access to content.

611 4.1.5 Engagement

612 The overview of the assessments of solutions with respect to metrics addressing engagement is
613 provided in Table 12. As visible from this table, the aspects of usability and ease of use are,

614 at best, hard to assess for most solutions. Indeed, while most solutions provide at least some
615 reasonable documentation (EUA1), the large majority of systems does not provide information
616 about usability tests or other forms of assessments of usability (EUA2).

Table 12: Overview of assessments of solutions for engagement.

	EUA1	EUA2	EES1	EES2	EES3	EES4
Academia.edu	h	-	y	n	y	n
arXiv	m	l	n	n	n	n
Bibsonomy	m	-	n	n	n	n
figshare	h	-	n	y	y	n
ResearchGate	h	m	y	n	y	n
Zenodo	h	-	n	n	y	n
CKAN	h	n	n	n	y	n
Dataverse	h	n	y	y	y	n
DSpace	h	n	n	y	y	n
EPrints	m	-	y	y	n	n
Invenio	h	-	n	n	n	n

617 Regarding supporting engagement, the availability of analytics tools (EES4) is absent from
618 all the solutions. Other metrics are addressed differently by solutions. Push notifications
619 (EES1) for example tend to be more present in online solutions that also include social con-
620 nection functions (see next section), while the possibility to customise the depositing workflow
621 (EES2) is present only in a few systems for which the ability to curate the content of the
622 repository is particularly important. About half of the solutions allow to visualise the content
623 of artefacts without the need to download them and use external tools (EES3).

624 4.1.6 Social Connections

625 The overview of the assessments of solution with respect to metrics addressing social connections
626 is provided in Table 13. With the exception of arXiv and Zenodo, all assessed systems provide
627 ways to reflect the social context in which an artefact has been created. Most on premise and
628 few online solutions enable the customisation of system branding and themes, e.g. to clearly
629 identify the institution (SRT1). About half of the systems enable creating dedicated collections
630 that can correspond to people, projects, groups, or broader organisations (SRT1). Surprisingly,
631 only few systems create dedicated pages for researchers who are authors of deposited artefacts
632 (SRT3). Those are the systems that tend to put more emphasis on social features.

633 As mentioned above, some of the systems assessed put a strong emphasis on features that
634 enable social connections, by providing functions such as the ability to comment on artefacts

Table 13: Overview of assessments of solutions for social connections.

	SRT1	SRT2	SRT3	SCN1	SCN2	SCN3	SCN4	SCN5	SCN6
Academia.edu	n	y	n	n	y	y	y	n	c
arXiv	n	n	n	n	n	y	n	n	c
Bibsonomy	n	y	y	n	y	y	y	n	m
figshare	y	y	y	n	n	y	y	n	c
ResearchGate	n	y	y	y	y	y	y	y	c
Zenodo	n	n	n	n	n	n	n	n	h
CKAN	y	y	n	n	n	y	y	n	h
Dataverse	y	y	n	n	n	n	n	n	h
DSpace	y	y	n	n	n	n	n	n	h
EPrints	y	n	y	n	n	n	n	n	h
Invenio	y	y	n	n	n	n	n	n	h

635 (SCN2), share artefacts with others (e.g. through social media - SCN3), or follow (artefacts,
636 people, or collections - SCN4). ResearchGate is noticeable for providing all of those three
637 features and also for being the only one including discussion forums (SCN5). Surprisingly,
638 none of the systems provide explicitly a ‘like button’ for their artefacts (SCN1), common on
639 social media platforms, even though ResearchGate includes a ‘recommend’ feature which can
640 be seen as similar.

641 SCN6 is particular here as it considers social connections specifically with the development
642 community for the system. For proprietary systems, access to the developers of the platform
643 is naturally closed, but almost all open source systems are assessed to have highly active and
644 reachable development communities at the time of writing.

645 4.1.7 Trust

646 The overview of the assessments of solutions with respect to metrics addressing trust is pro-
647 vided in Table 14. All systems provide an authentication mechanism (TC1). Interestingly,
648 only one online and three on-premise solutions provide a gate keeping feature to implement
649 an internal, organisational review process (TC2). Only Bibsonomy and Dataverse offer a fea-
650 ture, allowing users to provide reviews to research artefacts (TC3). This is surprising, since
651 (peer) review processes are very common in the scientific domain. Regarding scientific indica-
652 tors, only ResearchGate provides an advanced research indicator for their users, while other
653 solutions only provide basic usage statistics. arXiv, Bibsonomy, and DSpace do not offer any
654 statistics (TCS1). Naturally, the long-term preservation metric can only be applied to online
655 solutions and correlates with the first availability of the respective solutions. arXiv offers its
656 services the longest, since 1991 (TCS2).

Table 14: Overview of assessments of solutions for trust.

	TC1	TC2	TC3	TCS1	TCS2	TS1	TS2	TG1	TG2	TG3	TG4	TG5	TG6
Academia.edu	y	n	n	s	2009	n	h	-	n	y	n	n	n
arXiv	y	n	n	n	1991	-	h	n	n	n	n	n	n
Bibsonomy	y	n	y	n	2005	y	-	y	n	y	n	n	n
figshare	y	y	n	s	2012	n	h	y	n	y	n	n	n
ResearchGate	y	n	n	a	2008	n	h	-	y	y	n	n	n
Zenodo	y	n	n	s	2016	y	-	y	n	n	n	n	n
CKAN	y	n	n	s	n/a	y	n/a	n	n	n	n	n	n
Dataverse	y	y	y	s	n/a	y	n/a	n	n	n	n	n	n
DSpace	y	y	n	n	n/a	y	n/a	y	n	n	n	n	n
EPrints	y	y	n	s	n/a	y	n/a	n	n	n	n	n	n
Invenio	y	n	n	s	n/a	y	n/a	y	n	n	n	n	n

657 Regarding the use of open source software, it is very positive, that all on-premise solutions
658 are available as open source. In addition, the online solutions Zenodo and Bibsonomy are also
659 based on open source software, where we could not determine it for arXiv (TS1). The number
660 of active users is only relevant to online solutions. Here, most solutions have a high uptake
661 with thousands of users each month (TS2). For Bibsonomy, we were not able to find usage
662 statistics.

663 The assessment regarding GDPR compliance is mostly negative across all solutions. Only
664 two on-premise solutions offer comprehensive backup mechanisms (DSpace and Invenio) and for
665 the online solutions only Bibsonomy, figshare and Zenodo offer transparent information (TG1).
666 Of all solutions only ResearchGate offers the functionality to retrieve all data about one
667 user (TG2). Regarding the deletion of user-related data (right to be forgotten) the online
668 solutions are leading, since only arXiv and Zenodo do not offer this features. Unfortunately, no
669 on-premise solution implements this important and arguably required feature (TG3). Finally,
670 no solution allows users to opt-in to single personal data management processes individually
671 (TG4) or offers a features to export all personal data (TG5). In addition, we could not find any
672 public information regarding measures to protect against data leaks for any solution (TG6).

673 4.2 Overview of Assessments: Solutions

674 Taking an orthogonal view to the previous section, we now highlight interesting aspects of the
675 assessment of each system. As mentioned previously, those assessments have been realised by
676 using the systems and inspecting relevant documentation as well as by requesting feedback
677 from the developers of each platform. We received acknowledgements for our request from

678 Academia.edu, arXiv, Zenodo, and Invenio, and detailed feedback on our framework and the
679 assessments for Bibsonomy, figshare, ResearchGate, CKAN, and DSpace.

680 **4.2.1 Academia.edu**

681 As a commercial “academic social network”, the system puts special emphasis on engagement
682 and social connections of the FAIREST principles. Besides the free version evaluated in this
683 paper, a paid version exists, providing some additional functionalities.

684 For findability and interoperability, the system is comparable to other online solutions,
685 especially to ResearchGate. Some additional functionalities are available in the paid version,
686 including advanced search functionalities for metadata and data.

687 Academia.edu does not fulfil any of the criteria we formulated for accessibility and reusabil-
688 ity. Although we could not find any information about it, and hence rated it as “no”, we assume
689 that long-term preservation and availability are ensured by this commercial system.

690 The system scores well in the categories engagement and social connections. For instance,
691 it provides a mechanism for email notifications. Some additional functionalities are available
692 in the paid version, e.g. researcher profiles. It further provides some analysis tools, including
693 the translation and summarisation of documents.

694 For trust, the system again does not score well. For most indicators we could not find
695 information whether or not this functionality is available.

696 In summary, the system clearly focuses on engagement and social connections, and is rather
697 limited in its functionalities when it comes to the other categories. However, in its paid version
698 it provides some additional features, and can serve as a reliable academic social network.

699 **4.2.2 arXiv**

700 As one of the most considerable preprint servers in the field of science and technology, this
701 solution offers an uncomplicated way to publish one’s research. The focus lies on publications
702 and less on other research data, but the artefacts do not receive a DOI. Instead, identifiers
703 specific to arXiv are assigned together with a URL. Furthermore, users can also add their own
704 DOI.

705 As it is provided by the US-based Cornell University, the interface is only available in
706 English and offers no support for other languages. Overall, the range of functions is reduced

707 to the essentials compared to other online solutions. However, the most important file formats
708 and API protocols are supported. It is not possible to enter additional (meta) information.

709 An advantage is the long-term continuity of arXiv. The platform has been available, rel-
710 atively unchanged, since 1991, managing a significant number of publications. As a result,
711 however, functions related to social interactions and design improvements have been slow to
712 appear in arXiv. A detailed view of artefacts is also not possible: Available publications can
713 only be published, downloaded, or distributed via sharing buttons.

714 Even without a review feature, the service's scientific domains are managed by moderators
715 in their structure and content (with 13,000 to 18,000 publications per month). Information
716 about GDPR was not found on the website.

717 In summary, while limited in features, because of its adoption and stability, arXiv is a good
718 solution for someone looking to ensure that artefacts are and will remain accessible through a
719 platform that is known by researchers.

720 **4.2.3 Bibsonomy**

721 Built as a semantic web system, Bibsonomy tends to score high in the first three of the FAIREST
722 principles. Indeed, the creation of unique, resolvable identifiers, the availability of APIs, and
723 the possibility to import/export from various sources and formats are part of the design of the
724 system. In addition, because it is meant as a social web system, Bibsonomy tends to provide
725 many of the features considered through the social connection principle.

726 Since Bibsonomy focuses on the open sharing of web resources, the aspect of reusability is
727 not well addressed, in particular with no available support for specifying the rights and licences
728 applying to shared items. In addition, as seen from the metrics related to engagement, the
729 system does not provide an advanced level of usability or functions one might expect from a
730 commercial system.

731 On trust, while Bibsonomy is comparable to other online systems with respect to that
732 principle, one of the few systems that provides a review function through a five star system.
733 Additionally, the platform on which it is based is open source.

734 Furthermore, while we considered Bibsonomy as a shared online system, the platform on
735 which it relies can be re-deployed to provide a repository for a specific institution, with the

736 possibility to customise it in that case.³²

737 In summary, Bibsonomy can be seen as an experiment towards academic social networks. It
738 represents a valid solution when the aspects of social interaction and the ability to share with
739 others, beyond simple accessibility, are important.

740 4.2.4 figshare

741 figshare strongly focuses on giving users tools to enable the publication of FAIR data [33].
742 In terms of findability, figshare implements all assessed features, except for content search.
743 Contrary to the public online version, figshare for institutions supports the migration of content
744 from preexisting or legacy repositories, including handles or unique identifiers. A function to
745 allow users to choose not to mint a new object identifier but use a pre-existing one was scheduled
746 to go live in 2021. Furthermore, the ability for full-text indexing of publications was expected
747 in 2021.

748 figshare accepts all file formats and offers several data viewers³³ with a well-documented
749 API for accessing and publishing data. figshare for institutions provides tools for customising
750 the submission process³⁴ and figshare for publishers includes flexible submission workflows³⁵.

751 Despite being not strongly focused on Social Connections, figshare has some social features
752 such as the creation of individual profiles that can be followed by other users. Generally, figshare
753 does not provide discussion forums for users but figshare for institutions allows communication
754 between administrators and submitting authors during the review process. Finally, figshare is
755 a closed source software platform. However, the developers provide a detailed roadmap and a
756 feature request forum with comments.

757 In summary, figshare represents a valid choice for institutions looking for a well established
758 platform providing solid foundations towards enabling the FAIREST principles broadly.

³²see for example <https://puma.uni-kassel.de/>

³³<https://drive.google.com/file/d/11N1D0e7b36SbeysmZeYc7-vP9qQyUIUx/view> (Accessed in July 2021)

³⁴<https://support.figshare.com/support/solutions/articles/6000225218-reviewing-items> (Accessed in July 2021)

³⁵<https://knowledge.figshare.com/publisher/workflows> (Accessed in July 2021)

759 **4.2.5 ResearchGate**

760 ResearchGate is more a social network for researchers than a repository. It offers many features
761 to establish social connections, such as comments, sharing, following, and a type of discussion
762 forum. Individual researchers have rich profiles and the connection to other researchers is
763 endorsed and supported with many (automatic) recommendation functionalities.

764 Yet, ResearchGate offers many features to manage and publish research artefacts, e.g. pub-
765 lications, presentations and raw data. It also offers free DOI assignment and integrates existing
766 DOIs. References and links are automatically extracted from publications and displayed. The
767 metadata of all artefacts can be searched and filtered, while the content itself is not indexed.
768 ResearchGate does not follow any established metadata standard and does not offer an API.
769 However, metadata can be imported based on the OAI standard and citations can be exported.

770 The interface is only available in English. The entire submission process is highly auto-
771 mated, with little space for customisation. For instance licences are automatically assigned and
772 cannot be set manually. ResearchGate is highly interactive and social as it offers push noti-
773 fications, preview features for many file formats, individual profiles, comment functions, and
774 sharing/follow features. The access control mechanism for artefacts is notable, e.g. because it
775 allows users to only offer private content to other researchers upon request.

776 The RG Score offers an interesting tool to monitor the individual impact of artefacts (mostly
777 for publications), but since its calculation is limited to the content on ResearchGate, its validity
778 is questionable. In addition, the handling of personal data and the compliance with the GDPR
779 is not clear in every aspect.

780 In summary, ResearchGate is an interesting platform to interact with other researchers and
781 broadly disseminate artefacts. However, it is highly proprietary and promotes a strong vendor
782 lock-in.

783 **4.2.6 Zenodo**

784 Zenodo is committed to enabling the publication of FAIR data³⁶ and scores well in the assess-
785 ment of these principles, but has almost no features to enable Engagement, Social Connections
786 or Trust.

³⁶<https://about.zenodo.org/principles/>

787 In particular, Zenodo is assessed highly on metrics that focus on aspects already included in
788 FAIR, including for example providing persistent, external identifiers for artefacts (findability),
789 or using open licences (reuse). There is also a focus on the simplicity of the publication workflow
790 and on ensuring programmatic access through a well documented and comprehensive API.

791 A unique feature in Zenodo is the long-term preservation policy, that guarantees availability
792 for at least 20 years and, presumably, a migration to alternative repositories in case of a
793 shutdown.³⁷ Since Zenodo is built upon the open source solution Invenio, it has an active
794 development community and accepts contributions from community members.³⁸

795 In summary, Zenodo should be considered for managing a collaborative and public repository
796 for publications and research data within consortia, e.g. cross-organisational research projects.
797 The close connection to Invenio and the open development indicate transparency and durability.

798 4.2.7 CKAN

799 CKAN is not primarily intended as a research data repository solution, but it is capable to
800 operate as one with some limitations. Its advantage is the relatively simple design and emphasis
801 on openness. CKAN offers a powerful search index and filter features. A special data store
802 allows to index and query tabular data very efficiently. The built-in federation feature via
803 harvesting allows to create a network of harmonised repositories.

804 CKAN targets the publication of Open Government Data and has established standards in
805 this domain. Those are, however, not always in line with the research data domain. For instance
806 CKAN has its own metadata schema and API specification. However, it can be extended and
807 the common DCAT format is already included. In addition, the API is very comprehensive and
808 allows a complete interaction with the repository. The CKAN frontend is also already available
809 in numerous languages.

810 Notable are the integrated data preview and visualisation feature, the extensive theming
811 module, and the well-documented extension interfaces. The latter allows users to customise
812 CKAN individually.

813 CKAN does not support the generation of DOIs and has a fixed submission process, that
814 is not suited for creating closed repositories. It also does not offer any relevant social features,

³⁷<https://about.zenodo.org/policies/>

³⁸<https://github.com/zenodo/zenodo>

815 such as user profiles or review functionalities. CKAN does not provide any mechanism for
816 long-term preservation.

817 Despite this, CKAN can act as a foundation for creating highly customised research data
818 repositories. Many missing features are available as community extensions, some requiring
819 additional custom development work. The core development is active and it can be expected
820 that CKAN will be supported and updated for the foreseeable future.

821 **4.2.8 Dataverse**

822 The system performs well in terms of findability, accessibility, and interoperability. It performs
823 weaker in the reusability category, and also in the remaining categories.

824 In the findability category, the only feature that is missing is content search, which is only
825 rarely available.

826 When looking at accessibility, Dataverse is one of just a few systems that provide different
827 access levels, ranging from open to closed, with the option of granting access to certain user
828 groups. Availability and long-term preservation depend on the running instance. Both aspects
829 are left to the system administrator.

830 Dataverse is also very powerful in terms of interoperability. It comes with a powerful
831 API, and provides a multitude of functionalities, including the support for different metadata
832 standards, linking of artefacts from outside the repository, and the possibility to use it for
833 metadata harvesting. The only feature that is missing is a customisable submission process.

834 Despite this, its portfolio in terms of reusability is limited. Nevertheless, the systems proves
835 to be very flexible, e.g. leaving content support to external tools.

836 The system also does not perform very well in the social connections category, but is compa-
837 rable to other on-premise solutions. Despite this, the system is well documented and provides
838 several features in the engagement category.

839 The trust category shows a mixed picture. On the one hand, it offers a variety of features,
840 including a review feature, which is only available in two of the reviewed systems. On the other
841 hand, we could not find any information about GDPR compliance. Only system backups are
842 possible, which needs to be handled by the system administrator.

843 In summary, Dataverse appears to be a valid solution for institutions looking for a robust

844 approach towards providing their users with flexibility both with respect to the consumption of
845 (i.e. access to) research artefacts, and with respect to the publication (i.e. depositing) process.

846 **4.2.9 DSpace**

847 Many universities, libraries, and similar organisations use DSpace, since its data model is based
848 on the organisational structure of academic institutions. This is achieved by linking the role
849 system with the gate keeping process. As soon as a user wants to create a publication, the
850 responsible persons of the organisation are automatically included in the publishing process.
851 The entire process can be highly customised. DSpace supports the ability to set an embargo
852 so that an artefact is only made available after a particular time.

853 DSpace relies on Dublin Core as its core metadata standard, including options to extend
854 and adapt it to the organisational requirements or scientific domain via configuration. However,
855 the metadata structure of DSpace remains very flat, allowing easy editing of properties, but
856 preventing the creation of a more complex and customised data structure. DSpace emphasises
857 import and export features of artefacts and their metadata, including a large variety of feature-
858 rich API standards and protocols. Long-term preservation is also supported, allowing the
859 creation of backups of the latest version of all artefacts. Currently, DSpace's development
860 community is implementing GDPR-related features, allowing to view and remove person-related
861 data.

862 DSpace is a proven solution to build on-premise institutional repositories for research pub-
863 lications and data. It is highly customisable and one of few solutions allowing to adapt the
864 submission process to the organisational realities.

865 **4.2.10 EPrints**

866 Since EPrints originates from a research group specifically looking at open access research
867 outputs and data, it tends to score well in the first three of the FAIREST principles. It provides
868 a platform meant to enable high accessibility and interoperability, especially through the use of
869 machine readable formats and APIs, and provides common functions to enable findability, as
870 well as enabling content search. Regarding reusability, EPrints mostly focuses on publications,
871 for which it supports common formats, but surprisingly does not allow to specify a licence for
872 the publications deposited.

873 EPrints does not provide many of the functions and capabilities other systems might include
874 as part of the engagement and social connection principles.

875 Since it is meant to provide a trusted repository for institutions, many of the metrics
876 considered in the trust principle are positively assessed for EPrints. It is useful to mention
877 in particular that EPrints is an open source system, and one of few that enable a customisable
878 depositing process to support gatekeeping. As an on-premise system, however, it expects the
879 operations related to GDPR compliance to be implemented by the local administrator rather
880 than providing those functions already embedded in the system.

881 In summary, EPrints appears to provide a valuable solution for institutions wanting to
882 focus on trust, both because of the reputation of a system originating from academia, but also
883 because of some of the features it focuses on (e.g. the customisable depositing process).

884 **4.2.11 Invenio**

885 Invenio is geared towards the implementation of large-scale digital repositories and features
886 that are not available in the base framework can be added by extending the publicly available
887 source code. For example, Zenodo is an implementation of Invenio, showcasing a potential
888 application of this framework.

889 In terms of the FAIREST principles, Invenio tends to be assessed positively for metrics
890 related to the findability, accessibility, and interoperability principles, due to a design that
891 favours compliance with FAIR: The use of persistent identifiers, of interoperable standards, of
892 comprehensive APIs and others.

893 As a counter point to this, the aspects related to user experience tend to be assessed less
894 positively, since Invenio was not designed to focus on those aspects. It especially makes no
895 claim towards enabling social network-like features and therefore scores poorly in terms of
896 Engagement and Social Connections.

897 It is worth mentioning that Invenio has recently (August 2021) launched a long-term sup-
898 port version of InvenioRDM³⁹ which is a tool built on top of the Invenio framework together
899 with Zenodo. This tool promises to enable anyone (e.g. institutions) to run a complete and
900 customisable service similar to Zenodo.

³⁹<https://inveniosoftware.org/products/rdm/>

901 In summary, Invenio appears to be a valid choice for institutions looking for a robust solution
 902 to enable the FAIR principles, just like Zenodo, but that is to be deployed on-premise.

903 5 Analysis & Recommendations

904 A core objective of this article is to provide a framework, through the FAIREST principles,
 905 enabling users and, in particular, research institutions, to select a solution that best meet their
 906 requirements. Indeed, besides making a choice between deploying on-premise solutions and
 907 using an online services, the framework and the individual assessments presented above can be
 908 used to make a selection, first, based on which part of the FAIREST principles is given higher
 909 priority. In a second phase, specific metrics can be considered to further refine this selection.

910 To make this principle-based approach to selecting a solution more concrete, Figure 1 shows
 911 a heatmap of aggregated scores for each principle and each solution. A cell represents a score
 912 for a solution in a principle, based on mapping the values of assessments to numerical values
 913 (e.g. yes is 1 and no is -1), and normalising the sum of those scores using the minimum and
 914 maximum possible scores for each principle.⁴⁰

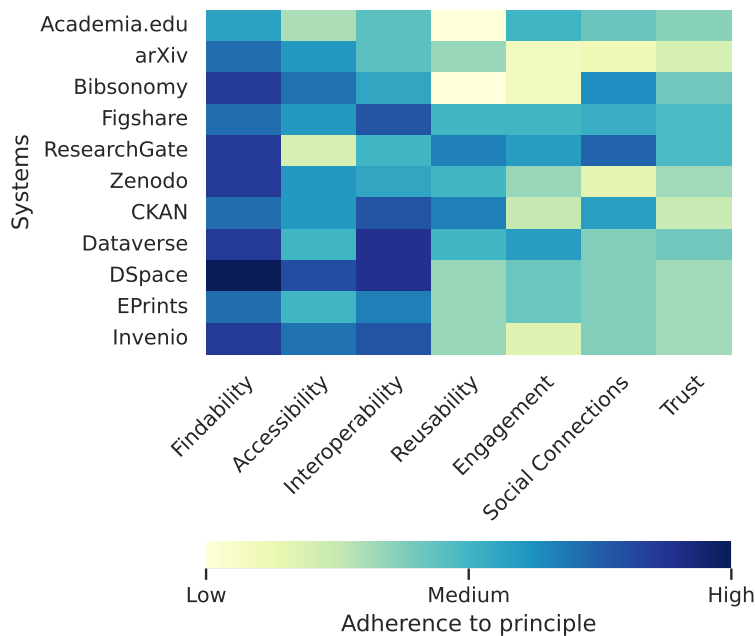


Figure 1: Level of adherence to the FAIREST principles.

915 As can be seen, this gives an overall picture of the degree to which each solution addresses the

⁴⁰spreadsheet templates in the supplementary material contains the mapping of value to scores and the normalisation formula.

916 FAIREST principles and acts as a decision support tool for the most appropriate solution. For
917 example, an institution that puts a strong focus on building a highly available infrastructure for
918 their research artefact might choose DSpace since it scores comparatively high on the findability,
919 accessibility, and interoperability principles. Another institution keen on ensuring that social
920 connections are well represented might turn to ResearchGate instead. In a third example, an
921 institution that is looking for a solution that is reasonably robust across all principles, might
922 want to select figshare.

923 Naturally, this can only be an initial selection based on a broad overview and more specific
924 requirements might be taken into account. Our core contribution is that the framework of
925 metrics based on the FAIREST principles is highly applicable to a wider variety of research
926 repository solutions. The template scoring sheets and existing assessments are openly avail-
927 able.⁴¹ Any new solution assessed is then easily comparable to the ones already addressed
928 here.

929 Interestingly, besides supporting the selection of a solution, the assessments in this form also
930 give some insight into the level of development of existing solutions. Even though the metrics
931 tend to be based on existing features in the assessed solutions, we can find areas that are less
932 supported by these solutions. At a high level, it appears striking in Figure 1 how the first
933 three principles of the FAIREST framework are significantly better addressed than the rest.
934 Trust appears especially badly covered, and, even though some solutions put some emphasis on
935 social connections, the human element of research repositories (social connection, engagement,
936 trust) appears not to be well developed. Below, we discuss in particular the aspects of rights
937 management, data reuse/consumption, and usability which appear as areas where large gaps
938 currently exist in the assessed systems.

939 In more detail, on rights management, due to the GDPR in the European Union, we would
940 have expected to see research repositories including more functions related to managing re-
941 quirements associated to data protection. While, even without the corresponding functions,
942 assessed solutions can be GDPR-compliant, the assessments in the trust principle show that
943 they tend not to include mechanisms that would facilitate enabling such compliance for the
944 administrators and users of the platform. This lack of support for rights management is also
945 visible in the reusability principle, where most systems score poorly in relation to enabling

⁴¹<https://doi.org/10.5281/zenodo.5282929>

946 producers to assign a licence to their artefacts, and for users to understand the rights included
947 in those licences for consumption of the artefacts. While this might be based on a naive view
948 that open research implies open licences for artefacts, this could actually create a barrier, since
949 even in open research, some artefacts require some level of legal protection.

950 Another aspect that could be seen as surprising is the lack of focus on the consumption
951 of artefacts in the assessed solutions. Considering that this is an important function found in
952 domain specific repositories, the fact for example that none of the assessed repositories include
953 functions to analyse data directly on the platform, and only a few of them enable visualisations,
954 could be seen as unexpected. That we only assessed generic (i.e. non-domain specific) solutions
955 can possibly explain this finding, since those functions are much harder to provide for generic
956 content. We believe that a stronger focus on the consumption side of research artefacts is
957 essential for open research to become a global reality.

958 Not unrelated to the point above, the aspect of usability of the research repository solutions
959 is something that we were not able to assess clearly. Indeed, almost none of the solutions appear
960 to make available the results of usability tests, and it is unclear whether such tests are actually
961 carried out. However, it is expected that, when choosing a solution, an institution or research
962 group might put some emphasis on such aspects. It would therefore, for the development of
963 the field as a whole, be a positive step to systematically carry out and publish usability tests.

964 Finally, it is worth noting that, while our definition of research repositories is broad and
965 could include any type of artefact, the assessed solutions only focus on two types: publications
966 and data. As shown for example in [34, 20, 35], the application of the FAIR principles can
967 be extended to different types of research resources, including software, and some domain-
968 specific repositories include a larger variety of artefacts. To this can be added that many of
969 these research resources are often shared on repositories that are not specifically dedicated to
970 research (such as Github⁴² for example).

971 **6 Conclusion and Outlook**

972 In this article, we introduced the FAIREST principles and proposed a framework, based on
973 these principles, to assess research repositories and support institutions in selecting a solution

⁴²<https://github.com>

974 meeting their requirements. The FAIREST principles are inspired from, adapt and add to the
975 FAIR principles including aspects that focus more on human interaction, the social context of
976 research, as well as the trust users can place in the repository and the artefacts they contain,
977 than on aspects purely related to data exchange. For each of the principles, we included a set of
978 metrics with clear guidelines on assessing them, and used those to assess 11 domain-independent
979 and actively used solutions.

980 While the objective of those assessments is to provide a view of the strengths and weaknesses
981 of each solution for the purpose of selecting one, it also provides us with an overview of the
982 current state of development of the considered research repository solutions. It showed in
983 particular that some aspects, such as usability, data reuse, and data rights, were not well
984 addressed by the solutions. More focus in future development of the systems might be put on
985 improving those aspects to better enable in particular engagement and trust.

986 We chose to focus our exploration of existing solutions on domain-independent, actively
987 developed and used systems. However, the framework itself as a set of metrics and a scoring
988 mechanism using those metrics is straightforwardly applicable to other research repositories.
989 It would, in particular, be interesting to compare the results obtained here with assessments
990 of domain-specific repositories, to see if similar conclusions can be drawn and what the main
991 differences are. Even if our framework was designed to enable such use, additional elements to
992 assess, in the form of new metrics, might also be uncovered in this way.

993 Finally, when designing the FAIREST framework, our assumed target user was someone in
994 a position to decide on the solution to use or deploy within a university, a research institute or
995 another similar organisation. The end-users of the solution, such as researchers, were considered
996 implicitly included since they would be taken into consideration by the person making the
997 decision. However, researchers looking to decide on which solution to use to make available
998 their research artefacts might not focus on the same criteria as what we have established here,
999 and our framework might need to be adapted to support this scenario.

1000 Another category of users of the FAIREST framework are the developers of research repos-
1001 itory solutions. While those might find that some additional metrics are required to cover new
1002 features they are developing,⁴³ we hope and expect that developers of new and existing solu-

⁴³For example, ResearchGate having developed a mobile application for their platform, they might consider mobile availability a relevant metric.

1003 tions will use the FAIREST framework as a guide to evolve their platform and address some of
1004 the gaps identified.

1005 **Acknowledgements**

1006 We thank Hannes Wünsche for many fruitful discussions, and for contributing to the develop-
1007 ment of the framework. We also thank Leonard Mack for critically reviewing the paper.

1008 This research was supported by the Fundação para a Ciência e a Tecnologia through the
1009 LASIGE Research Unit, UIDB/00408/2020 and UIDP/00408/2020.

1010 This work was supported by the Federal Ministry of Education and Research of Germany
1011 (BMBF) under grant no. 16DII128 (“Deutsches Internet-Institut”).

1012 **Author Contribution Statement**

1013 Mathieu d’Aquin, Fabian Kirstein, Sonja Schimmler and Sebastian Urbanek proposed the re-
1014 search problem. All authors contributed parts of performing the research, of the design of the
1015 research framework, and of collecting and analysing the data. All authors wrote sections of the
1016 manuscript and contributed to its revision.

1017 **Supplementary material**

1018 Assessment tables for all 11 systems analysed as well as the template table for analysing new
1019 systems are available at <https://doi.org/10.5281/zenodo.5282929>.

1020 **References**

- 1021 [1] D. Nicholas, I. Rowlands, A. Watkinson, D. Brown, B. Russell, and M. Jamali, “Have
1022 digital repositories come of age? the views of library directors,” *Webology*, 2013.
- 1023 [2] M. D. Wilkinson, M. Dumontier, I. J. Aalbersberg, G. Appleton, M. Axton, A. Baak,
1024 N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, P. E. Bourne, J. Bouwman, A. J.
1025 Brookes, T. Clark, M. Crosas, I. Dillo, O. Dumon, S. Edmunds, C. T. Evelo, R. Finkers,

- 1026 A. Gonzalez-Beltran, A. J. Gray, P. Groth, C. Goble, J. S. Grethe, J. Heringa, P. A. 't
1027 Hoen, R. Hooft, T. Kuhn, R. Kok, J. Kok, S. J. Lusher, M. E. Martone, A. Mons, A. L.
1028 Packer, B. Persson, P. Rocca-Serra, M. Roos, R. van Schaik, S.-A. Sansone, E. Schultes,
1029 T. Sengstag, T. Slater, G. Strawn, M. A. Swertz, M. Thompson, J. van der Lei, E. van
1030 Mulligen, J. Velterop, A. Waagmeester, P. Wittenburg, K. Wolstencroft, J. Zhao, and
1031 B. Mons, "The FAIR guiding principles for scientific data management and stewardship,"
1032 *Scientific Data*, vol. 3, 2016.
- 1033 [3] A. Borrego, "Institutional repositories versus ResearchGate: The depositing habits of
1034 spanish researchers: Institutional repositories versus ResearchGate," *Learned Publishing*,
1035 vol. 30, no. 3, pp. 185–192, 2017.
- 1036 [4] D. Nicholas, I. Rowlands, A. Watkinson, D. Brown, and M. HamidR.Jamali, "Digital
1037 repositories ten years on: what do scientific researchers think of them and how do they
1038 use them?," *Learned Publishing*, 2012.
- 1039 [5] R. C. Amorim, J. A. Castro, J. Rocha da Silva, and C. Ribeiro, "A comparison of re-
1040 search data management platforms: architecture, flexible metadata and interoperability,"
1041 *Universal Access in the Information Society*, vol. 16, no. 4, pp. 851–862, 2017.
- 1042 [6] S. Manca, "ResearchGate and Academia.edu as networked socio-technical systems for
1043 scholarly communication: a literature review," *Research in Learning Technology*, vol. 26,
1044 no. 0, 2018.
- 1045 [7] D. Benz, A. Hotho, R. Jäschke, B. Krause, F. Mitzlaff, C. Schmitz, and G. Stumme, "The
1046 social bookmark and publication management system bibsonomy: A platform for evaluat-
1047 ing and demonstrating Web 2.0 research," *The VLDB Journal*, vol. 19, no. 6, pp. 849–875,
1048 2010.
- 1049 [8] K. Arlitsch and C. Grant, "Why so many repositories? examining the limitations and
1050 possibilities of the institutional repositories landscape," *Journal of Library Administration*,
1051 vol. 58, no. 3, pp. 264–281, 2018.

- 1052 [9] M. Kindling, H. Pampel, S. van de Sandt, J. Rücknagel, P. Vierkant, G. Kloska, M. Witt,
1053 P. Schirmbacher, R. Bertelmann, and F. Scholze, “The landscape of research data reposi-
1054 tories in 2015: A re3data analysis,” *D-Lib Magazine*, vol. 23, no. 3, 2017.
- 1055 [10] M. Andro, E. Asselin, and M. Maisonneuve, “Digital libraries: Comparison of 10 software,”
1056 *Library Collections, Acquisitions, and Technical Services*, vol. 36, no. 3, pp. 79–83, 2012.
- 1057 [11] M. Assante, L. Candela, D. Castelli, and A. Tani, “Are scientific data repositories coping
1058 with research data publishing?,” *Data Science Journal*, vol. 15, no. 0, p. 6, 2016.
- 1059 [12] C. C. Austin, S. Brown, N. Fong, C. Humphrey, A. Leahey, and P. Webster, “Research
1060 Data Repositories: Review of Current Features, Gap Analysis, and Recommendations for
1061 Minimum Requirements,” *IASSIST Quarterly*, vol. 39, no. 4, p. 24, 2016.
- 1062 [13] S. Kim, “Functional requirements for research data repositories,” *International Journal of*
1063 *Knowledge Content Development & Technology*, vol. 8, no. 1, pp. 25–36.
- 1064 [14] L. H. Marcial and B. M. Hemminger, “Scientific data repositories on the web: An initial
1065 survey,” *Journal of the American Society for Information Science and Technology*, vol. 61,
1066 no. 10, pp. 2029–2048, 2010.
- 1067 [15] D. Murphy and J. Gautier, “A comparative review of vari-
1068 ous data repositories.” Online article [https://dataverse.org/blog/](https://dataverse.org/blog/comparative-review-various-data-repositories)
1069 [comparative-review-various-data-repositories](https://dataverse.org/blog/comparative-review-various-data-repositories), 2017.
- 1070 [16] S. Joo and J. Yeon Lee, “Measuring the usability of academic digital libraries: Instrument
1071 development and validation,” *The Electronic Library*, vol. 29, no. 4, pp. 523–537, 2011.
- 1072 [17] J. Nielsen and T. K. Landauer, “A mathematical model of the finding of usability prob-
1073 lems,” in *Proceedings of the INTERACT’93 and CHI’93 conference on Human factors in*
1074 *computing systems*, pp. 206–213, 1993.
- 1075 [18] R. Máchová, M. Hub, and M. Lněnička, “Usability evaluation of open data portals: Eval-
1076 uating data discoverability, accessibility, and reusability from a stakeholders’ perspective,”
1077 *Aslib Journal of Information Management*, vol. 70, no. 3, 2018.

- 1078 [19] A. Jacobsen, R. de Miranda Azevedo, N. Juty, D. Batista, S. Coles, R. Cornet, M. Courtot,
1079 M. Crosas, M. Dumontier, C. T. Evelo, C. Goble, G. Guizzardi, K. K. Hansen, A. Hasnain,
1080 K. Hettne, J. Heringa, R. W. Hooft, M. Imming, K. G. Jeffery, R. Kaliyaperumal, M. G.
1081 Kersloot, C. R. Kirkpatrick, T. Kuhn, I. Labastida, B. Magagna, P. McQuilton, N. Meyers,
1082 A. Montesanti, M. van Reisen, P. Rocca-Serra, R. Pergl, S.-A. Sansone, L. O. B. da
1083 Silva Santos, J. Schneider, G. Strawn, M. Thompson, A. Waagmeester, T. Weigel, M. D.
1084 Wilkinson, E. L. Willighagen, P. Wittenburg, M. Roos, B. Mons, and E. Schultes, “FAIR
1085 Principles: Interpretations and Implementation Considerations,” *Data Intelligence*, vol. 2,
1086 no. 1-2, pp. 10–29, 2020.
- 1087 [20] W. Hasselbring, L. Carr, S. Hettrick, H. Packer, and T. Tiropanis, “From FAIR research
1088 data toward FAIR and open research software,” *it - Information Technology*, vol. 62, no. 1,
1089 pp. 39–47.
- 1090 [21] A.-L. Lamprecht, L. Garcia, M. Kuzak, C. Martinez, R. Arcila, E. Martin Del Pico,
1091 V. Dominguez Del Angel, S. van de Sandt, J. Ison, P. A. Martinez, P. McQuilton, A. Va-
1092 lencia, J. Harrow, F. Psomopoulos, J. L. Gelpi, N. Chue Hong, C. Goble, and S. Capella-
1093 Gutierrez, “Towards FAIR principles for research software,” *Data Science Journal*, vol. 3,
1094 no. 1, pp. 1–23, 2019.
- 1095 [22] A. Devaraju, M. Mokrane, L. Cepinskas, R. Huber, P. Herterich, J. d. Vries, V. Akerman,
1096 H. L’Hours, J. Davidson, and M. Diepenbroek, “From conceptualization to implementa-
1097 tion: FAIR assessment of research data objects,” *Data Science Journal*, vol. 20, no. 1, p. 4,
1098 2021.
- 1099 [23] Research Data Alliance FAIR Data Maturity Model Working Group, “FAIR Data Maturity
1100 Model: Specification and guidelines.” Report from the Research Data Alliance, 2020.
- 1101 [24] European Commission, Directorate-General for Research and Innovation, “Turning fair
1102 into reality: final report and action plan from the european commission expert group on
1103 fair data,” *Publications Office*, 2018.
- 1104 [25] D. Lin, J. Crabtree, I. Dillo, R. R. Downs, R. Edmunds, D. Giarretta, M. De Giusti,
1105 H. L’Hours, W. Hugo, R. Jenkyns, V. Khodiyar, M. E. Martone, M. Mokrane, V. Navale,

- 1106 J. Petters, B. Sierman, D. V. Sokolova, M. Stockhause, and J. Westbrook, “The TRUST
1107 principles for digital repositories,” *Scientific Data*, vol. 7, no. 1, p. 144, 2020.
- 1108 [26] S. R. Carroll, E. Herczog, M. Hudson, K. Russell, and S. Stall, “Operationalizing the
1109 CARE and FAIR Principles for Indigenous data futures,” *Scientific Data*, vol. 8, no. 1,
1110 p. 108, 2021.
- 1111 [27] M. Assante, L. Candela, D. Castelli, P. Manghi, and P. Pagano, “Science 2.0 Repositories:
1112 Time for a Change in Scholarly Communication,” *D-Lib Magazine*, vol. 21, no. 1/2, 2015.
- 1113 [28] M. L. Williams, “The adoption of Web 2.0 technologies in academic libraries: A com-
1114 parative exploration,” *Journal of Librarianship and Information Science*, vol. 52, no. 1,
1115 pp. 137–149, 2020.
- 1116 [29] S. Ovadia, “ResearchGate and Academia.edu: Academic Social Networks,” *Behavioral &
1117 Social Sciences Librarian*, vol. 33, no. 3, pp. 165–169, 2014.
- 1118 [30] N. Paskin, “Digital object identifier (doi®) system,” *Encyclopedia of library and informa-
1119 tion sciences*, vol. 3, pp. 1586–1592, 2010.
- 1120 [31] L. Chan, D. Cuplinskas, M. Eisen, F. Friend, Y. Genova, J.-C. Guédon, M. Hagemann,
1121 S. Harnad, R. Johnson, R. Kupryte, M. La Manna, I. Rév, M. Segbert, S. de Souza,
1122 P. Suber, and J. Velterop, “Budapest open access initiative.” Online declaration, [https:
1123 //www.budapestopenaccessinitiative.org/read](https://www.budapestopenaccessinitiative.org/read), 2002.
- 1124 [32] B. Fecher and S. Friesike, “Open Science: One Term, Five Schools of Thought,” in *Open-
1125 ing Science* (S. Bartling and S. Friesike, eds.), pp. 17–47, Cham: Springer International
1126 Publishing, 2014.
- 1127 [33] P. Splawa-Neyman, “Figshare and the fair data principles.” Online article:
1128 [https://figshare.com/articles/journal_contribution/Figshare_and_the_FAIR_
1129 data_principles/7476428/1](https://figshare.com/articles/journal_contribution/Figshare_and_the_FAIR_data_principles/7476428/1), 2018.
- 1130 [34] C. Goble, S. Cohen-Boulakia, S. Soiland-Reyes, D. Garijo, Y. Gil, M. R. Crusoe, K. Peters,
1131 and D. Schober, “FAIR computational workflows,” *Data Intelligence*, vol. 2, no. 1, pp. 108–
1132 121, 2020.

1133 [35] N. T. de Sousa, W. Hasselbring, T. Weber, and D. Kranzlmuller, “Designing a generic
1134 research data infrastructure architecture with continuous software engineering,” in *Soft-*
1135 *ware Engineering Workshops 2018*, vol. 2066 of *CEUR Workshop Proceedings*, pp. 85–88,
1136 CEUR-WS.org, 2018.