Accelerating Climate Change Adaptation in Cities with FAIR2Adapt: FAIRifying Hamburg's Risk Map

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1 ABSTRACT

As climate change intensifies, cities must develop adaptive strategies to mitigate risks and enhance resilience. The FAIR2Adapt project applies FAIR (Findable, Accessible, Interoperable, and Reusable) principles to climate adaptation data, ensuring long-term usability and interoperability across urban planning tools. This paper presents our work on identifying requirements for the FAIRification of Hamburg's Risk Map, a critical resource for urban climate adaptation.

We outline the methodological framework used to enhance data findability, accessibility, and interoperability, integrating the Risk Map with broader urban data infrastructures. The approach involves a requirements elicitation process as a pre-phase of the FDO-driven FAIRification Framework we develop in the FAIR2Adapt project. Based on the description of the city of Hamburg case study, which is one of six in the FAIR2Adapt project, we identified user stories and extracted more specific requirements. To address these requirements customized FAIR Supporting Resources will be needed, such as a FAIR metadata schema for geospatial risk maps and simulation models, improving data sharing and reusability within ArcGIS-based risk assessment tools, and applying Scientific Knowledge Graphs (specifically, the Open Research Knowledge Graph) to ensure scientific transparency and reproducibility. Additionally, we will enhance urban climate modeling workflows making the developed procedures accessible via RO-Crates that allow to package the software together with structured documentation.

By embedding these principles, we strengthen decision-making for urban climate adaptation, providing city planners and stakeholders with actionable, interoperable data. We discuss challenges in the uptake of FAIR implementation, and present an outlook on scaling our approach to other cities. Our findings contribute to the broader discourse on how FAIR principles can accelerate climate resilience efforts in urban environments.

Keywords: climate change, resilience, climate adaptation, interoperability, urban planning

2 INTRODUCTION

2.1 FAIR2Adapt for advancing Climate Adaptation

Climate adaptation efforts require reliable, accessible, and interoperable data to inform evidence-based decision-making. The FAIR2Adapt project, financed by the Horizon-INFRA-2024-EOSC-01-01 program, addresses this challenge by applying FAIR (Findable, Accessible, Interoperable, and Reusable) principles (Wilkinson et al., 2016) to climate adaptation data, ensuring that critical environmental and socio-economic datasets can be effectively utilized for urban long-term planning. The project has recently started and is currently in the process of developing an FDO-driven FAIRification Framework. This paper focuses on requirement elicitation, an initial phase within the FAIRification process that aims to identify the specific needs of stakeholders involved.

2.1.1 Why the FAIR principles matter for data management in CCA

The FAIR principles are crucial for data management in Climate Change Adaptation (CCA) due to the complex and multidisciplinary nature of climate data. Effective climate adaptation strategies depend on integrating diverse datasets, such as meteorological data, socio-demographic information, and infrastructure resilience indicators. Applying the FAIR principles ensures that these datasets are:

- Findable: Easily discovered and located by both humans and machines, enabling efficient identification and visibility of relevant data through searchable resources.

- Accessible: Reliably retrieved through standardized, open, and secure protocols, ensuring long-term accessibility of metadata even if restrictions apply.
- Interoperable: Compatible with various systems and tools, allowing seamless data integration across platforms.
- Reusable: Properly documented and standardized, promoting long-term usability and reproducibility.

By improving data FAIRness, FAIR2Adapt enhances the usability of climate risk assessments, such as Hamburg's Flood Risk Map, by integrating diverse sources, including urban flood data, socio-demographic information, and infrastructure resilience indicators.

2.1.2 Added value for the CCA communities

The added value of applying the FAIR principles to CCA data management lies in several key areas:

- Enhanced Decision-Making: With FAIR-compliant data, city planners and stakeholders have access to high-quality, actionable information, enabling informed, data-driven decisions.
- Scientific Transparency: The FAIR principles promote the sharing of well-documented and reproducible data, which is essential for scientific credibility and progress.
- Long-Term Usability: By standardizing metadata and documentation, the FAIR principles ensure that data remains usable and relevant over time, supporting ongoing adaptation efforts.
- Interdisciplinary Collaboration: FAIR-compliant data facilitates collaboration across different sectors and disciplines, fostering holistic approaches to climate resilience.

2.1.3 Key barriers and challenges

Despite the benefits, several barriers and challenges must be addressed to effectively implement the FAIR principles in CCA data management:

- Data Integration: Combining diverse datasets from different sources can be technically challenging due to varying formats, standards, and quality.
- Metadata Standardization: Establishing and maintaining consistent metadata standards across datasets is crucial for interoperability, but can be resource-intensive.
- Infrastructure Limitations: Existing data platforms may lack the necessary support for the FAIR principles, requiring upgrades or new implementations.
- Stakeholder Engagement: Ensuring that all relevant stakeholders understand and adopt the FAIR principles requires significant outreach and education efforts.

In addition to advancing climate adaptation efforts, the FAIR2Adapt project aligns with broader policy goals such as those outlined in the EU Data Act. While FAIRification is not a strict legal requirement for all datasets, the Data Act promotes data sharing, access, and reusability, reinforcing the importance of FAIR practices, particularly for publicly funded research data. By embedding these principles, FAIR2Adapt contributes to enhancing data governance and interoperability in line with EU policy objectives.

Addressing these challenges is essential for maximizing the impact of the FAIR principles on urban climate resilience. Through a structured approach that integrates user-driven needs, metadata standardization, and technology integration, FAIR2Adapt fosters collaboration among researchers, policymakers, and urban planners, creating a scalable model for cities seeking to strengthen their climate adaptation strategies.

2.2 Hamburg's Climate Risk Mapping: challenges, goals and key assets

2.2.1 Challenges and opportunities

Hamburg, a city with various climate-related risks, needs to adapt to climate change in a systematic, sustainable and cross-sectoral approach. At the organisational level, the interaction between the administration and public enterprises is crucial for the implementation of adaptation strategies and the consideration of interactions between the different actors and sectors of the urban system, which is a prerequisite for sustainable adaptation planning. In addition, adaptation and mitigation need to be weighed against each other to assess trade-offs and avoid incompatibilities (e.g. urban densification versus adaptation to climate-induced stressors), which requires tailored state-of-the-art climate and adaptation scenarios (e.g. Representative Concentration Pathways RCPs and Shared Socioeconomic Pathways SSPs).

2.2.2 Key assets for FAIR Climate Adaptation

Hamburg faces risks from pluvial flooding due to heavy rainfall events, exacerbated by urbanization and climate change. To support decision-making and adaptation strategies, the city has developed key assets that facilitate data integration, flood risk assessment, and predictive modeling. Unlike fluvial or coastal floods, pluvial floods are localized, unpredictable, and challenging for numerical weather models. Hamburg, with its flat topography and complex flood risks (pluvial, fluvial, coastal), serves as a case study for a high-resolution risk mapping approach.

The „Pluvial Flood Risk Assessment for Hamburg“ develops a risk assessment framework for pluvial flooding in Hamburg. The study follows the IPCC 2014 risk framework, considering hazard (flood levels), exposure (people in affected areas), and vulnerability (socio-economic factors) to develop Pluvial Flood Risk Indices related to well-being (PFRWB) and mobility/accessibility (PFRMA).

To quantify social vulnerability, the study incorporates socio-economic factors, namely children under 10, elderly singles, low education levels, and social welfare recipients. Exposure is defined by differentiating between people affected by mobility restrictions (all residents in a building) and direct flood impact on residential well-being (only ground-floor residents). The hazard component is derived from high-resolution flood simulations for Hamburg, based on a 100-year rainfall event (36 mm/h). The methodology applies TOPSIS and Shannon Entropy to quantify vulnerability and integrates spatial analyses using Delaunay-Triangulation for visualization.

The results identify risk hotspots in Hamburg, where high PFRWB and PFRMA values overlap. A key finding is that social vulnerability does not correlate directly with hazard occurrence, highlighting the complex spatial nature of urban flood risk. The study underscores the need for a holistic approach to risk assessment, integrating climate science, infrastructure planning, and social policies to enhance urban resilience. The methodology developed in this study is transferable to other urban areas, making it a valuable asset for climate adaptation planning and risk-informed decision-making.

The risk map was implemented in ArcGIS using a number of different tools after external data preparation. The whole procedure will be available as a customized ArcGIS tool, which will be prepared as a shareable resource to allow its application in other urban areas. This approach will be utilized for Hamburg's Risk Assessment Framework and will be used to produce a heat risk map for the city of Hamburg, adapting procedures with different input data.

In Hamburg, the Urban Data Platform Hamburg (UDP)[1] serves as a central hub for geospatial and hydrological data, enabling municipal agencies to access and analyze critical datasets such as those used to create the risk map. However, while it consolidates data from various sources, its FAIR compliance remains limited, posing challenges for data findability and integration with external data.

Complementing the UDP, the Urban Modelling Platform (UMP) provides advanced computational capabilities to run simulations using the OGC API Processes standard for easy access of executable models. Unlike the UDP, which primarily stores and visualizes data, the UMP enables the sharing of modeling methodologies like the flood risk assessment, enabling customization for local applications. Researchers and practitioners can contribute new methods and algorithms, which municipalities can then adopt and refine based on local needs. The platform supports Python-based frameworks such as SWMM (Storm Water Management Model) and TELEMAC for hydrological simulations, while leveraging ArcGIS-based spatial analysis tools for urban flood mapping. Through the integration of UDP and UMP, Hamburg fosters a collaborative ecosystem where researchers, municipalities, and policymakers can co-develop and share methodologies to address urban risks effectively.

[1] https://www.en.urbandataplatform.hamburg/

3 METHODOLOGY

3.1 FAIR2Adapt's FDO-driven FAIRification Framework

Based on the FAIR Hourglass concept (Schultes 2023), the FAIR2Adapt project develops a FAIRification Framework to turn data into actionable knowledge to shape climate adaptation strategies.

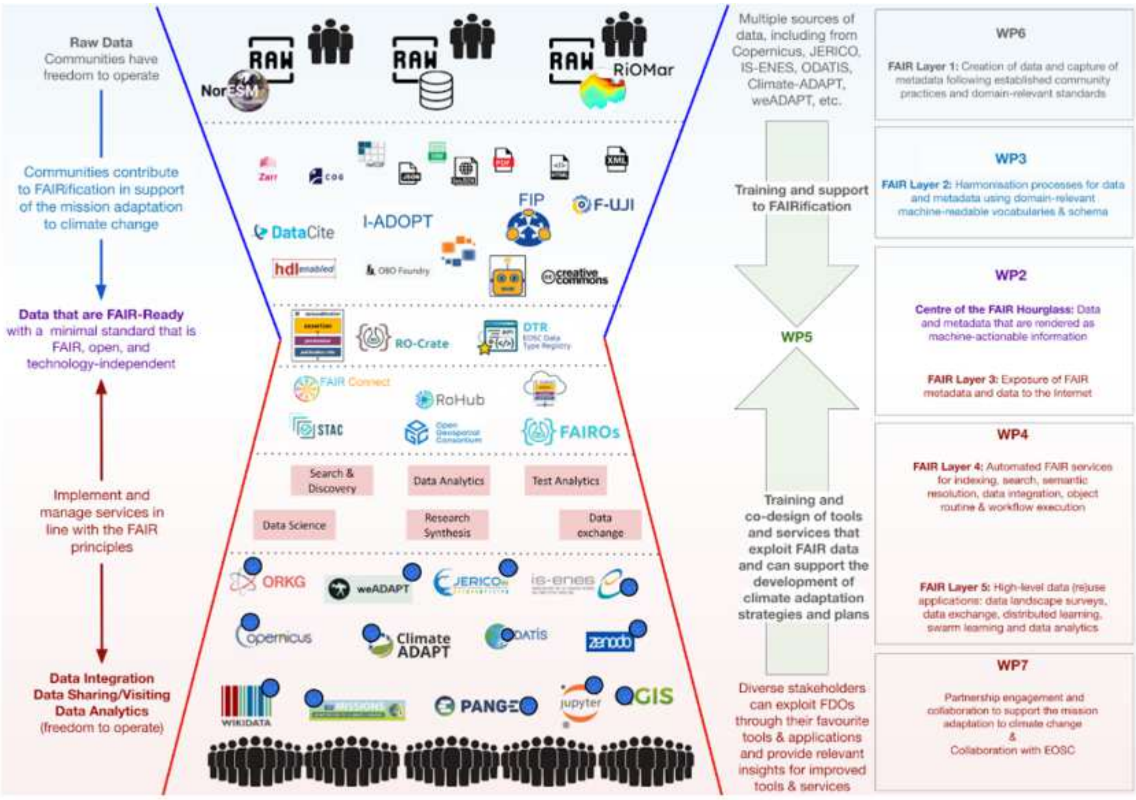

Fig. 1: The FAIR Hourglass applied to FAIR2Adapt.

The hourglass shape (Fig. 1) represents the flexibility at both the beginning and end of the process:

- The upper part focuses on FAIRifying community-provided data.
- The lower part ensures FAIR Orchestration, enabling services to act on FAIR-ready data.
- At the center, the FAIR Digital Object (FDO) ensures machine readability and interoperable reuse of digital objects.

To demonstrate the transformative impact of FAIR in advancing climate action and support the EU Mission on Adaptation, the FAIR2Adapt project engages in six case studies that address real-world challenges. The FAIR2Adapt case studies cover the six main steps defined by the Regional Adaptation Support Tool (RAST) to provide guidance to regional or local authorities during the adaptation planning process. By defining user requirements for each case study, the project develops tailored FAIR Supporting Resources to improve the FAIRness and semantic interoperability of critical CCA datasets and services. Where appropriate, these resources are transformed into FDOs using RO-Crate for packaging research data with their metadata and nanopublications for providing machine-readable metadata of FAIR Supporting Resources (FSRs). Additionally, the project provides training and support to the case study communities enhancing their awareness and capacity to effectively utilize the ecosystem of the developed and improved services.

3.2 Deriving requirements for the FAIRification process

This paper focuses on requirement elicitation, a pre-phase of the FAIRification process that aims to identify the specific needs of stakeholders. In agile software development, requirements are used to identify functions or features, constraints, rules, or other elements that must exist to satisfy user needs. A functional requirement defines what is needed, and not how it should be achieved (the solution). Non-functional requirements specify the criteria that will be used to test how well the solution meets the user's needs.

Gathering requirements to design the necessary services that the user expects is crucial, but is sometimes viewed as inefficient or overly restrictive when tried to be identified too early in the process because they can evolve over time. Thus, a more high-level requirement in the form of a user story is often used to express needs from the perspective of an end-user goal. A user story has three parts:

(1) The Who describes the user as a role (As a …)

(2) The What describes what is desired or needed, thus the goal as an activity (I want/need to …)

(3) The Why describes the reason or expected benefit (So that ..).

In FAIR2Adapt we apply user stories to identify the high-level FAIR requirements for each case study (see Fig. 2). We define a case study as a description of a real-life situation involving several users and digital objects. Hence, a case study refers to several user stories. While case studies are described by the case study provider by identifying the stakeholders involved, the addressed challenges, the goals and the aimed solutions, the user stories are extracted through interviews with stakeholders by FAIR data stewards as part of the Community Support and Engagement (WP5) activities.

From each user story, we derive specific functional requirements, identifying the necessary activities, as well as non-functional requirements, represented as constraints. Additionally, we determine the involved agents and digital objects (DOs) – some of which will be FAIRified, while others will serve as FSRs. It is crucial to keep the requirements free from concrete solutions, as these solutions should only be selected or developed after a thorough evaluation of the requirements. This ensures that the solutions align with the real needs, constraints, and goals of the stakeholders rather than being predetermined by available technologies or existing implementations.

By generalizing the requirements, we can distill reusable use cases that can be associated with potential FSRs, enabling their application in different CCA contexts. All components in the requirement elicitation process are planned to be collected via an online form. They will be represented in machine-readable format and made available within a queryable knowledge graph. A library of use cases can significantly help facilitate the uptake of FAIR implementation, allowing stakeholders to quickly adapt and apply proven solutions to their contexts ensuring consistency, scalability, and interoperability in CCA.

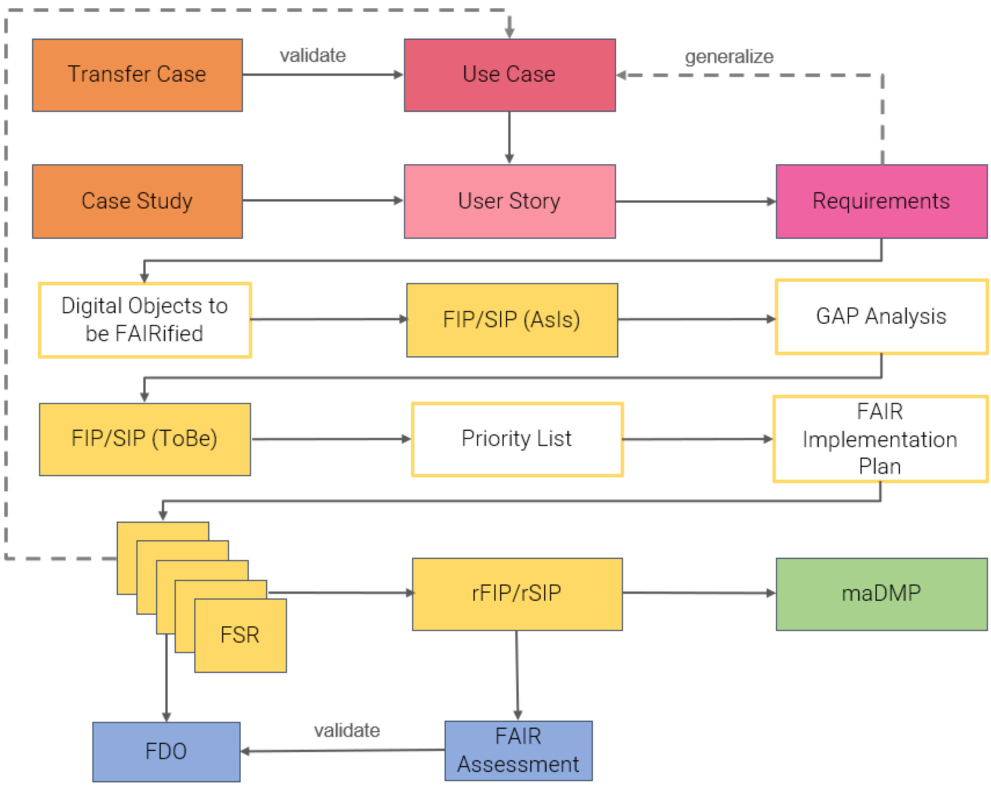

Fig. 2: Requirement elicitation process used in the FAIR2Adapt project.

To systematically address each of the FAIR Principles to enable the FAIRification of digital objects, the GO FAIR Foundation has developed the FAIR Implementation Profile (FIP) approach (Magagna et al., 2024). A

FIP is a structured questionnaire that documents relevant standards, technologies, and policies chosen by a community, made available as a collection of FDOs. In analogy, a Semantic Interoperability Profile (SIP) is a list of declared implementation choices focusing on the interoperability aspects of the FAIR principles including semantic artefacts and their supporting services. Rather than a one-size-fits-all approach, this methodology allows stakeholders from different case studies to specify the FAIR Supporting Resources best suited for their workflows. At the same time, FIPs and SIPs can serve as accelerators of FAIR convergence, as ready-made and well-tested collections of FSRs developed by trusted communities will be widely reused by other communities (Schultes et al., 2020).

In the context of FAIR2Adapt, FIPs and SIPs are used to:

- Assess the current state of the case study (AsIs)
- Identify the gaps in the profiles (Gap Analysis)
- Define the target state for a case study (ToBe)
- Prioritize and develop a FAIR implementation plan, agreeing on a reference list of FSRs (r)
- Integrate FSRs into researcher's daily workflows through machine actionable data management plans (maDMP)
- Validate FDOs via informed FAIR assessment tests

This systematic documentation helps evaluate the project's FAIR compliance decisions, ensuring the use of registries, vocabularies, and other resources that support FAIR data. We aim to assess FAIRness using specific tools, such as F-UJI or the RDA FAIR Maturity Indicators, to monitor progress. Establishing a baseline for FAIRness is essential, allowing reassessment after FAIRification of data, software, and workflows.

The FSRs listed in a rFIP may either already exist, or need to be created. In some cases, existing resources can be leveraged by FAIRifying them, while in other cases, new resources need to be developed from scratch. FAIRification begins with the provision of metadata. While there is a high degree of consensus on the use of domain-agnostic metadata standards to improve data discoverability, there is a lack of community-specific metadata schemas to enhance data reusability. Using the Metadata for Machines (M4M) approach, we will develop required metadata involving stakeholders from case studies. At the same time, we will ensure that these schemas are machine actionable by mapping them to existing standards and reusing FAIR vocabularies. The key role of M4M in the FAIRification process is to enable automated workflows for data discovery, retrieval, and integration, aligning with the FAIR principles.

3.3 Hamburg Risk Map user stories and their requirements

To demonstrate the user requirements elicitation process in FAIR2Adapt, we examine the case study of the city of Hamburg and describe three user stories that we were able to identify in a stakeholder meeting in Hamburg in early March 2025. Each user story is outlined with its corresponding requirements and thoroughly analyzed to identify the potential FAIR Supporting Resources that could be implemented to properly address the stakeholders' needs.

3.3.1 User Story 1: Sharing the ArcGIS Toolbox for Risk Mapping

User Story:

As a researcher I want to share the Hamburg Pluvial Flood Risk Map ArcGIS toolbox so that other implementers can use it to calculate risk and sensitivity maps in other urban areas.

Analysis:

FAIR2Adapt will evaluate together with the stakeholders of the case study how these requirements should be properly met. The aim of the toolbox is to create a reproducible framework, where stakeholder and flood risk managers can holistically assess flood risk providing information at building-resolving scale in order to support climate adaptation. From Table 1, it is clear that the ArcGIS toolbox needs to be FAIRified to some extent. For this a FIP will be developed to identify what is missing and what can be achieved within the timeframe of the FAIR2Adapt project. Nevertheless, here are a few preliminary thoughts on how we might FAIRify the tool:

- Requirement 1 calls for FAIR metadata about the high-resolution data needed to run the tool. A dedicated M4M workshop with the risk map developers will identify the required metadata elements to be included in the data description.
- Requirement 2 asks for the tool to be deposited in a public repository and GitHub is a good solution to make the software accessible and version controlled. ArcGIS is a proprietary and expensive tool and therefore it is recommended to transfer the code in open source systems like Python which makes geospatial workflows more efficient, scalable, and reproducible. Overall, it will be reasonable to follow the recommendations of the recommendations of the FAIR for Research Software RDA WG.
- Requirement 3 requires contextualizing the ArcGIS toolbox with a paper describing the technical procedures. The paper in preparation (Von Szombathely, 1) addressing the methodology of the Hamburg Pluvial Flood Risk Map describes the methods used and and toolbox developed, following the risk framework of the IPCC. It was tailored to high-resolution data and the assessment of two risk types (mobility/accessibility & well-being). Using RO-Crate allows to package and share the tool together with the paper in a FAIR-compliant manner, making it machine-actionable, well-documented, and interoperable.

Requirement 1	Information about the data required to run the tool.		
Activity	Provide metadata about data		
DO Name	Socio-economic data	Buildings and streets data	Modelled flood level data
DO Type	Dataset	Dataset	Dataset
Resource Type	DO to be FAIRified	DO to be FAIRified	DO to be FAIRified
Constraint	Metadata should be FAIR	Metadata should be FAIR	Metadata should be FAIR
Requirement 2	Make the ArcGIS tool accessible.		
Activity	1. Put ArcGIS toolbox in public repository	2. Transfer code in open source systems	
DO Name	ArcGIS tool	ArcGIS procedures	
DO Type	Software	Software	
Resource Type	DO to be FAIRified	DO to be FAIRified	
Constraint	Follow FAIR4RS Principles	Follow FAIR4RS Principles	
Requirement 3	Contextual information required for the ArcGIS toolbox		
Activity	Package tool together with a technical paper describing the ArcGIS toolbox.		
DO Name	Urban Pluvial Flood Risk: Methodological Framework		
DO Type	Puplication		
Resource Type	Supporting Resource		
Constraint	Increase Reusability		

Table 1: Requirements for user story 1.

3.3.2 User Story 2: Making my research paper machine-processable

User Story:

As a researcher I want to make the scientific knowledge and findings in my paper machine-processable, so that other researchers and systems can easily access, interpret, and reproduce my work.

Analysis:

Academic articles remain the primary expression of scientific knowledge. This form of knowledge recording and communication has persisted over centuries, which speaks for its usefulness for knowledge sharing among experts. However, knowledge expressed in narrative text documents is not machine readable, is hardly findable, interoperable, reusable. To integrate or synthesize scientific knowledge, for instance in systematic reviews or meta-analysis, researchers routinely manually extract knowledge from documents and organize the extracted knowledge in databases that then support reuse. This extraction activity is time-consuming, error-prone, inaccurate, and potentially repeated, since (different) researchers may extract the same knowledge multiple times.

To address the requirement 1 (see Table 2), the Open Research Knowledge Graph (ORKG) (Stocker et al, 2023) has developed services for the production, curation, publication, and reuse of structured scientific knowledge. The ORKG's reborn article initiative (Stocker et al., 2024) has developed an approach that enables the production of high-quality and reproducible machine-readable scientific knowledge produced in (statistical) data analysis. Leveraging these systems, User Story 2 aims to FAIRify the scientific knowledge published in an upcoming article (Von Szombathely, 2) presenting the scientific findings on pluvial flood risk assessment for the city of Hamburg, Germany. By publishing a reborn article in addition to the original article we ensure that the scientific findings are published also in machine-readable format. Depending on whether the scientific findings are produced using open scripting languages (e.g. R or Python), it will also be possible to publish the findings so that they are reproducible. This is achieved by interlinking the scripts used to compute the findings. The requirement 2 can be addressed in the same way as requirement 3 of user story 1 by providing a RO-Crate.

Requirement 1	Make scientific knowledge in my paper machine-processable
Activity	Use services to extract knowledge
DO Name DO Type Resource Type Constraint	Research paper about Pluvial Flood Risk Assessment in Hamburg Puplication DO to be FAIRified
Requirement 2	Add data to the paper
Activity	Provide persistent identifier to refer to the input data.
DO Name DO Type Resource Type Constraint	Input data for deriving the risk map datasets DO to be FAIRified Increase Findability and Reusability

Table 2: Requirements for user story 2.

3.3.3 User Story 3: Improving Findability and Reusability of the Urban Data and Modelling Plattform

User Story:

As a data manager I want to make data and models more findable in Urban Data Platform (UDP) and Urban Modelling Platform (UMP) so that urban planners, climate modellers and citizens can make use of them according to defined usage licenses.

Requirement 1	Improve usability of UDP		
Activity	Provide metadata for datasets	Provide identifiers for datasets	Provide data usage license
DO Name DO Type Resource Type Constraint	UDP Datasets datasets DO to be FAIRified Increase Findability	UDP Datasets datasets DO to be FAIRified Increase Findability	UDP Datasets datasets DO to be FAIRified Increase Reusability
Requirement 2	Improve usability of UDM		
Activity	Provide metadata for models	Provide identifiers for datasets	Provide data usage license
DO Name DO Type Resource Type Constraint	UDM models models DO to be FAIRified Follow FAIR4RS Principles	UDM models models DO to be FAIRified Follow FAIR4RS Principles	UDM models models DO to be FAIRified Follow FAIR4RS Principles

Table 3: Requirements for user story 3.

Analysis:

User Story 3 focuses on FAIRifying the datasets in the Urban Data Platform (UDP) and models for Urban Modeling Platform (UMP). The goal of this FAIRification effort is to provide global unique persistent identifiers for all assets and to provide FAIR metadata, ensuring that the platform's outputs – such as climate risk predictions – are not only accessible but also findable and reusable under defined usage licenses. The key requirements include establishing a standardized metadata schema and ensuring interoperability with external models, which are essential for integrating UMP data into broader climate adaptation frameworks. A central activity involves enhancing discoverability and enabling efficient search and retrieval based on the reuse of common vocabularies. Potential measures for FAIRification include the development of a robust metadata framework based on ISO standards, as well as integration with Hamburg's Metadata Catalog. Identifying useful FAIR Supporting Resources can be best achieved by involving stakeholders in FIP workshops. Additionally, the FAIRification of models should also align with the FAIR for Research Software (FAIR4RS) approach, where not only the data but also the methods and algorithms used to generate it are made FAIR. This ensures full provenance, enabling researchers to track the inputs and parameters used in climate models. This holistic approach enhances the transparency and reusability of both the data and the underlying methods, contributing to the long-term sustainability and credibility of climate modeling efforts.

4 OUTLOOK AND UPSCALING

4.1 Overcoming Identified Barriers

One of the primary barriers to scaling the FAIRification process is the lack of convergence among existing standards, which can create challenges in ensuring interoperability across different systems, sectors, and regions. Furthermore, there is often a lack of interest from communities in adopting these standards, primarily because the added value of FAIRification may not be immediately evident. To overcome this, the FAIR2Adapt project uses real-world case studies to demonstrate the practical benefits of FAIR principles, helping to onboard key stakeholders and fostering a community-driven approach to climate adaptation. By showcasing tangible examples, we aim to highlight how FAIRification can enhance the discoverability, accessibility, and usability of data and tools, thereby driving greater engagement from the CCA (Climate Change Adaptation) community.

Another significant barrier is the lack of skills and knowledge in FAIR data management among CCA practitioners. To address this, FAIR2Adapt has developed a comprehensive capacity-building strategy, to raise FAIR awareness and embed the FAIR skills into the case study communities. Additionally, the use of AI technologies to support semi-automated FAIRification processes is a key aspect of this capacity-building effort. By integrating AI into the workflow, we aim to make the FAIRification process more efficient, reducing the burden on stakeholders and enabling them to focus on more strategic aspects of climate adaptation. Through these efforts, we not only address the barriers of interest and skills but also create a sustainable framework for scaling the adoption of FAIR principles across the CCA sector.

4.2 Vision for Future Developments (Upscaling)

To ensure a sustainable impact, comprehensive evaluation and dissemination of the project results in various formats is essential. A central component of this process is the implementation of transfer cases to validate the FAIRification framework, including the requirements elicitation process, in terms of its effectiveness and ease of adoption. These cases will showcase the process of applying FAIR principles to real-world datasets and workflows, highlighting both the challenges and opportunities in scaling across different contexts.

The concept of upscaling encompasses the scaling of the developed approaches beyond initial pilot projects with the aim of effectively addressing a larger number of users. This includes both geographical expansion and the structural development of political and administrative framework conditions in order to promote sustainable implementation. In addition, cross-sectoral dissemination of the results will be sought in order to maximise synergy effects between different areas and enable interdisciplinary application of the findings. (Guentchev et al., 2023)

The upscaling process in the FAIR2Adapt project will focus on two key aspects: the FAIRification framework and the reuse of FAIRified data, tools, and workflows.

As a pre-phase of the FAIRification framework the requirement elicitation process ensures that the real needs of stakeholders are captured in order to tailor the FAIRification of various components, including data, tools, and workflows. The goal is to enable CCA (Climate Change Adaptation) partners to independently apply this framework by the end of the project. The capacity-building effort in WP5 includes a "train the trainer" program that equips community members with the skills to teach and lead others in applying FAIR principles in their own contexts. The framework will be adaptable and scalable across diverse CCA sectors, empowering stakeholders to continuously apply FAIRification practices to new datasets and workflows.

For scaling the adoption of FAIR practices, we also aim to facilitate the reuse of identified use cases, along with their potential FAIRified datasets, tools, and workflows. The vision is to create a flexible ecosystem that allows various stakeholders to mix and match these components to support a wide range of use cases. By standardizing the FAIRification of data and tools, we create the conditions for easy reuse and adaptation to new scenarios. For example, a tool developed for Hamburg to assess pluvial flood risks could be easily adapted for other cities or regions facing similar challenges. This reuse model significantly reduces the cost of developing new solutions while enhancing the impact and scalability of the FAIR2Adapt project.

A comparison between FAIR2Adapt and other initiatives, such as VALORADO and FARCLIMATE reveals shared interests in applying FAIR principles to climate change adaptation data. Engaging with these projects can provide valuable insights and foster collaboration. Particularly, VALORADO partners involved in CLIMATE-ADAPT4EOSC, a project funded under the same EOSC topic, offer potential entry points for dialogue. Understanding these projects' approaches enriches our perspective on scaling FAIRification practices across different contexts.

The successful implementation and scaling of the FAIR principles requires coordinated efforts at various levels. The use of new technologies, targeted training measures and the promotion of international cooperation are essential building blocks for sustainably anchoring FAIR data management in climate adaptation.

5 CONCLUSION

In summary, the FAIR2Adapt project is not only focused on the technical FAIRification of data, tools, and workflows but also on ensuring that these components can be effectively scaled and reused across different case studies. Through WP3 and WP5, we aim to establish a robust FAIRification framework, preceded by a requirements elicitation process, that will enable CCA partners to integrate FAIR principles into their own work according to their needs, promoting long-term sustainability and impact. Furthermore, by fostering the reuse of FAIRified resources, we create an ecosystem that accelerates the development of new solutions, expands the reach of the project, and makes it easier to replicate successful approaches in diverse contexts.

The scaling process is thus twofold: building the capacity of stakeholders to apply FAIR practices independently and ensuring that the resources developed are flexible and adaptable enough to meet the needs of future case studies. This approach will enable the FAIR2Adapt project to have a lasting impact, offering scalable solutions that can be reused across various domains to support climate change adaptation efforts globally.

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