Towards a sustainable Open Data Ecosystem

D2.2
User needs from a technical perspective

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Abbreviations

CPO   Chief Privacy Officer
D   Deliverable
ESR   Early Stage Researcher
FAIR   Findable, Accessible, Interoperable and Reusable
FAV   Fully Automated Vehicles
LOD   Level of Detail
M   Milestone
MQA   Metadata Quality Assessment
NGO   Non-Governmental Organizations
NPO   Non-Profit Organizations
OD   Open Data
ODE   Open Data Ecosystems
ODP   Open Data Portals
ODECO   Project "Towards a sustainable Open Data ECOsystem"
PBR   Perspective-Based Reading
WP   Work Package

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8	Farosnet S.A.	FAROSNET S.A.	Greece
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2	Digitaal Vlaanderen	DV	Belgium
3	City of Copenhagen	COP	Denmark
4	City of Rotterdam	RDAM	Netherlands
5	CoC Playful Minds	CoC	Denmark
6	Derilinx	DERI	Ireland
7	ESRI	ESRI	Netherlands
8	Maggioli S.p.A	MAG	Italy
9	National Centre of Geographic Information	CNIG	Spain
10	Open Knowledge Belgium	OKB	Belgium
11	SWECO	SWECO	Netherlands
12	The government lab	GLAB	United States of America
13	Agency for Data Supply and Infrastructure	ADSI	Denmark

1. Introduction

1.1. Background

In the current digital landscape, the Open Data (OD) movement is experiencing rapid growth, driven by the exponential increase in data accessibility through open data portals (de Juan-Espinosa & Luján-Mora, 2020; Reggi & Dawes, 2022). Projections from the European Commission estimate that by 2025, the net value of the size of the European Union open data market will be almost 200 billion euros, impacting over a million employees in the open data sector (Publications Office of the European Union, 2022).

The core principle of open data is to enable free and unrestricted usage, sharing, and access to data in any available format (European Comission, 2011). Governments are progressively initiating OD initiatives and setting up dedicated portals to facilitate the dissemination of open data in reusable formats. Consequently, a multitude of open data repositories, catalogues, and websites have appeared to serve this purpose.

OD Portals (ODP) play a pivotal role in easing data openness. ODPs serve as online repositories featuring detailed dataset descriptions based on key attributes such as authorship, provenance, and licensing (Neumaier, Umbrich, & Polleres, 2016). These catalogues ease the exploration and administration of metadata records which provide valuable insights into datasets that may be accessible for download in various distribution formats. OD initiatives assume that publication of open data through ODPs will increase the demand for high-quality data and enhance the overall quality of the ODPs. Complementary, the publication of public sector data stands as significant drivers behind the prevailing movement to open government data via an open data portal (Carrara, Chan, Fischer, & Van-Steenbergen, 2015).

Open Data Ecosystems (ODE) is an emerging concept for data sharing under public licenses in software ecosystems. However, many existing ODEs are provider-centric and often struggle to effectively align supply with demand (Van Loenen, et al., 2021). There is a widely recognized consensus that user engagement plays a pivotal role in shaping the evolution of ODE. Despite this, the current landscape stays influenced by data providers. The design and implementation of existing ODPs reflect this misalignment. Therefore, a more collaborative and user-centred approach is essential for the best use and value of OD.

In this context, ODECO Task 2.2 focuses on investigating the technological requirements for the provision of Findable, Accessible, Interoperable and Reusable (FAIR) data for different categories of users (Wilkinson, Dumontier, Aalbersberg, & al., 2016). This includes identifying gaps between the needs of user groups and the current features of ODPs and define and evaluate new approaches for designing user driven user interfaces for finding data that fulfils different findability and accessibility requirements from different domains, developing 'data integrators', enabling the technical interoperability of OD stemming from different domains, and determining the minimum and optimal set of metadata descriptions to be adopted to allow for semantic interoperability of open data across domains and disciplines. Partner organisations will support Task 2.2 with their experience in data provision issues.

1.2. Problem definition

ODECO Task 2.2 has its origins in **the lack of a systematic integration of technical perspectives into understanding user needs related to open data.** This deficiency hampers efficient OD discovery, use, innovation, interoperability, and reusability, compromising the adherence to FAIR principles of OD initiatives. The absence of a comprehensive approach to align user needs with technical requirements hinders the integration of diverse user groups and domains, impeding the development of a collaborative and well-integrated ODE. Addressing this gap is critical for fostering effective OD use and ensuring the successful implementation of OD initiatives to maximize their benefits across various sectors and domains.

ODECO

Failure to address these technical aspects could undermine the success of OD initiatives and limit their impact on easing OD usage. The lack of a technical perspective on the understanding of user needs is a problem for several reasons:

- **Inefficient Data Discovery and Utilisation**: Without a clear understanding of the technical requirements that user needs imply, data discovery and utilisation may become inefficient and time-consuming. Users may struggle to find relevant data, leading reactions than ranges from. frustration (e.g., a non-specialist user that has not access to specialized tools for using data) to reduced productivity (e.g., a journalist that find limited the indexing capabilities of open data portals).
- **Missed Opportunities for Innovation in ODPs:** Diverse user groups bring unique insights and requirements to data usage. These opportunities only can be understood in the context of their user needs. Ignoring these technical needs (e.g., provide guidance for connecting open data API to business data pipelines) means not only to miss opportunities for innovative solutions and novel applications of open data but also hampers the daily use of open data.
- **Fragmented Data Ecosystem**: The absence of tailored user interfaces (e.g., a user interface adapted to Non-Profit Organizations (NPOs) and Non-Governmental Organizations (NGOs) focused on health can be different from a user interface adapted to NPOs and NGOs focused on poverty) and interoperability mechanisms based on the user needs (e.g., the interoperability needs of a government body are different from the interoperability needs of a company) inhibits data sharing and collaboration across domains, hindering the potential for cross-disciplinary insights.
- **Reduced Data Reusability**: Technical requirements play a crucial role in ensuring data reusability. Without considering these needs, data may not be appropriately formatted or described for being reused, limiting its usefulness, and hindering its potential for reuse.
- **Undermining FAIR Principles**: The FAIR principles focus on ease data sharing and reuse and are technology independent, but neglecting technical requirements derived from user needs undermine these principles. Data may not be as accessible or interoperable as intended, undermining the overall FAIR-ness of the data.

In conclusion, the lack of a technical perspective on user needs poses significant challenges for the ODEs and the overarching goal of promoting FAIR data provision. This shortfall hinders efficient data utilisation, innovation, and collaboration, impeding the realisation of OD initiatives' objectives and the broader benefits of OD. Addressing this problem is crucial to unlocking the full potential of open data for diverse user groups and driving meaningful advancements across various domains.

1.3. Role of this deliverable in the ODECO project

In ODECO deliverable 2.2, we aim to reduce the gap between the needs of various user groups and technological solutions intended to enable them to make the best use of the data. The result is a list of user-driven technologic requirements that OD initiatives should consider. This deliverable is a logical continuation of ODECO deliverable 2.1, "Open data user needs: seven flavours" (Staso, y otros, 2023), and provides valuable input for future ODECO Task 3.2, "Closing the cycle: promoting data user's contribution from a technical perspective".

The challenge of understanding user needs from a technical perspective in the context of FAIR data provision is considerable. The ODECO project aims to address the fundamental issue of making data Findable, Accessible, Interoperable, and Reusable for diverse user groups. However, the lack of a comprehensive understanding of user needs from a technical standpoint has far-reaching implications. This is the main reason that ESRs involved in Task 2.2 are committed in their respective Research Projects to research on the technological requirements for the provision of FAIR data:

- The identification of gaps between the needs of user groups and the current features of open data platforms and the definition and evaluation of approaches for designing user driven user interfaces for finding data that fulfils different findability and accessibility requirements from different domains (ESR 2).

- The development of data integrators to enable the technical interoperability of open data stemming from different domains (ESR 5).
- The determination of a minimum set of metadata descriptions to allow semantic interoperability of open data across different domains (ESR 7).
- The use of technical features in open data portals to improve data reuse (ESR 8).

As a result, the main goal within ODECO of deliverable 2.2 is to identify and document technical prerequisites for FAIR data provision, originating directly from user needs. That is, this deliverable is a key block in the collective ODECO work to harness the potential of ODE.

1.4. Structure

The next Section details the methodological approach adopted in Task 2.2, encompassing theoretical foundations, strategy, scope, and definitions. Section 3 clarifies the alignment of FAIR Principles with user needs and OD by exploring user needs related to findability, accessibility, interoperability, and reusability in the literature. Transitioning to a technical perspective, Section 4 outlines user requirements based on user needs in the context of user interfaces, accessibility, interoperability, and data portals. A requirement assessment ensues in Section 5, followed by a comprehensive FAIR Data provision requirements specification (Section 6). Finally, we conclude this deliverable by summarizing the insights gained for the ODECO project.

2. Methodology

Finding the gaps that characterises the lack of a systematic integration of technical perspectives into understanding user needs related to open data is challenging. This section provides, firstly, a comprehensive foundation for our research method and approach to identify these gaps and secondly, it proposes technical requirements that may help to close the gap. It introduces *Perspective-Based Reading* (PBR) and how can it be useful to the elicitation of *FAIR implementation recommendations*.

Next, this section outlines the method implemented in detail, including literature examination, requirement extraction, alignment with ODECO early-stage researchers' projects, and open data platform assessment, all aimed at user-centric, FAIR-compliant open data dissemination implementation. Additionally, it clarifies the scope of this deliverable, which focuses on technical requirements addressing open data user needs and introduces a Table defining key actors and stakeholders in the open data ecosystem for a better understanding of their roles and interests.

2.1. Theoretical foundations

The methodological approach is based on *Perspective-Based Reading* (PBR) and its application to requirements documents (Victor, et al., 1996). The goal of PBR is to provide operational scenarios where members of a review team read a document (in this case, literature on open data) from a particular perspective (e.g., distinct types of open data users). The assumption is that the combination of different perspectives provides a better understanding of the topic, i.e., uncovers a wider range of requirements and gaps.

OD user needs are often misunderstood and improperly specified due to lack of open data expertise in data publishers and bias on solving the needs of data publishers first during the requirements elicitation process of open data initiatives. To tackle these problems, we express open data user needs using user stories. A user story is a short, simple description of a feature told from the perspective of the user who wishes the capability. This approach has been proven successful in other challenging requirements elicitation and review scenarios (Femmer, Méndez Fernández, Wagner, & Eder, 2017; Villamizar, Kalinowski, Garcia, & Mendez, 2020).

Discovery and reuse of OD by society maximize its usefulness. The FAIR principles describe the ideal way data should be stored and shared by data publishers to achieve this goal (Wilkinson, Dumontier, Aalbersberg, & al., 2016). FAIR stands for:

- *Findability* is the extent to which humans and machines can easily discover (meta)data.
- *Accessibility* is the extent to which humans and machines can fetch (meta)data successfully.
- *Interoperability* is the extent to which different applications and systems can successfully communicate and exchange data with unambiguous, shared meaning.
- *Reusability* is the extent to which (meta)data are well-described, rich, and appropriate so that others can reuse it.

FAIR guiding principles do not dictate specific technological implementations, but provide guidance for improving Findability, Accessibility, Interoperability and Reusability of open data. However, this lack of technical specification may result in inconsistent interpretations that carry the risk of increasing the gap between user needs and open data portal features. We adhere to the vision expressed by (Jacobsen, et al., 2020) of explicit *FAIR implementation considerations* (i.e., *FAIR technical requirements*) to operationalize the implementation of FAIR principles. Therefore, the identification of the principles implemented by the requirements will be one of the parts of the implemented methodology.

2.2. Strategy

The first step is the examination of pertinent literature and sources gathered in the ODECO deliverable 2.1, "Open data user needs: seven flavours", for the identification of user needs that may possess a technical dimension. The identified user needs from different user types are correlated with the FAIR principles according to their content. This is a PBR activity. It is important to acknowledge that some user needs may be related with multiple FAIR principles. In such scenarios, the determination of their placement is guided either by the closest conceptual affinity or, in instances where an only source holds relevance to multiple FAIR principles, the identified need is associated to multiple principles. For example, it is quite easy from the text below to identify the following requirement that can be related to Findability:

> "Open data portal users demand feedback and collaboration tools, so they enable the possibility to read interesting thoughts and ideas of other users on the datasets through the comments they enter on them." (Alexopoulos, Zuiderwijk, Charapabidis, Loukis, & Janssen, 2014)

Section 3 contains a detailed report of the above examination.

Next, we derive from the documentation a list of requirements that may have technical requirements in the form of user stories. This is a PBR activity but restricted to point of view and experience of the ODECO early-stage researchers in their own research projects. User stories typically follow a simple template:

> As a [type of user], I want [some goal] so that [some reason].

Example, in *"as a visitor of the open data portal, I can access a list of old featured datasets that are no longer on the home page, so I can access datasets I remember from the past or that others mention to me"*:

- The type of user is a visitor of the open data portal.
- The goal is to be able to access the list of old featured datasets.
- The reason is to quickly access them on demand.

To enrich the analysis, user stories should be rewritten in a systematic way. For each requirement, the outcome of this work should produce:

- A unique ID (this can be done at a later stage).
- A description of the feature, condition, capability; it should be based on the "goal."
- A description of the stakeholder who requested it; it should be based on the "type of user."
- A description of its relevance; it should be based on the "reason."

Section 4 shows the user stories and requirements identified following this procedure.

Next, this list of requirements should be assessed. The discussion must answer at least the following questions:

1. Are the requirements implemented in open data platforms?
2. If they are implemented, are they implemented in a way that user needs are satisfied?
3. If the user needs are not satisfied, can we identify the root cause?

Section 5 summarizes this assessment.

Finally, we associate each requirement to the fulfilment of one or more of the FAIR principles outlined in the previous subsection. Section 6 presents the output of this task.

2.3. Scope

User needs vary in nature and cover a wide range of related issues. Requirements derived from user needs include direct, indirect, functional, non-functional, governance and technical requirements. The

focus of the ODECO deliverable 2.2 are the technical requirements derived from user needs, especially those that open data portals fail to satisfy. Especially for systems with frequent user interactions like data portals, the gap between user expectations and system data delivery becomes more pronounced. Additionally, these discrepancies significantly affect open data usage by various user groups. Addressing this diverse range of user needs is a challenge that requires a multidimensional and focused approach. This deliverable intends to translate these issues into technological requirements, following FAIR data provision principles.

In ODECO deliverable 2.1, the ODECO project had identified user types and stakeholders in the open data ecosystem, each with unique needs and expectations. These needs span various contexts, such as local governments, open data intermediaries, disadvantaged groups, and non-specialist users. The analysis performed in this deliverable is a continuation of such deliverable. Specifically, we concentrate on technological requirements conceptually aligned with FAIR data provision principles that address the user needs of D2.1 user types.
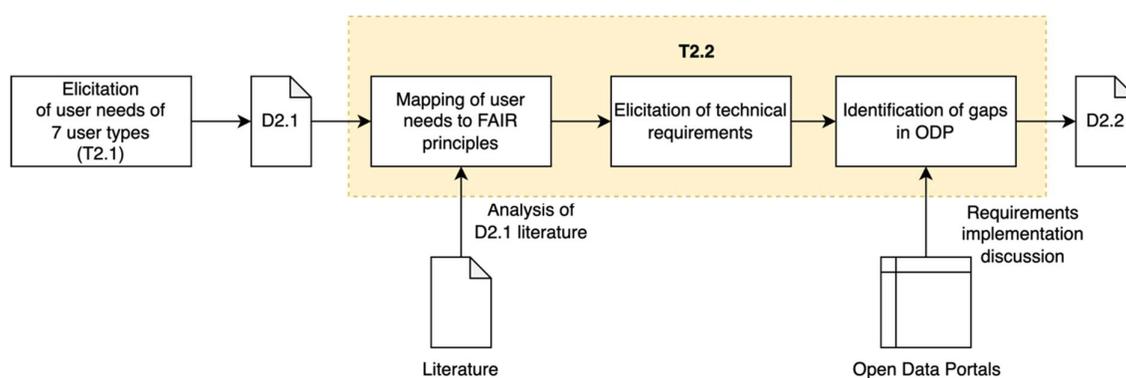
Figure 1. Scope of ODECO deliverable 2.2

These technological requirements encompass both functional (related to system technical details) and non-functional aspects (e.g., interoperability, accessibility, governance). We present the mapping of user needs to FAIR principles in section 3, the elicitation of requirements in Section 4 and Section 5, and categorize these requirements as functional or non-functional in section 6 of this deliverable.

2.4. Additional definitions
Below we provide definitions for the actors, user, stakeholders considered during the analysis.

Table 1: The actors/users/stakeholders considered for user stories and requirements.

Stakeholder	Role in Open data ecosystem
Academic institutions	The organisation engages in research activities, provides educational courses, and advocates for the use of open datasets in conducting data-driven investigations (Staso, et al., 2023).
Artificial users	Automated systems or bots that access, process, or interact with open data without human intervention (Staso, et al., 2023).
Chief Data Officers	Manage the planning, implementation, and evaluation of an organisation's data strategy and governance to foster data-informed decision making (Amezaga & Sarin, 2023).
Communities (Cities)	To enhance local governance, infrastructure, and citizen services, generate and utilize open data (Corbett, Templier, & Takeda, 2018).
Companies/Corporates	Utilize open data to inform business strategies, develop products, or provide services, often with a profit motive (Zuiderwijk, Janssen, Poulis, & Van De Kaa, 2015).

Stakeholder	Role in Open data ecosystem
Curriculum Designers	The incorporation of open data ideas, tools, and datasets into educational materials is essential for the cultivation of data literacy and the development of related skills (Saddiqa, Magnussen, Larsen, & Myrup, Sept 2021).
Data curators	Maintain and improve datasets to increase their accuracy, usefulness, and timeliness.
Data experts	Expertise in one or more data fields is necessary for ensuring that data is useful and accurate.
Data hackathon organizers	Promote creative use of open data by hosting events where people may work together to find solutions to problems (Briscoe & Mulligan, 2014).
Data infrastructure developers	Build and maintain the technical platforms and tools required for the storage, processing, and distribution of open datasets.
Data Scientists	Analyse and model publicly available open datasets to generate actionable insights and predictive outcomes.
Data stewards or data custodian	Protect the quality and integrity of data by making sure it is well-cared-for and widely shared.
Educational ecosystem	This concept encompasses all stakeholders, technologies, and approaches that facilitate and use open data for the sake of learning and skill enhancement.
End-users	Individuals might get direct or indirect advantages from the use of open data-driven apps, services, or insights in their everyday routines (Staso, et al., 2023).
Governments	Produce and distribute datasets to the public, promoting openness, accountability, and participation in civic life (Chattapadhyay, 2014).
Journalists	Utilize open data for investigative journalism, story lines, and fact-checking (Tabary, Provost, & Trottier, 2016).
Legal advisors (Data Licensing Specialist or Licensing Manager)	Instructions for staying within the law while exchanging information (Brugger, et al., 2016).
NGOs and NPOs	Advocate for open data and utilize it to support their missions and goals (Brugger, et al., 2016).
Non-specialist users	Engage with open data without deep technical expertise, relying on more user-friendly platforms and applications (Staso, et al., 2023).
OD Intermediaries	Bridge the disparity between data publishers and users, typically by providing tools, platforms, or services that improve the accessibility and usability of data (Dumpawar, 2015).
OD Publishers	Facilitate the dissemination of open datasets, assuring data integrity, accessibility, and the application of the correct licensing (Radchenko & Sakoyan, On Some Russian Educational Projects in Open Data and Data Journalism, 2016).
OD users with Special (varying) needs	Individuals can get access to and make use of open data by using specialized accommodations or tools that have been customized to meet their distinct needs (such as physically impaired OD users, the blind, the visually impaired, and dyslexics).
OGD Users	Utilize open government data to inform research, policy development, and the creation of citizen-centric solutions (Radchenko & Sakoyan, The View on Open Data and Data Journalism, 2014).
Open data users	Analyse and put into operation open datasets to gain insights, make decisions, or develop applications.

Stakeholder	Role in Open data ecosystem
Policy makers/Decision makers	Utilize insights derived from open data to educate, formulate, and execute public policies or organisational objectives (Baack, Datafication and empowerment, 2015).
Privacy analyst or Chief Privacy Officer (CPO)	Protect people's privacy and guarantee that their open data is handled and shared properly.
Researchers	Use open data as the basis for academic, scientific, or policy-related research and writing.
Smart Applications (Transportation apps)	Leverage publicly available (open data) information to provide timely advice on travel options, optimized routes, and other customer-focused services.
Students/Teachers/ Academia	Utilize open data for pedagogical purposes, either as a learning resource or an instructional instrument (Saddiqa, Rasmussen, Magnussen, Larsen, & Pedersen, 2019).
Tech companies	Design and create software, platforms, and solutions that effectively use open data to foster innovation, enhance service delivery, and provide valuable business insights.
Technical experts	Ensure the quality, integrity, and usability of open data, and develop efficient data processing and analysis methodologies.
UI designers for storytelling	Design user experiences that tell stories using data to simplify otherwise opaque information.
User needs in FAVs (Fully Automated Vehicles)	Determine what data is most important for the smooth functioning, safety, and user experience of autonomous cars, and prioritize its collection (Lee, Nadri, Sanghavi, & Jeon, 2022).
Volunteer users	Participate in the creation, verification, or use of open data on a purely voluntary basis, often motivated by a sense of civic duty (Johnson & Greene, 2017).

3. FAIR Principles: when User Needs meet Open Data

In this section, we present the initial results of the methodology as described in Section 2. The examined literature and sources provided the foundation for the initial identification of user needs with a technical orientation, which will be later used in the requirements elicitation process. The user needs are mapped to the respective FAIR principles based on their content. Understandably, there may be cases where this process includes non-mutually exclusive elements. In such cases, either the closest conceptual proximity defines where they belong, or if a source is relevant to more than one FAIR principle, the identified source is divided to refer to the other relevant principles it falls under. A brief reference to the explanation of each FAIR element, along with the mapping of the identified user needs to one or more FAIR principles is presented below.

3.1. Findability

Findability, the first concept of the FAIR principles, refers to the ability of information or data to be easily located or identified (Foundation Interaction Design, 2020) either by search engines or users. For data to be used in various contexts, it first needs to be found, making findability a critical aspect. In this section, we refer to the findings which have a direct or indirect, yet significant, impact on the aspect of findability.

- **Inclusive ODPs:** Discovering relevant datasets in data portals related to the educational profession is challenging with the existing open data portals. Therefore, there is a need for improved search tools and better descriptions of datasets to facilitate the location of suitable data in data portals for students and individuals unfamiliar with utilizing open data in education. This indicates a gap that needs to be addressed. For example, some authors had conducted interviews, experimental tests, and surveys with educators and students in the 11-15 age range to explore ways to bridge this gap (Saddiqa, Magnussen, Larsen, & Myrup, Sept 2021; Coughlan, 2020).
- **Inclusive and Accessible Infrastructure**: Authors emphasize the necessity for developing inclusive and accessible infrastructure for some user types such as NPOs and NGOs. For example, these users need aggregated data for improved analysis, data science, and information dissemination adapted to their characteristics (Baack, Datafication and empowerment, 2015; González-Zapata & Heeks, 2015; Hasselwander, Kiko, & Johnson, 2022; Ricker, Cinnamon, & Dierwechter, 2020; Thakuriah, Dirks, & Keita, 2017). Some works, such as Schwoerer (2022), also highlight the importance for publishers to be informed about the data they publish, considering usability, relevance, and discoverability from the user's perspective to overcome unnecessary barriers to open data us.
- **Domain-Specific Data Discovery Tools**: Corporate decision-makers and journalists require tools to easily find data related to their specific business domains to drive innovation and effective storytelling. This includes demands for tools that support storytelling with data and enable the discovery of complex data visualizations for effective presentation to the public (Zuiderwijk, Janssen, Poulis, & Van De Kaa, 2015; Rind, Pfahler, Niederer, & Aigner, 2016; Windhager, Mayr, Schreder, & Smuc, 2016). Providing concise, informative dashboards that compile community-related data in an open-source format is also identified as a critical need (Bozsik, Cheng, Kuncham, & Mitchell, 2022).
- **Contextualized discovery:** Users want data discovery tools that consider their context, providing relevant information based on their preferences or location (Cranefield, Robertson, & Oliver, 2014).
- **Access to Micro-Level Data and Comprehensive Meta-Information:** Specialised users in NGOs and NPOs emphasize the need for access to micro-level data and comprehensive metadata to increase accessibility and findability through centralized hubs, consolidating reliable and necessary data sources in one place. Additionally, they stress the importance of complete metadata including lineage, quality, and completeness, along with corresponding validation tools (Chattapadhyay, 2014; Cranefield, Robertson, & Oliver, 2014; Erete, Ryou, Smith, Fassett, & Duda, 2016).
- **Ensuring Data Quality During Discovery**: Various stakeholders, including corporate decision-makers and journalists, demand data quality-checking capabilities to reduce uncertainty and adoption risk. Enhancing the cleanliness and pre-processing of open datasets to increase their

quality is an identified requirement (Tabary, Provost, & Trottier, 2016; Zuiderwijk, Janssen, Poulis, & Van De Kaa, 2015; Porlezza & Splendore, 2019; Bozsik, Cheng, Kuncham, & Mitchell, 2022).

- **Engagement in the Data Analysis Process**: In some domains, public engagement is a need. For example, journalists express a desire for crowdsourcing and gamification strategies to engage the public in the data analysis process (Handler & Ferrer Conill, 2016).
- **Efficiency in Dataset Discovery**: Stakeholders, including OGD users and journalists, seek tools and applications that streamline the discovery of datasets, making it more efficient (Cranefield, Robertson, & Oliver, 2014).
- **Improving User-Friendly Interfaces:** User interfaces and forums should be intuitive and user-friendly, especially for non-technical consumers of data such as students and instructors (Radchenko & Sakoyan, 2014; Selwyn, Henderson, & Chao, 2017).
- **Incorporating additional data:** Volunteer users demand to contribute external datasets to ODPs, enriching the available data sources (Hou & Wang, 2017).

3.2. Accessibility

Accessibility, in general, refers to the ability of individuals, businesses, and society to access information once they find the required data. This process may include to perform first authentication and authorization. In this section, we refer to the findings which have a direct or indirect, yet significant, impact on the aspect of accessibility.

- **Demand for Data Hubs**. Some authors state some kind of users, such as NGOs and NPOs, need access to micro-level data and findability of unpublished data. The objective is to increase accessibility and findability through the creation of a centralized hub and to consolidate more reliable and necessary data sources in one place (Chattapadhyay, 2014; Cranefield, Robertson, & Oliver, 2014; Erete, Ryou, Smith, Fassett, & Duda, 2016). Wilson & Chakraborty (2019) mention the need for a common fact base (such as a government or community-managed data portal) which empowers users (e.g., through mobile applications), but also caters for the provision of data to user groups such as citizens with impaired vision or other, facilitates public engagement through collecting information for informed governance, monitors relevant indicators to improve services, but also helps minimize the gap between open data and citizens by providing visualizations (via web and mobile platforms) to the user.
- **Expectation of a Robust Data Provisioning Infrastructure:** NGOs and NPOs, for example, need smooth, efficient, and effective open data access for the development of applications. This need can be met by providing access to open data in a complete and smooth manner. For example, there should not be any broken links in the datasets for application development (Baack, 2015; González-Zapata & Heeks, 2015; Hasselwander, Kiko, & Johnson, 2022; Johnson & Greene, 2017).
- **Demand for a Stable and Sustainable Supply of Data**: Corporate decision-makers demand a stable and sustainable supply of data to minimize the vulnerability of their products and service (Zuiderwijk, Janssen, Poulis, & Van De Kaa, 2015). In some scenarios, there is a need for continuous access to data. In their description of user needs in Fully Automated Vehicles (FAVs), Lee et al. (2022), mentioned, among others, the need for continuous connectivity between the vehicles and personal devices/ data infrastructure.
- **Lowering Barriers to Data Access:** Boyd & Crawford (2012) identified the importance of enhancing access to data. The limited or restricted access to data by various data sources promotes the digital divide, while data companies escape responsibility to make their data available, thus controlling access to it. Many works focus on the development of inclusive and accessible infrastructure for some users such as NPOs and NGOs. This implies the existence of high barriers to data access (Baack, Datafication and empowerment, 2015; González-Zapata & Heeks, 2015; Hasselwander, Kiko, & Johnson, 2022; Ricker, Cinnamon, & Dierwechter, 2020; Thakuriah, Dirks, & Keita, 2017) . Moreover, Klímek et al. (2018) identifies that in some cases users, such as journalists and data publishers, require access only to move the data to a different data infrastructure.

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- **Understanding Reasons for Dataset Unavailability**: There are many reasons and users demand to be reported. Hasselwander et al. (2022) identify that some datasets are unavailable due to difficulties in data gathering or resistance to data sharing by government and transportation bodies. This lack of availability severely hampers transportation advancements, especially mobility app development. Additionally, Chattapadhyay (2014) describes that making government datasets available online is a priority, but many datasets remain inaccessible, necessitating a rethinking of government data lifecycles and fostering trust and working relationships with government entities.
- **Multiple Ways to Access the Same Datasets:** Data accessibility in different formats is a need for some domains such as NGOs and NPOs. The goal of this need is to prepare individuals for better processing of the data (raw) or working with APIs (Erete, Ryou, Smith, Fassett, & Duda, 2016).
- **Delegating Data-Related Access Tasks to Intermediaries:** Wilson & Cong (2021) acknowledged that the use of open data is highly dependent on the technical capability of the user and mentioned data intermediaries whose role is to access and next release cleaned and integrated data back into the ecosystem.

3.3.   Interoperability

Interoperability, a key aspect of the FAIR principles, in the context of data refers to the need to merge data in meaningful ways (National Library of Medicine, 2023). Through data interoperability, information can be accessed and processed across different systems seamlessly, and it is an aspect that, in its absence, massively affects the usage of data.

- **Addressing Technical Data Challenges:** Challenges related to technical aspects of the data, such as different data formats, sources, and collection methods, need to be addressed to enhance the ease of use of the data. (Bezuidenhout, Leonelli, Kelly, & Rappert, 2017).
- **Need for Technical Interoperability Based on Open Standards:** There is a need for technical openness in file formats, standards, and technologies (Meng, 2016; Navalkha, 2021). By using open formats, standards, and technologies, tools may make it simpler to integrate data in a smooth way. Users' access to data may be enhanced in this way, and the capacity to reuse and interchange data across multiple systems and applications can be fostered. The importance of promoting open and interoperable solutions that enable greater collaboration and creativity in the use of data is highlighted by the need for technological openness of data.
- **Need for Locally Meaningful Data:** There are different types of needs, such as learning about communities through individual datasets and their sources, as well as the difficulties (time-consuming) related to data accessibility, discoverability, analysis, aggregation, transformation, efforts, and technical experience or expertise that local communities need to understand the development undergoing in society through the usage of open data (Bozsik, Cheng, Kuncham, & Mitchell, 2022).
- **Need for Interpretable Data:** Boyd & Crawford (2012) argue that numbers alone are not sufficient to reach a high level of intelligibility in models. Data interpretation needs to be embraced by appropriate methodologies which aim to reduce subjectivity and facilitate the "data cleaning" process.
- **Need for Interoperable Cross-sectoral Data:** The need for efficient data sharing with emphasis put on interoperability for cross-sector and cross-government data re-use is brought up by Schwoerer (2022), along with the consequent increase in transparency, accountability, and collaboration.
- **Metainformation about Lineage, Quality, and Completeness and the Corresponding Validation Tools:** In many domains, such as NGOs and NPOs, users need open data and metadata checker applications. Open data and their metadata should be complete, contain no missing data, and be cleansed, restructured, and screened for sensitive information (Chattapadhyay, 2014; Saxena & Muhammad, 2018; Hou & Wang, 2017).

3.4. Reusability

In the context of open data, reusability is a key aspect enabling data utilisation in more contexts and applications to promote new research, serve more purposes for society and boost innovation in products and services. Reusability allows data to serve multiple purposes beyond its original collection, enhancing analysis, meta-analysis, and research impact (ELIXIR, 2021).

- **Communication and Understanding End-User Needs:** Users should be in touch with the data publisher and the data provider when required (Chattapadhyay, 2014; González-Zapata & Heeks, 2015; Heimstädt, Saunderson, & Heath, 2014). Establishing communication channels between data publishers and users can reduce the gap and foster a user-driven open data ecosystem. Organizational activities like events and campaigns facilitate this connection.
- **Skills Development:** Users need to develop digital skills for effective use and analysis of open data (Erete, Ryou, Smith, Fassett, & Duda, 2016; Hou & Wang, 2017; Yoon, Copeland, & McNally, 2018; Walter, et al., 2021). Addressing the lack of skills and resources is crucial for successful use of open data in some settings, such as the educational, necessitating the use of various technological resources (Celis Vargas & Magnussen, 2022; Saddiqa, Magnussen, Larsen, & Myrup, Sept 2021; Ridgway, 2016; Van Audenhove, Van Den Broeck, & Mariën, 2020).
- **Privacy and Legal Aspects:** Users have needs related to addressing challenges related to privacy and understanding legal aspects of licensing associated with data reusability. They are considered essential in some scenarios (Chattapadhyay, 2014; Cranefield, Robertson, & Oliver, 2014). For example, providing journalists with tools to handle identification and re-identification of personal data is crucial for enabling data reusability (Bozsik, Cheng, Kuncham, & Mitchell, 2022; Krotoski, 2012).
- **Data Quality and Reliability**. Ensuring reliable, accurate, and consistent open data is a need vital in some reuse scenarios such as those where artificial users are involved (Janssen, Brous, Estevez, Barbosa, & Janowski, 2020; Lee, Nadri, Sanghavi, & Jeon, 2022; Schwoerer, 2022). Addressing data errors, biases, and improving data quality are clearly identified as user needs (Boyd & Crawford, 2012).
- **Contextualization and cultural alignment.** In some scenarios, contextualization and cultural alignment are user needs. For example, integrating open data effectively into educational ecosystems requires considering as user needs cultural alignment and indigenous data infrastructure (Celis Vargas & Magnussen, 2022; Walter, et al., 2021).
- **Data Processing and Intermediaries:** Open data, even in machine readable format, still requires additional processing and time-consuming procedures to reuse it (Wilson & Cong, 2021). User demands tools and capacity building to deal with data processing and engage with intermediaries can enhance data usability and further dissemination of resulting data products (Bezuidenhout, Leonelli, Kelly, & Rappert, 2017; Baack, Datafication and empowerment, 2015).
- **Transparency and Impact Assessment:** Promoting transparency in data treatment and measuring the impact of data reuse are considered as user needs in some domains (Lawson, 2022; Sandoval-Martín & La-Rosa, 2018).
- **Data Visualization and Tools:** Availability of tools for data visualization and processing big datasets is perceived by users as critical for efficient use of open data (Handler & Ferrer Conill, 2016; Badioze Zaman, Baharin, & Ahmad, 2021).
- **Engagement and Collaboration:** Facilitating collaboration, public engagement, and partnerships that can lead to innovative uses of open data and broader societal benefit is considered a user need in some domains (Dander & Macgilchrist, 2022; Berntzen, Johannessen, Andersen, & Crusoe, 2019; Jarke, 2019; Handler & Ferrer Conill, 2016).

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4. FAIR Principles from a technical perspective

This Section shows the output of the process for deriving requirements from documentation by converting them into user stories, with a focus on the perspective and experiences of early-stage researchers in ODECO research projects. User stories typically consist of a template that includes the type of user, their goal, and the reason behind it. To enhance the analysis, user stories should be systematically rewritten for each requirement, resulting in a unique ID, a feature description based on the goal, a stakeholder description based on the type of user, and a relevance description based on the reason.

4.1. User Interfaces

The Findability aspect of FAIR Data Provision is the primary focus. This principle of data discovery is acknowledged as the fundamental premise of data use. Data and metadata should be easy to find for both humans and computers. Rich metadata is essential to automatically discover datasets and their related services. One of the main research goals is the definition and evaluation of approaches for designing user driven user interfaces for finding data that fulfils different findability and accessibility requirements from different domains. It also addresses the identification of gaps between the needs of user groups and the current features of open data platforms.

User stories

Below we show a list of user stories with the purpose of facilitating the elicitation of technical requirements for the discoverability of open data domains. User stories are intended to reflect real-life situations users face when searching for data sets on open data portals for various purposes, whether their search goals are specific or exploratory.

1. As an open data portal user, I need tools that allow me to search for datasets under precise criteria so that I can identify valuable datasets to solve my information need.
2. As an open data portal user, I need tools that allow me to quickly explore the supply of datasets available in a portal so that I can identify valuable datasets for my domain and future information needs.
3. As an open data user, I need tools that allow me to quickly evaluate the result of a search so that I can more quickly find the most appropriate datasets.

Requirements

The functional and non-functional requirements associated with the findability dimension of the FAIR principles are shown in the Tables below. These requirements are directly derived from the available literature review and previously prepared user stories. Each requirement is accompanied by segments of stakeholders that could be particularly affected by it, as well as a brief reflection on its relevance with respect to user stories.

Table 2: Functional requirements for user interfaces and findability

ID	Feature	Stakeholder	Relevance
REQ-1	The ODP should provide a free text search bar to search datasets by keyword.	Open data users	Because it provides flexibility and precision in the search, as suggested in US-1. Keyword searches are one of the most common mechanisms in the mental model of search engine users.
REQ-2	The ODP should offer a category menu to search for datasets by category.	Open data users	Because it provides flexibility and precision in search and navigation, as suggested in US-1 and US-2.

![ODECO logo]

ID	Feature	Stakeholder	Relevance
REQ-3	The ODP should provide a map for the user to find relevant datasets associated with specific locations by drawing a bounding box.	Open data users	Because it provides flexibility and precision in the search, as suggested in US-1, especially in the case of users specialized in geographic or geolocated information.
REQ-4	The ODP should provide a temporal filter that allows users to search for relevant datasets associated with specific periods. Temporality can be associated with the events described by the dataset itself or its creation or update date.	Open data users	Because it provides flexibility and precision in the search, as suggested in US-1. This functionality makes it possible to serve both users with historical interest in certain past periods and those who want the freshest and most recent data possible.
REQ-5	The ODP should provide faceted filters to refine search results.	Open data users	Good filters provide selectivity, that is, the ability to narrow the search universe into manageable chunks. Faceted filters help to reduce information overload, as suggested in US-3.
REQ-6	The ODP should offer the user the possibility to sort the results according to different criteria (relevance, date, quality, size).	Open data users	Because it helps to reduce information overload, as suggested in US-3. This functionality is particularly useful for dealing with datasets with quantitative descriptors.
REQ-7	The ODP should show the user lists of recommended datasets based on search history, popularity, or novelty.	Open data users	Because it facilitates the exploration of portal content, as suggested in US-2. Recommendations should facilitate users' ability to extract value from data and its relationships.
REQ-8	The ODP should show the user a list of results identified by title and other relevant metadata elements.	Open data users	Because it helps to reduce information overload, as suggested in US-3. These elements should make it easier for the user to assess the potential of the resource for their information needs and speed up the overall search process.
REQ-9	A user can view the full details about the metadata of a particular dataset.	Open data users	Metadata records should help to quickly assess the potential of the datasets found against the search criteria.

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Table 3: Non-Functional requirements for user interfaces and findability

ID	Feature	Stakeholder	Relevance
REQ-10	Dataset categories should be aligned to well-known standard vocabularies.	Open data providers	Because it provides flexibility and precision in the search, as suggested in US-1 and US-2. It is important to seek alignment to pre-existing mental models in users, industry, and institutions.
REQ-11	Dataset titles and descriptions should incorporate terms aligned to well-known standard vocabularies.	Open data providers	Because it provides flexibility and precision in search, as suggested in US-1. It is important to seek alignment to pre-existing mental models in users, industry, and institutions.
REQ-12	Toponyms used by geographic search mechanisms must come from official and standardised sources.	Open data providers	Because it provides flexibility and precision in search, as suggested in US-1. It is important to seek alignment to pre-existing mental models in users, industry, and institutions.

4.2. Accessibility, interoperability, and technology

In this Section, the technical (or technological) part of the interoperability term will be discussed with the help of user stories, and from these stories, functional requirements will be elicited. Furthermore, functional requirements may be related to performance, effectiveness, and efficiency aspects, which we will extract in the form of non-functional requirements. Interoperability is the "I" of FAIR. According to the Metadata Quality Assessment (MQA) methodology of the European Data Portal[1], interoperability analysis is focused on analysing whether format information is available, formats can be recognized (belong to internationally accepted lists of formats), and formats are machine processable. The work on this topic could be to assess whether the data complies with the expected format, provide tools for the visualisation of data in different formats, and provide tools for data analysis, integration, transformation, data scrubbing, and data fusion (data fusion is the process of integrating multiple data sources to produce more consistent, accurate, and useful information than that provided by any individual data source). In this Section, more user stories, functional requirements, and non-functional requirements will come from the technology spectrum. Furthermore, these technical and functional requirements can help us narrow down the development of a smart data integrator that can be used to unify the datasets from different domains (e.g., governments, non-governmental organisations). Alternatively, this can lead to the development of a technology-based tool to help the users (data producers, consumers, and prosumers) in the open data ecosystem share, use, and re-use open data in the best way possible.

User stories

To facilitating the process of eliciting user requirements for the technical interoperability and accessibility of open data domains, a list of user stories is provided below. The motivation behind the extraction of user stories is to reveal a real-life depiction or representation of the problems that open data users are facing. What are these different open data user groups expecting and demanding from the open data ecosystem and infrastructure? How can these be fulfilled afterwards in a technical and technological way (technical interoperability in this scenario)?

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[1] https://data.europa.eu/mqa/methodology?locale=en

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1. As an educational activist, I want smooth integration of open data to the education field so that open data could be useable by the students for better designing of education curriculum.
2. As an educational institute, I want open data in widely adoptable format so that schools, colleges, and universities can take benefits of the multi-format publishing.
3. As a teacher, I need to have data processing tools so that I can share authentic open data-based information or knowledge for my students.
4. As a student, I need to have access to data collections, generation tools such as sensors, devices, and environment so that I can be part of the open data ecosystem.
5. As a data intermediary, I want technological tool so that the social-technical barrier within our job could be reduced and job effectiveness and efficacy will be increased.
6. As a data intermediary, I need tool/s for my staff so that they can engage with open data in a more productive manner and readily get insights.
7. As a data intermediary, I need data augmentation tool to increase the quality of the dataset which already exists in the open data systems.
8. As a data intermediary, I need access to tools for the derivations of insights from the raw data so that to be able to deliver more insightful guidance to our customers.
9. As a data intermediary, I want to have a tool to evaluate the quality of open data so that the data curation process can be easy to implement.
10. As a publisher and OD consumer, I want data to be technically open so that data integration can be smooth and Users' access to data may be enhanced in this way, and the capacity to reuse and interchange data across multiple systems and applications can be fostered.
11. As a data intermediary, I need to have access to ensure that they have the data literacy they need to effectively analyse data, identify patterns, and communicate their results to relevant stakeholders.
12. As a data intermediary, I need to have common ground to access the domain specific knowledge so that the technical community of open data ecosystem could be enhanced. Like other communities exists in the world.
13. As a corporate user, I need to have proper profile of the dataset mentioning the quality and search options of the datasets so that they can reduce uncertainty and adoption risk of the open data.
14. As a corporate user, I want to have advanced open data searching and accessibility functionalities so that we can filter out datasets temporally, spatially, and textually to access and discover the datasets in an efficient manner to use this data further for analysis.
15. As a corporate user, I want to have a functionality which allows me to upload an updated version of an existing dataset so that other can re-use the modified version of the dataset.
16. As an artificial user, I need consistent and reliable data provision to feed into applications and algorithms to avoid the inaccurate results generated by faulty data sources or inconsistent formats.
17. As an artificial user, I need privacy and security protocols to preserve the legal and ethical usage of the open datasets.
18. As an artificial user, I need proper and continuous monitoring of my activities to make the accountability and transparency better.
19. As a data consumer, I need access to open data thorough smart phone so that I can access the open data in low-cost environment.
20. As a data consumer, I need access to mix valued datasets not just qualitative and quantitative contrary to existing situation.
21. As a data consumer, I need not only access to big data but also to be able to be searched, aggregated, and cross-referenced by any concerned side.
22. As a data consumer, I need statistics that describe the dataset volume, velocity, and veracity so that I can estimate the time, space, and computation powers to explore these datasets.
23. As a data consumer, I need access to the tools that suggest data interpretation and methodologies based on the underlying datasets so that the problem formalisation and solution are supported by the state-of-the-art at least.

24. As a data consumer, I need a proper statistical profile of the dataset explaining the claims about its verification from different researchers or independent entities. In this way, it would be easier to choose a dataset with better quality.
25. As a data publisher, I need a tool to verify the dataset if it contains someone's very personal or confidential data so that this data can be anonymized before publishing.
26. As a data consumer, I need to build my skillset in the field of data visualisation and build capacity regarding data issues (fragmentation, aggregated data, unreliable data, and sensitive data).
27. As a data publisher, I need to take data anonymisation into account in real-time in the data publishing phase.
28. As a data publisher, I need to automatically check the metadata suitability for the dataset in hand for publishing so that published data has a quality view.
29. As a data Publisher, I need an indigenous data infrastructure to ensure the indigenous governance to prove the priorities, values, and culture.
30. As a data publisher, I need functionality to evaluate the FAIR and CARE principles to contribute towards the improvement of data integration and the promotion of data reusability.
31. As a data consumer, I need tools to better communicate my issues and opportunities with the data providers, or producers, in a better way.
32. As a data publisher, I need functionality in the open data portals so that citizens can participate to complete missing datasets.
33. As a data consumer, I need access to variety of integrated datasets from different fields.
34. As data publisher, I need functionalities or features to reduce the complications in data formatting, sourcing, data collection, and others.
35. As a data publisher, I need support in building technical capacity to publish datasets in an efficient and effective way.
36. As a data publisher, I need real-time functionality to draw insights about the openly available datasets.
37. As a data consumer, I need functionality to access, find, and discover the dataset, but keep in mind I am having special conditions.
38. As a data consumer, I need to know about the data contextualisation, such as breaches, discrepancies, algorithmic transparency, and other errors available in the dataset.
39. As a data publisher, I need tools to improve the use and re-usability of the OGD data.
40. As a journalist, I need tool for the investigative journalism purpose.
41. As a journalist, I need to detect the low-trust dataset in the open data spaces.
42. As a journalist, I need functionalities in the tool to visualize and generate compelling stories for the public.
43. As a journalist, I need to have access to the portable open data infrastructure if I want to publish my local datasets.
44. As a data consumer, I need access to multi-format, multi-way (e.g., API and Bulk download) datasets to access and analyse in depth.
45. As a Data publisher, I need access to the data transformation tools or functionalities to provide the dataset in Level of Detail (LOD) format.
46. As a Data consumer, I need to have functionalities to explore the LOD cloud to generate insights asap from the datasets.
47. As a Data publisher, I need to have functionalities where I can publish datasets from multiple government agencies in a unified and accessible way.

Requirements

To elicit technical or technological requirements related to open data accessibility and interoperability, we have recorded or collected user needs from different user groups in section 3, e.g., education, NGOs, Journalism, and government. The user needs have been transformed into user stories, which are specifically related to data accessibility, interoperability, and technology. By using these user stories, user requirements have been elicited by following a structured approach such as feature (what the user

wants), stakeholder (to which user group that stakeholder belongs), and relevance (why the user wants this feature). For instance, if a user-story demands the functionality of data processing tools, its relevance could be explained as "the data analysis tool can help end-users engage without any coding experience or less expertise required." In this manner, user-stories are used to extract user requirements related to accessibility, interoperability, and technology. The Tables below present the user functional and non-functional requirements that need to be fulfilled for the smooth functioning of the features.

Table 4: Functional requirements for accessibility, interoperability, and technology

ID	Feature	Stakeholder	Relevance
REQ-13	Open data should be useable by the students	Educational institutions	open data could be useable by the students for better designing of education curriculum (US-1)
REQ-14	Open data should be available using standard data format/serialisation	Educational institutions	A widely acceptable open data format can enhance the accessibility, useability, and re-useability of open data (US-2)
REQ-15	Low-code data processing tools should be available.	Teachers	By having data analysis tool in which less coding, or expertise required, a teacher can extract information for the students (US-3)
REQ-16	Tool for data sharing dedicated to open data intermediaries should be available	Open data intermediaries	This might consist of software designed specifically for intermediaries, data-sharing networks, or collaborative platforms (US-5).
REQ-17	Tools for active data analysis should be available	Open data intermediaries	Users need assistance with tasks like data collecting, data augmentation, contextualisation, and visualisation, all of which may be accomplished with the use of appropriate tools or platforms (US-6).
REQ-18	Data integration tools for the data intermediaries should be available	Open data intermediaries	Need data automation, collection, and integration solutions to make the process of data integration simpler. It is crucial for open data intermediaries to have access to technology that simplifies the process of acquiring data from a variety of sources (US-7)
REQ-19	Quality enhancement tools (data augmentation tools) should be available	Open data intermediaries	Quality enhancement tools can be used to improve the quality of the existing open datasets. For different type of datasets, we need different tools e.g., image augmentation, text data augmentation (US-8)

ID	Feature	Stakeholder	Relevance
REQ-20	Tools to generate the insights from the raw data should be available	Open data intermediaries	access to tools for the derivations of insights from the raw data so that to be able to deliver more insightful guidance to our customers. These tools may assist users in generating meaningful and interactive visual representations of the data and in deriving insights from open data resources, which may help users better interpret and utilize the data (US-9).
REQ-21	Tools to evaluate the data quality should be available	Data intermediaries	The availability of software tools that may assist intermediaries in evaluating and validating open data is necessary to ensure the data's high quality and dependability (US-10).
REQ-22	Datasets should be technically open	Open data users and provider	By opening the datasets, it technically means to follow the dataset standards, formats, and other protocols to enhance the data integration across different systems and to facilitate the better accessibility of the open data (US-11).
REQ-23	Advanced open data searching and accessing tools should be available	Corporate users	A user filters out datasets in many ways (e.g., temporally, spatially, textually, and others) to access and discover the datasets in an efficient manner to use this data for further analysis (US-15).
REQ-24	Users should be allowed to upload updated versions of existing datasets	Corporate users	A user can upload an updated version of the existing dataset. In this way, other users can use cleaned, modified, augmented, or transformed datasets for specific tasks (US-16).
REQ-25	Consistent and reliable delivery of datasets should be provided to the artificial users	Artificial users	consistent and reliable data provision to feed into applications and algorithms to avoid the inaccurate results generated by faulty data sources or inconsistent formats (US-17).
REQ-26	Access to open data through smart phone should be available	Open data users	Using a smart phone to access the open data, participation in the open data ecosystem can be enhanced. The smart gadgets are easily purchasable and accessible in all countries (US-20).

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ID	Feature	Stakeholder	Relevance
REQ-27	Big data search, aggregation, and integration should be available	Open data users	The intensive searching, aggregation, and integration of big datasets can contribute to the sustainability and value creation of the open dataset (US-22).
REQ-28	Big dataset categorisation should be available	Open data users	In this way, the formalisation of the working or experimental environment and the estimation of the efforts to achieve the solution will be easier (US-23).
REQ-29	Data interpretation should be available	Open data users	Data interpretation should be accompanied by a set of suitable methodologies that could be useful for the underpinning dataset. In this way, a better solution can be found. A tool explaining or suggesting the data exploration and cleaning methodologies would be a plus (US-24).
REQ-30	Capacity-building tool for data consumers should be available	Open data users	In modern open data spaces, capacity-building tools in the areas of data visualisation, data fragmentation, aggregation, and detection of unreliable datasets are required (US-27).
REQ-31	Anonymisation of the open dataset before publishing must be the norm	Open data providers	The tools developed to anonymize the dataset can help the publishers anonymize the feature or properties, which can lead to the identification or re-identification of individuals in the OD spaces (US-28).
REQ-32	Indigenous data infrastructure may be required	Open data providers	an indigenous data infrastructure to ensure the indigenous governance to prove the priorities, values, and culture (US-30).
REQ-33	A functionality to complete the missing values in the datasets with the help of citizens is needed	Open data providers	In this way, more complete data sets can be provided to the citizens with real values (augmentation) (US-33).
REQ-34	Making available integrated datasets from diverse fields for users with diverse needs is needed	Open data users	The necessity for integration of data and accessibility feasible for user groups with varying needs (e.g., visual impairment, dyslexia, and others) is also emphasized by Ossom-Williamson et al. (Ossom-Williamson, Williams, Kim, & Kindratt, 2021) (US-34).

ID	Feature	Stakeholder	Relevance
REQ-35	Functionalities for reducing data-related complications should be available	Open data users and providers	In this way, a data producer can produce the dataset in the easiest way possible and integrate the dataset into the ecosystem in a more convenient and adaptive way for the data consumers (US-35).
REQ-36	Real-time integrated visualisation functionalities in open data portals are needed	Open data users	data that is available openly, even in machine-readable format, still requires additional processing and time-consuming procedures to understand it. A countermeasure as an intermediate step of this situation is the use of data visualisations, interactive mapping and graphs, and the provision of other intuitive media integrated in the data platform (US-37).
REQ-37	Functionalities to detect low-trust dataset are needed	Open data users	There can be a big matrix to decide the trustworthiness of the dataset itself, or its source should be available (US-42).
REQ-38	Tools to visualize and create compelling storytelling for complex datasets are required	Open data users	Journalists demands Visualisation and compelling storytelling tools for the purpose of increasing the public's participation and having a better view of the problem or news (US-43).
REQ-39	Portability of infrastructure in the open data domain is necessary	Open data providers	The portability of infrastructure will help transfer the knowledge of OD infrastructure to another organisation (US-44).
REQ-40	Provision of datasets in LOD format is demanded	Open data providers	Enhancing the reusability of the open data by provision of data in LOD, Helping the providers with the data publication process, Quantifying the open data deployment schema, specifying a methodology, tool, or software to publish the 1-star data as a 5-star data, LOD preparation and publishing environment (US-46)
REQ-41	Functionalities to explore Linked open data cloud are needed	Open data users	Linked open data cloud exploration techniques: This can help the journalists to find the real-time breaking news stories by exploring the large, linked datasets (US-47).

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ID	Feature	Stakeholder	Relevance
REQ-42	Functionalities to publish unified and easily accessible dataset from multiple sources are demanded	Open data providers	Sometimes data is produced by multiple government agencies but is not published in a uniform and easily accessible manner, to not only share the analytical findings from the government data but also the collated and sanitized data itself (US-48).

Table 5: Non-Functional requirements for accessibility, interoperability, and technology

ID	Feature	Stakeholder	Relevance
REQ-43	Technical support for data integration from multiple sources is required	Open data users and providers	The data integration process should be transparent to avoid any discrepancies in the data. It would be useful for artificial users as well.
REQ-44	Technical support for data visualisation tools and their performance is demanded	Open data users and providers	The data visualisation tool should be efficient enough to deal with a large amount of data on the web portal.
REQ-45	Data integrity and quality should be part of the platforms	Open data users and providers	The data should be accurate, dependable, and up to date. Quality assurance processes must be in place to detect and resolve any inconsistencies or errors in the data.
REQ-46	Performance and scalability of the OD infrastructure is required	Open data users and providers	Emerging database technologies, cloud services, and modern data collection devices are being introduced around the globe, so open data infrastructure should be scalable enough to support these technological transformations.
REQ-47	The development of documentation for each functionality or services provided by the OD portal is required	Open data users and providers	Documentation is the key part of the use and re-use of the open data services, and data itself. It would be necessary to provide the end-user with documentation to understand the data and portals.

4.3. Accessibility, interoperability, and semantics

In this Section, the dimension of FAIR data provision regarding interoperability and semantics is the focus. Interoperability is the "I" of FAIR. In the case of Open Government Data in European countries and the European Data Portal this is typically assured thanks to the compliance (in higher or less degree) with DCAP-AP v2.0. The work on this topic could be to identify other domains, different from Government Data, using other metadata models and see how mappings between different models can be established. From a user perspective, it is necessary to provide context regarding the needs various user categories have when they search for, use, or try to understand open data.

User stories

To facilitate the process of extracting user requirements as far as the dimension of semantic interoperability is concerned, a list of collected user stories about scenarios related to accessibility and

the interoperability of data are presented below. The user stories aim to provide a better real-life scenario understanding of what different user groups could potentially be expecting of or demanding from open data infrastructures and how these can be afterwards achieved in technical means (in this case semantic technologies and more).

1. As a curriculum designer of a school schedule, I want to be able to tell which topics of interest can be included in the OD education programme in schools, so I can include the most relevant ones according to each class/grade.
2. As a school student I want to be able to see the usefulness of the open data curriculum in more contexts and applications, so that the knowledge domain becomes interesting to me.
3. As a school system administrator, I need to have an updated source of information, so that the relevance and accuracy of data is constantly ensured.
4. As an OD user I need to have access to complete, up-to-date relevant, cross-referenced, and aggregated data to ensure it is usable and re-usable.
5. As an OD user I need to develop digital skills so I can use and work with datasets.
6. As an OD user I need to have access to tools and techniques which make the data more approachable, comprehensible, and easy-to-use for me.
7. As an OD portal user, I need to be able to easily discover relevant datasets according to my profession or interests easily, so I can find use of them in my current tasks or activities.
8. As an OD user I want to be able to improve the status of datasets that I need to use if I notice something problematic about them, so I can then use the data for my intended purpose.
9. As an OD portal administrator, I need OD users to be able to collect data and link it to existing resources so that new data that is added in the portal is in good condition and ready to be found/discovered and used by other users.
10. As a policy/decision maker I want data to be of superior quality, so that I know decisions that depend on this data are dependable, truthful, and trusted.
11. As and OD portal user I need to have recommendations from the portal to help my search through the data, or suggestions to help me fix problematic datasets.
12. As a policy maker in a company, I want data to be contextual so I can see relations and conceptual connections that will help me develop better strategies based on it.
13. As an OD intermediary user, I need access to conceptually connected data so I can help curate/structure datasets in the right context and way.
14. As a healthcare professional (e.g., doctor) I need OD to facilitate my profession by giving me access to contextual information to give me insights on where else my domain-specific knowledge is useful.
15. As an OD portal user, I want to have easy access (by inserting keywords or choosing from available menus) to datasets of my interest, or according to my spatial location or temporal criteria without too many complexities.
16. As a data contributor user, I want to have clear guidelines on what I can do to meet domain-relevant or community standards when I upload a new dataset to ensure that the dataset is going to be useful.
17. As an OD user I want to be able to find data even when the dataset is no longer available, for historic or personal reasons.
18. As an OD user I want the ability to connect with other users in a community with similar interests to exchange knowledge and assistance.
19. As a professional/domain expert I want to see datasets about my domain in relation to other closely related domains to be able to find easily more knowledge about it.
20. As an OD user I want my personal/sensitive data to be anonymous to ensure the property of non-linkability and to not be identifiable.
21. As a citizen I want to put minimum effort in providing data to my government while using public services (e.g., public welfare, electronic healthcare services, tax services) no matter where I am located at the time that I need to use it.

22. As a civil servant I want the datasets used in my work to be easily fed to the system I use for my work to visualize or understand the data.
23. As a legal professional (e.g., lawyer, judge) I want an effortless way to compare legislations among different countries to make my work easier and have a faster overview of existing laws and practices.
24. As a data journalist I want the data which comes from unreliable sources to not be recommended to me by the search engine of the portal I use to retrieve it to ensure verified sources, quality, and contextuality.

Requirements

After creating the previously presented user stories, which were used to provide a general impression of potential needs of different types of users regarding the expectations and usage of open data, the methodological process was applied to help elicit and collect specific technical requirements of functional and non-functional nature directly connected with the existing literature and the user stories. The functional and non-functional requirements in respect of the FAIR dimension of accessibility and semantic interoperability of data elicited from the methodological process are presented in the Tables below.

Table 6: Functional requirements for accessibility, interoperability, and semantics

ID	Feature	Stakeholder	Relevance
REQ-48	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data users	Because with this requirement we can prioritize in searches the comments that can be more relevant to their profile (US-14, 15).
REQ-49	The datasets used in an education context should provide proper visualisations and stories related to their content.	Open data users and School students	The study information based on OD included in the curriculum can become more appealing and interesting (US-2).
REQ-50	The data portal should provide the functionality of allowing the users to improve the quality of data (e.g., enrich metadata) if they discover the dataset lacks it, and there should be guidelines to the user to do it correctly.	Open data users	This way users can contribute to data quality and improve the status of the datasets they are interested in using, making them more usable and discoverable to other users (US-8).
REQ-51	The data portal should provide the functionality of guiding the users through the process of linking data to existing resources to allow for semantic connection.	Open data users	This way new data that is added to the portal is in superior quality and ready to be discovered by other users (US-9).
REQ-52	The data portal should provide recommendations to help the user while searching, based on semantic technologies (such as linked open vocabularies).	Open data users	The user can receive more accurate recommendations on finding what they are looking for instead of just inputting keywords and getting loosely relevant results (US-11).
REQ-53	The data portal should provide alternative input methods for search (e.g., based on the geospatial location of the user or temporal criteria they might insert).	Open data users	The search function is easy for the user and returns relevant results according to the users' geospatial in formation in a straightforward manner which does not require digital literacy skills (US-15).

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ID	Feature	Stakeholder	Relevance
REQ-54	The data portal should provide clear guidelines on how a new dataset uploaded in the portal meets community standards or domain relevant standards.	Open data contributor	When a new dataset is uploaded it instantly adheres to community standards, thus improving its findability and contextuality (US-16).
REQ-55	The data portal should provide information about dataset even when these are not available anymore, the dataset metadata should still be accessible.	Open data users	The dataset itself might not be available anymore but the context (coming from the metadata) will still enable the user to conduct their intended study properly (it could be needed for historical or personal reasons) (US-17).
REQ-56	The data portal should provide a place where users can connect with other users in a community, based on similar interests.	Open data users	The users can be grouped under similar interests and topics, being allowed to exchange knowledge, and assist each other (US-18).
REQ-57	The data portal should have a function to distinguish the data which comes from unreliable sources and avoid recommending it to the user.	Data journalists	This way a data source can be easier to verify, check its quality and contextuality (US-24).

Table 7: Non-functional requirements for accessibility, interoperability, and semantics

ID	Feature	Stakeholder	Relevance
REQ-58	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data users	Because with this requirement we can prioritize in searches the comments that can be more relevant to the user profile (US-14, 15).
REQ-59	The datasets in the data portal should be linked to knowledge representation schemata (such as vocabularies and ontologies) to have connected semantic meaning.	Open data users and School curriculum designers	This way, the most relevant topics for choosing datasets to be used in the education context can be shown according to their proximity with other linked topics (US-1).
REQ-60	The datasets in the data portal should have proper thematic tags to reflect sufficiently their actual content.	Open data users	This way, the user can more easily discover data relevant to their profile, profession, or desired subject of search (US-7).
REQ-61	The datasets in the data portal should adhere to data models and metadata standards (e.g., DCAT).	Policy/Decision makers	By doing so the data quality is improved so decisions based on this data are more likely to be dependable and trusted (US-10).
REQ-62	The datasets in the data portal should be linked to knowledge representation schemata (such as vocabularies and ontologies) to have connected semantic meaning.	Policy/Decision makers in a company	This way the interested user can see relations and conceptual connections among data, helping them to develop better strategies (US-12).

ID	Feature	Stakeholder	Relevance
REQ-63	The datasets in the data portal should be linked to knowledge representation schemata (such as vocabularies and ontologies) to have conceptual connection.	Open data intermediaries	This way data intermediaries can more easily curate or structure data in the right context (US-13).
REQ-64	The datasets related to healthcare in the data portal should be linked to the most prevalent ontologies and vocabularies in the biomedical sector.	Healthcare professionals and Open data users	Helps the professional in their occupation (they can see where else their domain knowledge is useful) providing improved diagnosis (US-14).
REQ-65	The datasets in the data portal should be linked to the most prevalent ontologies and vocabularies of their respective domain.	Professionals and Domain experts	The user can then have access to more context about their domain and can build on the knowledge around it based on other, conceptually related domains (US-19).
REQ-66	The datasets in the data portal need to be available in machine-readable and processable format.	Civil servants and Open data users	The data used in the daily activities of public systems (e.g., in electronic services), can seamlessly run through different systems (US-22).
REQ-67	The datasets related to law and legislation in the data portal should be linked to the most prevalent ontologies and vocabularies in the legal sector.	Legal professionals and Open data users	Helps the professional compare legislations among different countries and have a faster and better overview of existing laws and practices, as well as conflicts (US-23).

4.4. Data portals and reusability

This Section is dedicated to the Reusability dimension of the FAIR data provision. This principle recognises that the data reuse is a fundamental principle of open data. It implies that there should be no restrictions on how data can be used for different purposes by different users.

User stories

Below we show a list of user stories with the purpose of facilitating the elicitation of technical requirements for the reusability of the data at open data portals. User stories are intended to reflect real-life situations users face about how to reuse the data sets on open data portals for various purposes.

1. As a data user, I need to have basic data processing skills and knowledge to evaluate data quality, so that I can make informed decisions while reusing open data.
2. As a portal administrator, I want to possess fundamental data processing skills and data quality checking abilities, so that I can ensure the data available on the portal is valid and complete.
3. As an open data portal user, I need access to visualisation tools on the portal to gain insights from datasets without the need for downloading and external processing, so that I can reuse the gained insights for various purposes.
4. As a data provider, I need to clearly document the origin, ownership, and updates of datasets to ensure data provenance and reusability, promoting data authenticity and quality.
5. As a data user, I want to access datasets with well-documented provenance and reuse standards, such as open data licenses, to confidently use data in various contexts.
6. As an open data portal user, I expect the portal to suggest/recommend datasets related to my preferences, making it easier to discover relevant data for the reuse purpose.

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7. As a portal administrator, I want the data portal to recommend similar datasets based on user interests and previous searches, enhancing user experience, and facilitating dataset discovery.
8. As a user of the data portal, I understand the importance of functional knowledge about data interpretation and curation, enhancing my ability to use data effectively.
9. As an end user, I want to understand the fundamentals of data and information, so that I can effectively engage with the open data portal, gather meaningful insights, and contribute to decision-making processes.
10. As a data user, I want the open data portal to provide a user forum where I can connect with other users, share experiences, collaborate on projects, and exchange insights related to open data.
11. As an educator, I recognize the significance of students acquiring digital skills, enabling them to access and create value from open data, fostering their data literacy and innovative thinking.
12. As an open data intermediary, I need software tools to evaluate, validate, and curate open data, ensuring its quality and usefulness.
13. As a government official, I seek open data portals that provide accessibility and usability across a range of use cases, allowing internet users to access valuable data on diverse topics, thus encouraging innovative applications.
14. As a policy maker, I aim to promote the integration of Open Data education, and I require user-friendly tech-oriented solutions that facilitate the inclusion of open data concepts into the curriculum.
15. As a stakeholder in open data initiatives, I require an inclusive open data portal that ensures accessibility and usability for individuals from diverse user domains.

Requirements

The functional and non-functional requirements associated with the reusability dimension of the FAIR principles are shown in the Tables below, respectively. These requirements are directly derived from the available literature review and previously prepared user stories. Each requirement is accompanied by segments of stakeholders that could be particularly affected by it, as well as a brief reflection on its relevance with respect to user stories.

Table 8: Functional requirements for data portals and reusability

ID	Feature	Stakeholder	Relevance
REQ-68	Portal administrators and data users must have the basic skills for data processing and for checking the quality of data.	Open data users and providers	For reusability of open data, data quality, validity and completeness of the data may be evaluated with the use of technologies available via data portal
REQ-69	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data users	Because with this requirement we can prioritize in searches the comments that can be more relevant to their profile.
REQ-70	If a user wants to visualize a dataset on the data portal, then the data portal must have visualisation tools and resources.	Portal Administrators and Open data users	For better insights of the dataset, it will be better to visualize it in the portal before downloading and processing it for further tasks
REQ-71	Users should have access to data provenance	Open data users and providers	Data provenance and reusability in open data portals ensure data authenticity and quality. This involves clearly documenting the dataset's origin, ownership, and

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ID	Feature	Stakeholder	Relevance
			updates. Metadata and reuse standards like open data licenses promote data sharing and accessibility.
REQ-72	ODP should recommend similar datasets based on the previous search results	Open data users and providers	Data portal can recommend the similar datasets based on the interests of the user and previous search of the user
REQ-73	All users of Data portal should have the functional knowledge about data interpretation and data curation	Open data intermediaries	Software for evaluating, validating, and curating open data

Table 9: Non-functional requirements for data portals and reusability

ID	Feature	Stakeholder	Relevance
REQ-74	All users who want to get involved with the open data portal should know the basics of data and information.	Open data users	Involving end users in data gathering and somehow in decision making process make the data portal more user-driven.
REQ-75	If users who want to use an open data portal and create value added value must have digital skills.	Educators, students, journalists, and intermediaries.	Acquiring basic understanding of technology as well as access to various data sources and tools.
REQ-76	If a user wants to engage with the open data community, then an open data portal must provide a forum where users can connect with each other.	Open data users and developers	A common feature of data portal is to facilitate a forum where user to user communication and project collaboration is possible.
REQ-77	Tech-oriented solutions or platforms to incorporate Open Data education into the curriculum should be available.	Policy makers, curriculum designers, academic institutions	Policy makers, curriculum designers, academic institutions or any other stakeholders involved in promoting the integration of Open Data education want Open Data to be used by all students.

5. Requirements assessment

In the previous section, we derived a set of requirements, setting the stage for the next crucial step: assessing these requirements. This assessment will revolve around key questions: firstly, whether these requirements are currently integrated within open data platforms; secondly, if they are indeed implemented, whether they effectively meet user needs; and lastly, in cases where user needs are not met, identifying the root causes for this shortfall. The purpose of this evaluation is to assess the alignment between the derived requirements, their practical implementation, and user satisfaction levels within open data platforms.

Our approach to analysing the needs of potential open data users has been technically focused. We aimed to identify and translate these needs into functional and non-functional requirements. Specifically, this work has sought to elicit the technological requirements for OD user within the FAIR data provision paradigm. The methodology outlined in section 2 has led to the identification of 77 requirements – 55 functional and 22 non-functional. These requirements span the dimensions of FAIR data principles, aligning with the research objectives of the ODECO project.

Importantly, the requirements extracted from the literature to translate the FAIR principles do not contradict one another. For example, a single requirement could pertain to the accessibility or interoperability of open data, highlighting the interdependence among the FAIR dimensions. However, determining the exact adherence to one, two, or three FAIR principles can be challenging due to this interdependence.

In extracting technological requirements from the identified user stories, a primary challenge was incorporating the user perspective in the elicitation process. The FAIR dimension of findability is linked to the user through interaction with user interfaces. Interoperability, accessibility, and reusability are more technically oriented and operate in the background. While user stories might offer an initial overview and intuition of what could be expected, more targeted (less general) requirements may necessitate alternative methods such as expert opinions and questionnaires. For instance, if the user desires data stream continuity, the user in this case did not specify at what level of the open data provision they want data stream continuity, either for data publication from the providers or for the usability of the datasets (e.g., API and bulk download), or even if they want continuous provision of open datasets.

The first set of technical requirements are focused on **findability**, recognizing it as the foundation for a successful user experience within an open data portal. The volume, diversity, and complexity of modern datasets mean that efficient search and navigation tasks consume an enormous amount of energy and time on the part of users. **Findability functional requirements** focus on providing practical tools for users to search for relevant datasets in a multidimensional way, from simple and well-known mechanisms such as keywords to more elaborate filters involving temporal and spatial aspects. On the other hand, the **findability non-functional requirements** emphasize the need to use a known language in all the labelling systems of the information architecture of ODP.

The identified requirements illustrate the dependence between the dimensions of the FAIR principles. **Findability depends on interoperability**. For instance, REQ-48 refers to the need for datasets to have schema.org tags for semantic meaning, clearly indicating the dependence between semantic interoperability and findability of data. In addition, the **findability affects reusability** because if data is not discovered in a timely manner, then this becomes a bottleneck for it to be reused. However, a major limitation regarding findability requirements is that they are often formulated with ODPs in mind as the main delivery mechanism. This relies on the literature assumption that users who have information needs turn to these platforms to search for data organically, which is not necessarily the case. This raises the challenge of extending findability to multiple contexts and information search platforms such as

search engines, social media, mobile apps, and other popular internet outlets. This reinforces the connection of findability with the principles of semantic data interoperability.

In the case of **accessibility**, the requirements elicited focus on the ability of users (and other interested stakeholders) to access the data they found, whether that refers to direct or indirect factors which affect this procedure. Understandably, accessibility is closely related to findability, due to the latter being an absolute prerequisite for the former, however, it also gets affected to a higher or lesser degree by interoperability issues. The functional requirements regarding accessibility, include, among others, the necessity for technological tools (e.g., data analysis tools, capacity-building tools, data interpretation, and more) in order to allow for easier access to the data, the possibility to access open data(sets) through mobile devices, and real-time integrated visualizations of data in the portals. The non-functional requirements identified for accessibility refer to arisen issues such as the technical support needed when multiple sources are integrating data, or to keep the performance level of technological tools high. As mentioned previously, accessibility is also directly or indirectly affected by interoperability, an example being that if datasets available in the data portal are not linked to existing knowledge representation schemata (e.g., vocabularies or ontologies), which is something necessary for the semantic interoperability of data, the data might become non-findable and consequently, not accessible by the interested stakeholders. Moreover, datasets in the data portal need to be available in machine-readable and processable format to be accessible both by human and non-human agents. The rationale behind the integration of solutions which address the identified accessibility requirements is the ability for a wider share of interested stakeholders to access data, regardless of their level of expertise or means to access the data.

In addition to the above-mentioned points regarding accessibility-related requirements elicited in this document, we highlight additional requirements, such as centralized data provision hubs, robust infrastructure without broken links, and access to data in efficient methods (APIs, streaming, direct download, etc.). Smooth, stable, and sustainable data access to all-inclusive stakeholders in the open data ecosystem, specifically businesses and organizations, is better at lowering the barriers to open data access, promoting inclusivity, and bridging the digital divide.

As far as **interoperability** is concerned, the requirements identified are related mostly to the ability of the ODP to provide the users with functionalities such as improved search and results retrieval, data of improved quality and guidelines on how users can assist in this process, usage of technological means in order to achieve and smoothen data integration, enhance quality, boost discoverability and contextual search, provide data visualisation to the users, access to data, and more. In further detail, **interoperability functional requirements** aim to describe what the system under analysis should be capable of doing. In our case, the essence of the identified functional requirements appear to be lying around some central themes, such as data integration, data standardisation, data sharing techniques, data processing tools for analysis, visualisation and interpretation, data quality improvement techniques, improved contextual data search (semantic search, user filters, advanced search), facilitated accessibility and infrastructure for access through portable devices, or for users with specific needs, linked data technologies to facilitate data interoperability across data portals and improve knowledge representation across various domains to support reuse and increase the semantic value of data (e.g., providing clear guidelines to the user upon data upload on how to link their data to existing resources), and improved metadata. When it comes to **interoperability non-functional requirements** (how the system is expected to perform certain actions) regarding interoperability, technology and semantics, the prevalent themes which were identified in the analysis include the performance and scalability of OD infrastructures, the data integration from multiple sources, data integrity and reliability, the linking of data available to known knowledge representation schemata (vocabularies, ontologies) for conceptual connection to their respective domain(s), the data availability in a standardized way (e.g., following metadata standards), as well as the provision of proper thematic tags which offer semantic meaning and facilitate the interested stakeholders. The requirement details about interoperability (from

a technological and semantic perspective) are a higher-level description of the essential parameters constituting the functional and non-functional requirements to sum them up. However, they can understandably be fragmented into more case-specific requirements which reflect the necessities of a specific context and application domain.

Since **data reusability** plays such a crucial part in the smooth functioning of an open data portal, it is the focus of the first set of requirements. The sheer size, variety, and complexity of today's data environments make it imperative that we find ways to make data reusable. These reusability specifications cover both practical and theoretical concerns, **with the end goal of providing both end users and administrators with the resources they need to make data reuse** a breeze. Basic data processing and quality control knowledge are required for portal administrators and data users to meet the functional criteria for reusability. These abilities are fundamental in making the portal's data both easily accessible and of superior quality, increasing its reusability. In addition, these requirements highlight the value of semantic annotations like Schema.org tags, which provide context and importance to data. Annotations like this are crucial since they increase data interpretability and encourage its reuse. However, the relevance of **digital literacy among users is highlighted by the non-functional requirements for reusability**. Everyone, from teachers to students to data nerds may find something useful in open data portals. The data provided via these platforms is only useful if users have the digital literacy to find their way around, interpret it, and put it to effective use. Additionally, **open data portal participation criteria are crucial to reusability**. Data must be understood, and user-driven portals work best when users actively participate in data collecting and decision-making. This collaborative approach increases the portal's content and promotes interdisciplinary problem-solving. **The interplay between reusability and accessibility is also evident**. Open data portals provide enterprises, institutions, and organizations the freedom and adaptability to utilize data for many reasons. This accessibility allows data exchange across governmental, business, and non-profit sectors, encouraging interdisciplinary cooperation to solve complicated problems.

From the literature review on technical needs, we can see the challenge of dealing with diverse interpretations. For instance, there may be gaps in the interpretation of what FAIR principles mean for stakeholders in different contexts. For example, accessibility in FAIR refers primarily to retrievability of data and metadata, whereas in many other spaces web accessibility is better understood as the ability for diverse users to perceive, understand, navigate, interact, and contribute to content.

6. FAIR Data provision requirements specification

In the following Section, we consolidate the work undertaken in the preceding Sections, where we systematically derived and assessed requirements based on user stories. Our focus now shifts towards aligning each of these requirements with the fundamental principles of FAIR data management outlined in the preceding subsection. This critical association process allows us to examine how each requirement contributes to the realization of the FAIR principles, thus providing a comprehensive understanding of how our efforts contribute to the overarching goal of fostering FAIR data practices within our context.

6.1. Requirements for findability

Table 10: Functional requirements for findability

ID	Feature	Stakeholder	Why is related to findability
REQ-48	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data users	Because with this requirement we can prioritize in searches the comments that can be more relevant to their profile.
REQ-51	The data portal should provide the functionality of guiding the users through the process of linking data to existing resources to allow for semantic connection.	Open data users	This way new data that is added to the portal is in superior quality and ready to be discovered by other users.
REQ-50	The data portal should provide the functionality of allowing the users to improve the quality of data (e.g., enrich metadata) if they discover the dataset lacks it, and there should be guidelines to the user to do it correctly.	Open data users	This way users can contribute to data quality and improve the status of the datasets they are interested in using, making them more usable and discoverable to other users.

Table 11: Non-functional requirements for findability

ID	Feature	Stakeholder	Why is related to findability
REQ-52	The data portal should provide recommendations to help the user while searching, based on semantic technologies (such as linked open vocabularies).	Open data users	The user can receive more accurate recommendations on finding what they are looking for instead of just inputting keywords and getting loosely relevant results.
REQ-53	The data portal should provide alternative input methods for search (e.g., based on the geospatial location of the user or temporal criteria they might insert).	Open data users	The search function is easy for the user and returns relevant results according to the users' geospatial in formation in a straightforward manner which does not require digital literacy skills.
REQ-58	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data users	Because with this requirement we can prioritize in searches the comments that can be more relevant to the user profile.
REQ-59	The datasets in the data portal should be linked to knowledge	Open data users	This way, the most relevant topics for choosing datasets to be used in

ID	Feature	Stakeholder	Why is related to findability
	representation schemata (such as vocabularies and ontologies) to have connected semantic meaning.	and School curriculum designer	the education context can be shown according to their proximity with other linked topics.
REQ-60	The datasets in the data portal should have proper thematic tags to reflect sufficiently their actual content.	Open data users	This way, the user can more easily discover data relevant to their profile, profession, or desired subject of search.

6.2. Requirements for accessibility

Table 12: Functional requirements for accessibility

ID	Feature	Stakeholder	Why is related to accessibility
REQ-55	The data portal should provide information about dataset even when these are not available anymore, the dataset metadata should still be accessible.	Open data users	The dataset itself might not be available anymore but the context (coming from the metadata) will still enable the user to conduct their intended study properly (it could be needed for historical or personal reasons).
REQ-26	Access to open data through smart phone.	Open data users	Using a smart phone to access the open data, participation in the open data ecosystem can be enhanced. The smart gadgets are easily purchasable and accessible in all countries.
REQ-14	Standard data format/serialisation.	Educational Institutions	A widely acceptable open data format can enhance the accessibility, useability, and reusability of open data.
REQ-49	The datasets used in an education context should provide proper visualisations and stories related to their content.	Open data users and School students	The study information based on OD included in the curriculum can become more appealing and interesting.

6.3. Requirements exclusive for interoperability

Table 13: Functional requirements for interoperability

ID	Feature	Stakeholder	Why is related to interoperability
REQ-13	Integration of education open data	educational institutions	Open data integration covers the data exchange, transfer, and integration within or between different OD systems.
REQ-16	Tool for data sharing dedicated to open data intermediaries	Open data intermediaries	Data sharing is also a sub-functionality or feature of the open data interoperability.
REQ-18	Data integration tools for the data intermediaries	Open data intermediaries	Need data automation, collection, and integration solutions to make the process of data integration simpler. It is crucial for open data

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ID	Feature	Stakeholder	Why is related to interoperability
			intermediaries to have access to technology that simplifies the process of acquiring data from a variety of sources. The integration of OD from diverse sources constitutes OD interoperability.
REQ-20	Tools to generate the insights from the raw data	Open data intermediaries	access to tools for the derivations of insights from the raw data so that to be able to deliver more insightful guidance to our customers. These tools may assist users in generating meaningful and interactive visual representations of the data and in deriving insights from the many resources of open data, which may help users better interpret and utilize the data. This functionality requires OD interoperability.
REQ-22	Technical openness of the datasets	Open data users and providers	By opening the datasets, it technically means to follow the dataset standards, formats, and other protocols to enhance the data integration across different systems and to facilitate the better accessibility of the open data. Technical openness contributes to the technical interoperability of open data.
REQ-24	Allowing the user to upload their dataset	Corporate users	A user can upload an updated version of the existing dataset. In this way, other users can use cleaned, modified, augmented, or transformed datasets for specific tasks. This feature also contributes to the OD interoperability.
REQ-25	Consistent and reliable delivery of datasets to the artificial users	Artificial users	consistent and reliable data provision to feed into applications and algorithms to avoid the inaccurate results generated by faulty data sources or inconsistent formats. This feature requires formal OD interoperability principles to be applied.
REQ-27	Big data search, aggregation, and integration	Open data users	The intensive searching, aggregation, and integration of big datasets can contribute to the

ID	Feature	Stakeholder	Why is related to interoperability
			sustainability and value creation of the open dataset. Aggregation and integration mean a clear connection between this feature and OD interoperability.
REQ-31	anonymisation of the open dataset before publishing	Open data providers	The tools developed to anonymize the dataset can help the publishers anonymize the feature or properties, which can lead to the identification or re-identification of individuals in the OD spaces. This can help with the legal and organisational interoperability of the OD.
REQ-39	portability of infrastructure in the open data domain	Open data providers	The portability of infrastructure will help transfer the knowledge of OD infrastructure to another organisation or other OD system. Common, portable, or standardized data infrastructure can help increase the interoperability of OD.
REQ-40	Provision of datasets in LOD format	Open data providers	Enhancing the reusability of open data by providing data in LOD In return, the interoperability of the open data might be semantically increased. And it can help with the technical interoperability of the open data, such as access, integration of data through SPARQL
REQ-43	Data integration from multiple sources	Open data users and providers	The data integration process should be transparent to avoid any discrepancies in the data. It would be useful for artificial users as well. Data integration from multiple sources increases the interoperability of the open data ecosystem.
REQ-61	The datasets in the data portal should adhere to data models and metadata standards (e.g., DCAT).	Policy/Decision makers	By doing so, the quality of the data is improved, so decisions based on this data are more likely to be dependable and trusted. More widely adopted dataset standards will enhance the semantic interoperability of open data.
REQ-62	The datasets in the data portal should be linked to knowledge representation schemata (such as	Policy/Decision makers in a company	This way the interested user can see relations and conceptual connections among data, helping

ID	Feature	Stakeholder	Why is related to interoperability
	vocabularies and ontologies) to have connected semantic meaning.		them to develop better strategies. More widely adopted dataset standards will enhance the semantic interoperability of open data.
REQ-48	All the comments to the comments of the open data portal users on third party datasets should have schema.org tags to provide a semantic meaning.	Open data providers	By doing so, the semantic interoperability of data is improved.
REQ-50	The data portal should provide the functionality of allowing the users to improve the quality of data (e.g., enrich metadata) if they discover the dataset lacks it, and there should be guidelines to the user to do it correctly.	Open data providers	By doing so, the semantic interoperability of data is improved, in a co-creative manner.
REQ-51	The data portal should provide the functionality of guiding the users through the process of linking data to existing resources to allow for semantic connection.	Open data providers	By doing so, the semantic interoperability of data is improved, allowing the users to also contribute to this process.
REQ-54	The data portal should provide clear guidelines on how new dataset uploaded in the portal meets community standards or domain relevant standards.	Open data Contributors	When a new dataset is uploaded it instantly adheres to community standards, thus improving interoperability.

Table 14: Non-functional requirements for interoperability

ID	Feature	Stakeholder	Why is related to interoperability
REQ-42	Functionalities to publish unified and easily accessible dataset from multiple sources.	Open data providers	Sometime data is produced by multiple government agencies but is not published in a uniform and easily accessible manner, to not only share the analytical findings from the government data but also the collated and sanitized data itself (US-48).
REQ-46	Performance and scalability of the OD infrastructure.	Open data users and providers	Emerging database technologies, cloud services, and modern data collection devices are being introduced around the globe, so open data infrastructure should be scalable enough to support these technological transformations.

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ID	Feature	Stakeholder	Why is related to interoperability
REQ-47	The manual development for each functionality or services provided by the OD portal.	Open data providers	Documentation is the key part of the use and re-use of the open data services, and data itself. It would be necessary to provide the end-user with documentation to understand the data and portals.
REG-61	The datasets in the data portal should adhere to data models and metadata standards (e.g., DCAT).	Policy/Decision makers and Open data users	By doing so the data quality and semantic interoperability is improved.
REQ-63	The datasets in the data portal should be linked to knowledge representation schemata (such as vocabularies and ontologies) to have conceptual connection.	Open data users and intermediaries	This way data intermediaries can more easily curate or structure data in the right context, improving semantic interoperability.
REQ-66	The datasets in the data portal need to be available in machine-readable and processable format.	Civil servants and Open data users	The data used in the daily activities of public systems (e.g., in electronic services), can seamlessly run through different systems, thus they are more interoperable.
REQ-45	Data integrity and quality.	Open data users and providers	The data should be accurate, dependable, and up to date. Quality assurance processes must be in place to detect and resolve any inconsistencies or errors in the data, making it more interoperable.
REQ-62	The datasets in the data portal should be linked to knowledge representation schemata (such as vocabularies and ontologies) to have connected semantic meaning.	Policy/Decision makers in a company	This way the interested user can see relations and conceptual connections among data.
REQ-65	The datasets in the data portal should be linked to the most prevalent ontologies and vocabularies of their respective domain.	Professionals and Domain experts	Build on the knowledge around each domain based on other, conceptually related domains, thus enabling interdomain interoperability.
REQ-64	The datasets related to healthcare in the data portal should be linked to the most prevalent ontologies and vocabularies in the biomedical sector.	Healthcare professionals and Open data users	Helps the professional in their occupation (they can see where else their domain knowledge is useful) and improved diagnosis.
REQ-67	The datasets related to law and legislation in the data portal should be linked to the most prevalent ontologies and vocabularies in the legal sector.	Legal professionals and Open data Users	Helps the professional compare legislations among different countries and have a faster and better overview of existing laws and practices, as well as conflicts.

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6.4. Requirements for reusability

Table 15: Functional requirements for reusability

ID	Feature	Stakeholder	Why is related to reusability
REQ-40	Provision of datasets in LOD format.	Open data providers	Enhancing the reusability of the open data by provision of data in LOD, Helping the providers with the data publication process, Quantifying the open data deployment schema, specifying a methodology, tool, or software to publish the 1-star data as a 5-star data, LOD preparation and publishing environment (US-46).
REQ-56	The data portal should provide a place where users can connect with other users in a community, based on similar interests.	Open data users	The users can be grouped under similar interests and topics, being allowed to exchange knowledge, and assist each other.
REQ-68	Portal administrators and data users must have the basic skills for data processing and for checking the quality of data.	Open data users and providers	For reusability of open data, data quality, validity and completeness of the data may be evaluated with the use of technologies available via data portal.
REQ-71	How can be Provenance and Reusability of Data via Repositories can be adapted.	Open data users and providers	Data provenance and reusability in open data portals ensure data authenticity and quality. This involves clearly documenting the dataset's origin, ownership, and updates. Metadata and reuse standards like open data licenses promote data sharing and accessibility.

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7. Conclusions

Since its inception, the ODECO project has recognised that one of the major challenges of open data ecosystems is to move from being provider centric to user centric. Technology has a strategic role to play in achieving this goal.

In this Section, we present conclusions about the research question: What are the needs of open data users from a technical perspective considering functional and non-functional requirements? First, taking the FAIR principles as a framework, we mapped the needs of eight key user groups: education, data intermediaries, companies, artificial users, non-specialist users, government, journalism, and NGOs. We then reformulated these needs into user stories that would help us reflect the everyday information search and access scenarios faced by diverse open data users. Finally, we listed the functional and non-functional requirements that open data initiatives, and specifically open data portals, must satisfy to align with user needs.

As conclusion we want to highlight:

- **Complementarity of requirements.** We would like to highlight the interdependence of the technical requirements in terms of the overall user experience of open data users. For example, how by improving interoperability conditions by adopting standard vocabularies and information representation models we can proportionally improve the findability conditions of datasets by achieving greater alignment to the mental models of users, industry, and government.
- **Data quality.** Data and metadata quality is a cross-cutting enabler to realise the functional and non-functional requirements listed in this report.
- **Data infrastructure.** Open data users need a reliable data infrastructure. This infrastructure usually takes the form of open data portals. Therefore, the functional and non-functional requirements outlined here can be integrated in a coherent way into existing portals. Semantic interoperability can play a vital role in extending the reach of these platforms to everyday information search scenarios on other platforms.

It is crucial to acknowledge certain limitations inherent to this report. The primary limitation of this study pertains to the fact that the existing literature on open data often does not directly delve into the concept of user needs from a technical standpoint. Consequently, some technical requirements must be inferred from the dispersed articulation of user needs. Furthermore, it is important to recognise the potential existence of multiple conceivable and feasible technical solutions to address the same set of user needs.

Notwithstanding these limitations, this work makes a valuable contribution to our comprehension of technical user needs. This report can function as a guide for the founding team of a data portal, or any analogous initiative aimed at disseminating open data.

Based on our analysis, we can outline a research agenda. First, research is required to define the best software/technology development framework to deliver this type of requirements taking into consideration that these are data-intensive products. Second, agile methodologies are required that actively incorporate user feedback in the definition, development, testing and improvement phases of the resulting open data technology platforms.

In the context of ODECO, the deployment of these requirements will require monitoring whether they are able to meet the needs of a wide range of stakeholders including non-specialist data users, local governments, journalists, students, NPOs, NGOs, companies, data intermediaries and if not, readjusting them accordingly. We also aim to make the requirements a factor in the governance mechanisms of open data ecosystems in terms of ownership, reporting, funding, and decision making.

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