



OneAquaHealth 

PROTECTING URBAN AQUATIC ECOSYSTEMS TO PROMOTE ONE HEALTH

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D3.5 FAIRness and FAIRification process and tools vs2

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Executive Summary

The OneAquaHealth project aims at improving the sustainability and integrity of urban freshwater ecosystems by investigating the interconnection between ecosystem health and human wellbeing. The project identifies early warning indicators and enhances environmental monitoring with AI-assisted tools to support decision-makers in restoring aquatic ecosystems and promoting One Health. By integrating FAIR principles (Findability, Accessibility, Interoperability, and Reusability) with the One Digital Health (ODH) framework, the project fosters transparent, equitable access to digital resources, enabling AI-driven environmental surveillance, cross-sectoral data integration, and evidence-based policymaking.

This deliverable focuses on the deployment of a One Digital Health Intervention, introduced as the implementation of a set of digital functionalities, or digital-ities, designed and deployed to (1) support specific initiatives that address human, animal, and environmental system needs and challenges; (2) assess and study these systems' expected and unexpected outcomes and effects and collect related data; and (3) select timely metrics for the outcomes of multicriteria decision analyses. A One Digital Health intervention is implemented to (1) *address One Health-related challenges*; (2) *achieve One Health-related important and strategic outcomes* for clinical follow-up and practice, such as for technology improvements needed; and (3) *achieve FAIR* (Findability, Accessibility, Interoperability, Reusability) uses of *digital technologies*. To this end, the design of a multidisciplinary approach was needed, which sits at the intersection of disciplines like One Health systems evaluation, FAIR maturity assessment frameworks, and MCDA/composite indicator design.

The OneAquaHealth project is herein conceptualized and operationalized as a large-scale, ecosystem-driven One Health intervention with a digital backbone aligned to the One Digital Health framework. The present work proposes a conceptual and operational (r)evolution in intervention modeling: OneAquaHealth is not only analyzed as a One Health Intervention, but is also methodologically transformed into a digital use-case intervention workflow, where (i) a formal rationale for identifying and selecting the Digital Objects produced within the project is grounded in the core economy of research advancement, and (ii) a quantified harmonization of OH Intervention multidimensionality (ODH_{score}) and FAIR maturity (via the FAIR Data Maturity Model designed for the project) are combined within a structured FAIR/ODH approach.

The main findings of present work mainly are twofold: (i) the soundness and internal consistency of the approach underlying the One Digital Health Intervention were proven, showing how it lies at the intersection of One Health systems evaluation, FAIR maturity assessment frameworks, and MCDA/composite indicator design, and (ii) the ODHness related to the project – as the principal output of the One Digital Health Intervention, here in its first iteration and covering the period up to M30 – was eventually calculated, shedding light on the balance achieved so far between the digital functionalities deployed in the project, and related to the three health-related Domains.

The results of this work are the foundation of the next steps, as either the Digital Objects produced within the project will likely undergo a FAIRification process, or new Digital Objects will be produced, whose compliance for the FAIR principles will be assessed. The overall objective is to guide the next steps of the project in view of an improvement of the results of the next iterations of the One Digital Health Intervention.

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Acronyms & Abbreviations

Term	Description
AI	Artificial Intelligence
API	Application Program Interface
BPMN	Business Process Management Notation
CS App	Citizen Science App
DALYs	Disability-Adjusted Life Years
DMT	Data Manipulation Tool
DO	Digital Object
DSS	Decision–Support Systems
ESS	Environmental Surveillance System
EWS	Early Warning System
FAIR	Principles of (meta)data Findability, Accessibility, Interoperability, Reusability
FAO	Food and Agriculture Organization
FDMM	FAIR Data Maturity Model
FHIR	Fast Healthcare Interoperability Resources
HL7	Health Level 7
IoAHT	Internet of Animal Health Things
IOF	Integrated ODH–FAIR Score
IOF _T	Target IOF
IoT	Internet of Things
LLM	Large Language Model
MCDA	Multi–Criteria Decision Analysis
NEOH	Network for Evaluation of One Health
OAH	OneAquaHealth project
OECD	Organization for Economic Co-operation and Development
ODBC	Open Database Connectivity
ODH	One Digital Health
ODHI	One Digital Health Intervention
OH	One Health
OHHLEP	One Health High-Level Expert Panel
OHI	One Health Intervention
OH–OT	One Health Operational Tool
OIH	Open Information Hub

D3.4 FAIRness and FAIRification process and tools vs2

PID	Persistent Identification
TZG	Tripartite Zoonoses Guide
UML	Unified Modeling Language
UNEP	United Nations Environment Programme
WHO	World Health Organization
WOAH	World Organization for Animal Health
WP	Work Package

1 Introduction

1.1 Overview

The scope of this deliverable is to develop and improve the results from D3.4, by introducing and thoroughly describing all the necessary steps for planning and performing a One Digital Health Intervention, as one of the main outputs of the OneAquaHealth project. In this regard, the deliverable is meant to show how this kind of activity lies at the intersection of One Health systems evaluation, FAIR maturity assessment frameworks, and MCDA/composite indicator design. A first iteration of a One Digital Health Intervention was conducted, based on the principles already introduced in D3.4, and a first evaluation of the ODHness of the project in its first 30 months was obtained. The results of this work are the foundation of the next steps, where the FAIRification processes of the Digital Objects produced within the project, and further One Digital Health Intervention iterations, are called to converge.

1.2 Relation to other tasks and deliverables

This deliverable is related to the following other OneAquaHealth tasks and deliverables:

Receives inputs from:

Table 1: D3.5 Input from other tasks and deliverables

Deliverable	Due Date	Input for D3.5
D2.1	M18	Synthesized information on the most relevant indicators of ecosystem health and biological health of rivers and streams, based on expert judgment and bibliographic review, as well as specific indicators and respective indices and brief overview of the methodologies/measurement approaches. Overview of existing datasets and sources of information that can be used in the next steps of the project.
D3.1	M18	Overview of human health and wellbeing indicators related to urban aquatic ecosystems.
D3.2	M24	Operationalization of human health and wellbeing indicators related to urban aquatic ecosystems. Application of the One Digital Health (ODH) framework to explore which available human health and wellbeing databases include data on these indicators.
D3.4	M28	Assessment of the compliance of the main Digital Objects (e.g., datasets) produced so far in the project with the FAIR principles, via the design of a project-aligned, ODH-driven FAIR Data Maturity Model (FDMM).

Provides outputs to:**Table 2: D3.5 Output for other tasks and deliverables**

Deliverable	Due Date	Output from D3.5
D3.6	M45	Performing the FAIRification process towards the realization of the One Digital Health Intervention, as a direct follow-up of the FAIRness assessment performed and described in the present document
D3.7, D3.8	M36, M42	Deployment of the FHIR implementation Guide in the mentioned FAIRification process
D4.3, D4.4	M36, M45	Assessment of the compliance of the Digital Objects related to the WP4 activities, with the FAIR principles, and inclusion in the FAIRification process
D5.4, D5.5	M36, M43	Assessment of the compliance of the Digital Objects related to the WP5 activities, with the FAIR principles, and inclusion in the FAIRification process
D6.4, D6.5, D6.8	M36, M42	Connection with the exploitation potential and sustainability of the OneAquaHealth result, as part of the evolution of the project's strategic vision to be translated into actionable plans aimed at ensuring the long-term adoption and impact of the project's innovations in the field of urban aquatic ecosystems and human health.

1.3 Structure of the deliverable

The document is organized as follows: in Section 2, after a formal introduction of the novel concept of One Digital Health Intervention a description of the main differences from the already existing concept of One Health Intervention is provided.

In Section 3 the methodological steps of the approach underlying the One Digital Health Intervention are introduced and described, showing the connection with the FAIR-related results from D3.4.

In Section 4 a concrete application of the mentioned approach in the OneAquaHealth project is then implemented in its first iteration, up to the evaluation of the ODHness so far – to be intended as how much/how well the harmonization between the different digital functionalities expressed in the project works to address the needs and challenges for which the Intervention was planned and delivered.

In Section 5 the importance of the One Digital Health Intervention is discussed, proving its capability to move beyond the current boundaries of the One Health approach, along its implications in the field of Public Health (Informatics).

Some conclusions and a glimpse to future steps are eventually provided in Section 6.

2 Evaluating One Health Interventions: a matter of feasibility?

2.1 Seeking for a One Health (agreed) definition

The One Health (OH) paradigm has expanded over the last two decades from a conceptual recognition of the interconnections among human, animal, and environmental health to a systemic approach emphasizing coordinated actions across sectors. In this regard, a series of conceptual definitions (partly reported in Table 3) were released by many organizations on different levels through the years, each one focusing on a *pro domo sua* lens. This emerges as a clear sign of how identifying, framing and solving complex health challenges – which demand for a delicate balance among skills regarding teamworking, interpersonal system thinking, critical thinking, as well as several domain-specific knowledges – still appears a rather complex issue.

Table 3: Examples of One Health approach definitions in the last decades [Elaboration from (Nzietchueng et al. 2023)]

Definition	Author	Year
One Health is the collaborative effort of multiple disciplines-working locally, nationally, and globally – to attain optimal health for people, animals, and our environment.	American Veterinary Medical Association. One Health Initiative Task Force Final Report.	2008
One Health is a holistic vision to address complex challenges that threaten human and animal health, food security, poverty and the environments where diseases flourish.	Food and Agriculture Organization of United Nation, Strategic Action plan	2011
One Health is the collaborative effort of multiple health science professions (veterinarians, physicians, public health officials, epidemiologists, ecologists, toxicologists and others), along with their related disciplines and institutions – working locally, nationally, and globally – to attain optimal health for people, domestic farm and food animals, wildlife, plants and our environment.	United State Department of Agriculture	2016
One Health is an integrated, unifying approach to balance and optimize the health of people, animals and the environment.	World Health Organization	2017
One Health is an approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes.	World Health Organization Europe	2017
One Health is a collaborative, multisectoral, and trans-disciplinary approach – working at local, regional, national, and global levels – with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment.	US Centers for Disease Control and Prevention	2017

In 2021 a further definition was developed by the One Health High–Level Expert Panel, an advisory panel to the One Health (now) Quadripartite made up of the FAO, WHO, WOA, and UNEP (One Health High-Level Expert Panel (OHHLEP) et al. 2022).

Anyway, as stated by Baum et al., “[...] *Despite existence of different definitions for the One Health approach, it is still unclear on what a One Health activity or intervention entails*” (Baum et al. 2017).

2.2 The concept of One Health Intervention

As seen, while earlier OH literature focused on definition and scope, more recent works highlight the need for operationalisation, where scientific insights translate into practical and codified sequences of actions. This has led to the emergence of the concept of One Health Intervention (OHI), as a coordinated set of actions that actively engage two or more OH domains (human, animal, environment) to prevent, detect, respond to, or mitigate health challenges, producing system-wide benefits that exceed single-sector approaches (Bardosh et al. 2014; *One Health Joint Plan of Action, 2022–2026* 2022). The rise of OHIs reflects a shift from theory to applied systems science, responding to global challenges such as zoonoses, antimicrobial resistance, climate-ecology dynamics, food system vulnerabilities, and urban environmental degradation. Among the most-known concrete attempts of interventions performed as a set of discrete, analyzable, and comparable units there are, e.g., the “Network for Evaluation of One Health” (NEOH) proposed by (Rüegg et al. 2018) – recently enriched to support as well the integration of gender equity and social inclusion (Garnier et al. 2025) –, or the “One Health Operational Tool (OH-OT)” – which refers to the collection of operational tools developed by the Tripartite organizations (WHO, FAO, WOA, later the Quadripartite with UNEP) under the umbrella of the Tripartite Zoonoses Guide (TZG) (“Tripartite Zoonoses Guide (TZG),” n.d.).

2.2.1 Characteristics of One Health Interventions

The main characteristics of an OHI shall include, but not be limited to the following areas (Nzietchueng et al. 2023):

- *Multisectorality*: actions meant to involve at least two OH domains, often requiring interministerial or interinstitutional collaboration;
- *System Orientation*: interventions operate on interdependencies across compartments, with specific focus on the recognition of dynamic, non-linear ecological–epidemiological interactions in not isolated events – e.g., upstream ecological drivers, animal reservoirs, human exposure patterns;
- *Evidence-Based Decision Making*: data integration guides the design, prioritization, and evaluation of interventions for either preventive, preparedness, response, and recovery phases;
- *Cross-disciplinary Methods*: incorporating epidemiology, ecology, veterinary sciences, public health, environmental monitoring, behavioural sciences, and increasingly digital health tools.

2.2.2 Classification of One Health Interventions

According to the literature, several recurrent categories of operational domains and actions can be acknowledged (Grace 2014; Hernando-Amado et al. 2019; Munyua et al. 2019; PREDICT Consortium et al. 2020; Tamburis et al. 2023; Brown et al. 2024):

- *Surveillance and Early Warning*, including integrated human–animal–vector surveillance, environmental/ecological sensors, and digital epidemiology and participatory surveillance;
- *Outbreak Response and Preparedness*, including joint investigation protocols, shared diagnostic platforms, and coordinated response teams;
- *Environmental and Ecosystem Management*, mainly referring to vector habitat control, water resource protection, and land use governance;
- *Antimicrobial Resistance Mitigation*, via integrated stewardship programs, and cross-sector antimicrobial usage monitoring;

- *Food System and Farm-level Interventions*, including biosecurity, traceability systems, and animal welfare interventions.

2.2.3 Evaluation and measurable impact

Metrics have been introduced by many scholars to provide qualitative/quantitative measures about e.g., spill-over prevention, ecological resilience, health system preparedness, or societal acceptance, to (i) improve health outcomes through multisectoral collaboration, and (ii) guide in measuring the process outputs and eventually the impact. Nonetheless, few results have been achieved in terms of effective measuring outcomes, cost-savings, or reduced duplication of effort within One Health programs, thus hindering more widespread political interest in the approaches developed (Rushton et al. 2012).

Evaluative metrics (e.g., cost-benefit analysis, cost-effectiveness analysis, or Disability-Adjusted Life Years (DALYs) averted) of OHIs (e.g., brucellosis, pandemic prevention) are often only derived from theoretical models rather than actual interventions. More generally, a lack of standardized One Health metrics emerges, which are capable of providing evidence on the potential benefits of these programs (“World Bank Document,” n.d.; Tidman et al. 2023).

2.3 Heading towards digital

Despite the evolution of OHIs demonstrating a transition from conceptual frameworks to tangible, multisectoral actions aimed at tackling global challenges, evolving scenarios bring new questions and new solutions to be found, which demand for:

- stronger methodological foundations;
- structured evaluation frameworks;
- integration of digital infrastructures;
- interoperable, data-driven workflows;
- ecosystem-level feedback mechanisms.

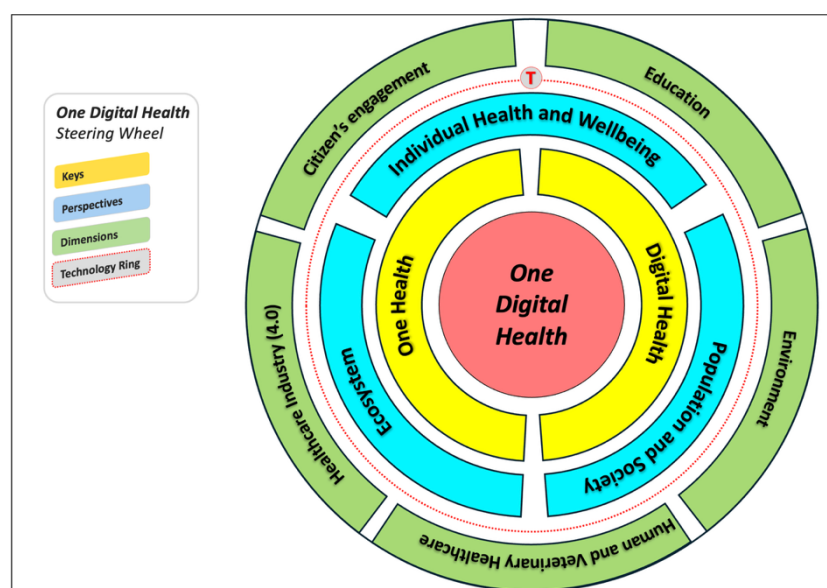


Figure 1: One Digital Health (ODH) framework (Source: (Benis et al. 2021))

Emerging fields connecting OH with digital health ecosystems are then expected to encompass topics like:

- IoT-enabled environmental monitoring;
- Digital twins of ecosystems;
- Machine-learning supported risk prediction.

The fusion of OH with Digital Health within the emerging framework of One Digital Health (ODH: see Figure 1), opens new pathways for designing, evaluating, and scaling an updated concept of OHIs to address issues belonging to complex urban socio-ecological systems – making it highly relevant for research projects such as OneAquaHealth (Ferrante et al. 2024).

2.4 From One Health Intervention to One Digital Health Intervention

As already introduced in (Benis et al. 2021; 2023), an ODH intervention (ODHI) can be seen as the implementation of a set of digital functionalities, or digital-ities, designed and deployed to (1) support specific initiatives that address human, animal, and environmental system needs and challenges; (2) assess and study these systems' expected and unexpected outcomes and effects and collect related data; and (3) select timely metrics for the outcomes of multicriteria decision analyses.

An ODHI is implemented to (1) *address One Health–related challenges*; (2) *achieve One Health–related important and strategic outcomes* for clinical follow-up and practice, such as for technology improvements needed; and (3) *achieve FAIR* (Findability, Accessibility, Interoperability, Reusability (Wilkinson et al. 2016)) uses of *digital technologies*.

The evolution step lies in the new kind of aspects an ODHI revolves and sets up around, such as: (i) the delivery of health care in a syndemic scenario; (ii) the digital transformation of human and animal health data (i.e., including the concept of animal welfare); and (iii) digital nature conservation (i.e., biodiversity and wildlife conservation, food security, antimicrobial resistance, climate change, etc.) by means of digital technology–based interventions. In other words, ODHI models aim to bridge OH system complexity, digital transformation, evaluation of digital objects, multi-criteria decision models,

and cyber-ecological feedback loops, stressing on aspects like data quality and stewardship, FAIR principles, as well as governance and ethical layers. This marks a paradigm shift toward measurable, digitally traceable interventions – see e.g., (Tamburis and Benis 2022; Tamburis et al. 2023; 2024; Benis et al. 2025)).

An attempt to compare OHI and ODHI is shown in Table 4:

Table 4: One Health Interventions (OHI) vs One Digital Health Interventions (ODHI)

Dimension	One Health Interventions (OHI)	One Digital Health Interventions (ODHI)
Core Objective	Address interconnected human–animal–environment health issues through integrated, multisector action.	Enhance One Health Interventions using digital technologies, digital objects, and cyber-physical systems.
Conceptual Foundation	Classical One Health framework; ecology–epidemiology interface; systems thinking.	One Digital Health framework; digitalities; FAIR and ODHness metrics; cyber-ecological integration.
Primary Components	Surveillance, risk assessment, field operations, policy coordination.	Sensors, IoT/IoAHT/IoT-environment, AI models, dashboards, data pipelines, FAIR digital objects, digital twins.
Data Perspective	Emphasis on cross-sector data sharing and integrated surveillance.	Emphasis on digital lifecycle of data, FAIRness, interoperability, metadata and digital object maturity.
Level of Digitality	Digital systems may be used, but are not central.	Digitality is intrinsic: interventions are defined by their technological infrastructure.
Scope of Action	Prevent/mitigate risks in ecosystems, animals, humans; environmental protection.	Digital monitoring, modelling, prediction, decision-support, and automation across health domains.
Key Outputs	Policies, surveillance programs, outbreak response, and environmental remediation plans.	Digital Objects (DOs), dashboards, predictive models, decision-support systems (DSS), sensor networks, algorithms.
Evaluation Frameworks	Mainly public health metrics, epidemiological outcomes, ecological indicators, and cost-effectiveness.	ODHness, FAIRness, digital ecosystem maturity, usability, and performance of digital components.
Stakeholder Engagement	Multidisciplinary institutional actors + communities.	Same actors + digital actors (data engineers, software developers, AI designers).
Examples	AMR national action plans, integrated zoonotic surveillance, and vector control.	Integrated environmental surveillance platforms, AI-based water ecosystem monitoring, and citizen-science apps.

A crucial difference lies in the concept of so-called “ODHness”, as an overall measure of how much/how well the harmonization between the different digital-ities works to address the needs and challenges for which the ODHI was planned and delivered.

The methodological steps to conduct an effective ODHI are shown in Section 4.

3 One Digital Health Intervention: methodology steps

A correct set-up and deployment of an ODHI is articulated in the following main passages, which involve many disciplines to be integrated within a larger perspective. The single passages will be further analyzed in the following sections:

1. Use Case Definition → What steps/actions make up the intervention?
2. FAIR Data Maturity Model → How FAIR are the Digital Objects involved?
3. Digital Objects Relevance assessment → Which Digital Objects matter the most?
4. Multi-Criteria Decision Analysis → How do FAIRness and ODH performance interact?
5. One Digital Health Target → How can digital relations be visually and geometrically represented?
6. ODHness calculation → What is the final measure of the overall harmonization of the intervention?

3.1 Use Case Definition

The first step is to figure out the most timely way to shift from a real/realistic scenario (described in natural language) to a structured use case. In this regard, several approaches can be retrieved from the literature, among which are:

- *Content Analysis*: qualitative/quantitative method for coding texts, segmenting them into thematic or conceptual categories, which can then be organised into coherent sections of a case study (context, actors, problems, solutions, results) (Kuckartz and Rädiker 2023; Nicmanis 2024);
- *Grounded Theory Coding*: iterative qualitative approach based on open coding, axial coding and selective coding to derive structures and concepts from raw text, ultimately formulating a coherent narrative model useful for generating use cases (Vollstedt and Rezat 2019; Moura et al. 2022);
- *Use Case Modeling frameworks* (e.g., UML, BPMN, Goal-Oriented Requirements Engineering): software engineering methodologies that involve the transformation of textual narratives into formalised use cases through actors, preconditions, event flows, and alternative scenarios (Sumesh and Krishna 2022; Van Der Aalst 2023; De Brock 2024);
- *Template Case Study protocols*: deployment of standardised protocols (background, context, research questions, units of analysis, evidence, results) that enable the restructuring of a narrative text into a coherent and replicable case study (Stake 2010; Yin 2018).

Summarizing:

- Content analysis or Grounded theory are preferred for extracting concepts and structuring them;
- Use Case modeling works better for formalizing an operational use case;
- Case study protocols with predefined sections can be adopted when the objective is to make up and showcase a scientific use case.

3.1.1 From activities to ODH_{score}

The original scenario is therefore deconstructed into a series of single independent events and steps, as the input of the ODH Intervention table (Benis et al. 2023), whose format is introduced in Table 5. For each step, several fields must be identified (see Sections 3.2 and 3.3) to provide the necessary information for assessing the overall effectiveness of the Intervention itself (described in Sections 3.4 and 3.5).

More specifically, for each step the Table reports: an identification name; a number indicating its position within the series of steps the use case is articulated into; the temporal length (in days, weeks, months, ...); the main goal and the main related activities as scheduled within the organization of the Intervention.

Further, for each step, its compliance is assessed with the five Dimensions of the mentioned ODH framework, also defined as *ODH performance* – **C**: Citizen Engagement; **E**: Education; **M**: Medical (Human and Veterinary health care); **I**: Industry 4.0; **S**: Surrounding Environment (see Figure 1). This is a qualitative evaluation scoring in the [0;5] interval (integer values), where the higher value means a better level of compliance with that specific Dimension.

The overall compliance to the five (C, E, M, I, S) dimensions is calculated as a normalized value (1):

$$ODH_{score} = \frac{\sum D_i}{25} \quad (1)$$

where D_i means the compliance level for each single ODH Dimension.

3.1.2 Digital Domains

As previously stated, an ODHI can be seen as the implementation of a set of digital functionalities, or digital-ities. This concept refers to the ability to use and perform tasks with digital technologies and tools, embedded into human experiences and humans' daily lives (Scientific Center of Innovative Research and Mihus 2024), spanning from either social and cultural anthropology issues (i.e., digital *human-ities*) to human-animal relations and animal welfare (i.e., digital *animal-ities*), up to the complex web of human, animal, and environmental interconnections, towards an improved environmental governance (i.e., digital *environmental-ities*) (Rüegg et al. 2018; Aydin et al. 2019; Daris 2022). With reference to what is reported in Table 5:

- each of the three health-related Domains accounts here for digital technologies, thus being renamed as *Digital-ity Domain*;
- the *Specialities* are the counterpart of the original (health-related) disciplines through which the Intervention's steps are performed. They are meant to operationalize the corresponding Digital-ity Domains via the implementation of some *Technologies*;
- each step may feature between 0 and n *Digital Objects* (DOs), to be intended as formally defined, discrete digital entities that can be stored, accessed, and exchanged via computational systems, e.g., datasets, documents, code, images, workflows, protocols, annotations, simulation outputs, dashboards, and more (Hui 2016; Wittenburg 2019).

For each of the DOs eventually associated with each of the Intervention's steps, the main Digitality Domain is identified. The Speciality/ies involved is/are reported, along with the Technology/ies engineered (University of Bayreuth et al. 2023). If the DO fall into a second health-related Domain, the same actions as for the main Domain will then be made. The same will eventually apply should the DO eventually encompass the third health-related Domain as well.

3.1.3 Data Linkage

This last field relates to the possible resulting connections between the above-mentioned Specialities. In case of a *relation* between 2 Specialities, this is formally reported as in (2):

$$r_{HA} = H(S_i) \oplus A(S_j) \quad (2)$$

where:

- r_{HA} means the relation between two Specialities;
- $H(S_i)$ is the i -th Speciality related to a digital functionality in the human domain;
- $A(S_j)$ is the j -th Speciality related to a digital functionality in the animal domain;
- The symbol $\oplus$ denotes a special defined operation similar to addition. It implies a possible confrontation between different specific deployments (in different domains) of the same kind of digital functionality.

If three digitalities – one from each Domain – connect with each other, we refer to it as a *triatlity*, as represented in (3):

$$r_{HAS} = (S_i) \oplus A(S_j) \oplus S(S_k) \quad (3)$$

where:

- r_{HAS} means the connection between three Specialities;
- $S(S_k)$ is the k -th Speciality related to a digital functionality in the environmental domain.

Finally, in case one Speciality from one domain has no connection with another Speciality from another domain, the single Speciality (called “dot”) is interpreted as a fictive relation anyway. The symbolism of (2) becomes therefore as in (4):

$$r_{H\emptyset} = H(S_i) \oplus \emptyset \quad (4)$$

where:

- $\emptyset$ is the null element – no other Speciality connects with $H(S_i)$;
- $r_{H\emptyset}$ means the absence of a relation (the second member is null).



Table 5: Format for the One Digital Health Intervention table

# Step	Timeframe	Step Name	Main Objective	Main Activities	ODH Dimension(s) + Scores					Digital Objects (DOs)	FAIRness level	Main Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Data Linkage
					C	E	M	I	S			Specialities	Technology (ies)	Specialities	Technology (ies)	Specialities	Technology (ies)	
1	.	.	-	-						-								
2	.	.	-	-						-								

H: Human Domain; **A:** Animal Domain; **S:** Surrounding Environment (Domain and ODH Dimension); **C:** Citizen Engagement; **E:** Education; **M:** Medical (Human and Veterinary health care); **I:** Industry 4.0; **FAIRness:** principles of (meta)data Findability, Accessibility, Interoperability, and Reusability.

3.2 FAIR Data Maturity Model (FDMM)

As described in D3.4 and in (Tramontano et al. 2025), a model was proposed to enable a systematic assessment of a DO across all four FAIR categories (Findability, Accessibility, Interoperability, Reusability) using a well-defined scoring scheme and indicator hierarchy.

For each DO identified in the project, the FDMM provides a FAIR Score, or FAIR Index ($F_i \in [1;3]$), which expresses the compliance of the specific digital resource to the mentioned FAIR categories. Also in this case, a higher value means a better compliance level.

3.3 Digital Objects Relevance Assessment

As also introduced in D3.4, it is useful to figure out the *relevance* as well of each DO produced in an Use Case, to be intended as its capacity to provide an effective contribution to the overall advancement of the research activity, as an actionable knowledge unit (De Smedt et al. 2020).

Starting from the concepts introduced in the FDMM, two orthogonal weights were calculated (Peng et al. 2024):

- the weights of the FAIR principles, considering the number and the priority (essential = 3/important = 2/useful = 1) of the criteria featured by each principle within the FDMM;
- the weights of the criteria, considering how many essential/important/useful ones are present in the FDMM.

In Table 6 the distribution of the FAIR principles weighing was obtained as a weighted normalization, as it was necessary to compare indicators with different weights in a composite and consistent index to improve decision-making (Vafaei et al. 2018; Aroge et al. 2023).

The sum of the weights is equal to 1:

Table 6: Weights of FAIR Principles

FAIR Principle	Type of criterion	# of criteria	Weight
Findability	Essential	4	$w_F = \frac{4 * 3}{12 + 9 + 5 + 10} = 0.33$
Accessibility	Essential	2	$w_A = \frac{(2 * 3) + (1 * 2) + (1 * 1)}{36} = 0.25$
	Important	1	
	Useful	1	
Interoperability	Important	2	$w_I = \frac{(2 * 2) + (1 * 1)}{36} = 0.14$
	Useful	1	
Reusability	Essential	2	$w_R = \frac{(2 * 3) + (2 * 2)}{36} = 0.28$
	Important	2	

Similarly, the distribution of the weighing for the three criteria is reported in Table 7. In this case, each weight was calculated as the percentage of the number of each type of criteria, relative to the total number of criteria reported in the FDMM. Also in this case, the sum of the weights is equal to 1:

Table 7: Weights of essential/important/useful criteria

Type and number of criteria per FAIR principle		TOT	Weight
TOT Essential Criteria / F	4	8	$w_{ESS} = 8/15 = 0.53$
TOT Essential Criteria / A	2		
TOT Essential Criteria / I	0		
TOT Essential Criteria / R	2		
TOT Important Criteria / F	0	5	$w_{IMP} = 5/15 = 0.33$
TOT Important Criteria / A	1		
TOT Important Criteria / I	2		
TOT Important Criteria / R	2		
TOT Useful Criteria / F	0	2	$w_{USF} = 2/15 = 0.14$
TOT Useful Criteria / A	1		
TOT Useful Criteria / I	1		
TOT Useful Criteria / R	0		

An Operational Research–like approach was then figured out to combine the main features of the FDMM with the above-mentioned weights (Mahdavi et al. 2021; Göncü and Çetin 2022; Farahani et al. 2023). For each FAIR principle, a linear combination was computed between: (i) the number of criteria fulfilled for each of the three stage values (1: minimally; 2: partially; 3: totally); (ii) the stage values; (iii) the number of essential/important/useful criteria accounted for by each FAIR principle. Such a combination was then combined with the weights of the criteria, and eventually with the weight of that principle. The overall sum lies approximately in the $]0.7;2.2[$ interval, so that the relevance index of a single Digital Object (R_i) can ultimately be classified as follows:

- *Low* Relevance: $R_i \in]0.7;1.2[$
- *Intermediate* Relevance: $R_i \in [1.2;1.7[$
- *High* Relevance: $R_i \in [1.7;2.2[$

Since no particular constraints were figured out or retrieved in pursuing the abovementioned approach, an equidistributed subdivision of the R_i interval was set.

In (5) the approach is described extensively in the first instance for each of the FAIR principles, and then summarized:

$$\begin{aligned}
 \alpha_F &= \left\{ \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,ESS}} \cdot \#St_{i,ESS}}{\#ESS \text{ Criteria}_F} \right) \cdot w_{ESS} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,IMP}} \cdot \#St_{i,IMP}}{\#IMP \text{ Criteria}_F} \right) \cdot w_{IMP} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,USF}} \cdot \#St_{i,USF}}{\#USF \text{ Criteria}_F} \right) \cdot w_{USF} \right] \cdot w_F \right] \right\} \\
 \alpha_A &= \left\{ \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,ESS}} \cdot \#St_{i,ESS}}{\#ESS \text{ Criteria}_A} \right) \cdot w_{ESS} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,IMP}} \cdot \#St_{i,IMP}}{\#IMP \text{ Criteria}_A} \right) \cdot w_{IMP} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,USF}} \cdot \#St_{i,USF}}{\#USF \text{ Criteria}_A} \right) \cdot w_{USF} \right] \cdot w_A \right] \right\} \\
 \alpha_I &= \left\{ \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,ESS}} \cdot \#St_{i,ESS}}{\#ESS \text{ Criteria}_I} \right) \cdot w_{ESS} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,IMP}} \cdot \#St_{i,IMP}}{\#IMP \text{ Criteria}_I} \right) \cdot w_{IMP} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,USF}} \cdot \#St_{i,USF}}{\#USF \text{ Criteria}_I} \right) \cdot w_{USF} \right] \cdot w_I \right] \right\} \\
 \alpha_R &= \left\{ \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,ESS}} \cdot \#St_{i,ESS}}{\#ESS \text{ Criteria}_R} \right) \cdot w_{ESS} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,IMP}} \cdot \#St_{i,IMP}}{\#IMP \text{ Criteria}_R} \right) \cdot w_{IMP} + \left[\left(\frac{\sum_{i=1}^3 S_{P_{i,USF}} \cdot \#St_{i,USF}}{\#USF \text{ Criteria}_R} \right) \cdot w_{USF} \right] \cdot w_R \right] \right\}
 \end{aligned}$$

$$R_i = \alpha_F + \alpha_A + \alpha_I + \alpha_R \quad (5)$$

where:

- $S_{Pi,ESS}$ is, in the FDMM, the “i” stage value attributed to the Essential Criteria;
- $S_{Pi,IMP}$ is, in the FDMM, the “i” stage value attributed to the Important Criteria;
- $S_{Pi,USF}$ is, in the FDMM, the “i” stage value attributed to the Useful Criteria;
- $\#St_{i,ESS}$ is, in the FDMM, the number of times that an Essential criterion was attributed an “i” value;
- $\#St_{i,IMP}$ is, in the FDMM, the number of times that an Important criterion was attributed an “i” value;
- $\#St_{i,USF}$ is, in the FDMM, the number of times that an Useful criterion was attributed an “i” value;
- $\#ESS\ Criteria_k$ is the number of Essential criteria associated to the k–th FAIR principle in the FDMM;
- $\#IMP\ Criteria_k$ is the number of Important criteria associated to the k–th FAIR principle in the FDMM;
- $\#USF\ Criteria_k$ is the number of Useful criteria associated to the k–th FAIR principle in the FDMM;
- w_{ESS} is the weight associated to the Essential criteria along the FAIR principles (see Table 7);
- w_{IMP} is the weight associated to the Important criteria along the FAIR principles (see Table 7);
- w_{USF} is the weight associated to the Useful criteria along the FAIR principles (see Table 7);
- w_F is the weight associated to the Findability principle, based on the criteria featured in the FDMM (see Table 6);
- w_A is the weight associated to the Accessibility principle, based on the criteria featured in the FDMM (see Table 6);
- w_I is the weight associated to the Interoperability principle, based on the criteria featured in the FDMM (see Table 6);
- w_R is the weight associated to the Reusability principle, based on the criteria featured in the FDMM (see Table 6).

The sum of the four α_i addends leads to the overall Relevance value of the DO analyzed. This approach is supposed to be applied to each of the DOs involved in the ODHI.

3.4 Multi–Criteria Decision Analysis (MCDA): model design

As reported in (Benis et al. 2021; 2023), an ODHI strong relies on an MCDA approach. In this section the necessary passages are described to connect the ODH performance score (0–5 scale) as introduced in the previous Section, and the FAIRness of the DOs (1–3 scale) associated with the intervention’s steps. The goal is to establish a quantitative link between two different kinds of compliance scores or, in other words, to figure out how well the *digital dimension of an Intervention step* (its FAIR-compliant data layer) enhances its *One Digital Health potential* (its Dimension-compliant data layer’s systemic impact).

3.4.1 Normalization of Input Scales

Both scales are standardized to the same [0, 1] domain:

- $ODH_n = \frac{ODH_{score}}{5}$
- $FAIR_n = \frac{F_i}{3}$

This allows comparability and prevents scale bias.

3.4.2 Setting the amplification range

In MCDA, when one criterion modifies the influence of another (here: FAIRness amplifies ODH performance), we enter the domain of *multiplicative aggregation*.

Multiplicative models are extremely sensitive and can become mathematically unstable if one criterion is allowed to amplify another too much. According to MCDA literature (see e.g. (Keeney and Raiffa 1993; Ishizaka and Nemery 2013; Frazão et al. 2018)):

- The amplification factor must be small enough to avoid dominance;
- The amplification must be large enough to be meaningful yet bounded so that no single criterion overrides the others.

Be it the case of two criteria: α (*amplifier* criterion) and β (*base* criterion, to be amplified). This leads to conventional ranges for the amplification window, as reported in Table 8:

Table 8: Conventional ranges for amplification windows

Type of amplification range	Range of amplification window
<i>Conservative minimum</i> (preferred)	$\beta_{amp,\alpha} \in [0.8*\beta; 1.2*\beta]$
<i>Moderate maximum</i> (still acceptable)	$\beta_{amp,\alpha} \in [0.7*\beta; 1.3*\beta]$
<i>Absolute upper bound</i> (not recommended unless justified)	$\beta_{amp,\alpha} \in [0.5*\beta; 1.5*\beta]$

Beyond 1.5 $\times$, the model becomes non-robust and too subject to compensability bias (one criterion overwhelms the others). According to e.g. (Ishizaka and Nemery 2013), the main reasons behind such this setting relate to:

- *Avoiding over-compensation*: a secondary criterion should contribute no more than 20–30% influence unless the model explicitly wants a dominating criterion.
- *Ensuring monotonicity*: A multiplicative factor above 1.5 $\times$ may break monotonicity: small measurement errors in FAIRness could produce disproportionate effects.
- *Sensitivity analysis norms*: according to (OECD et al. 2008), amplification factors should not exceed $\pm 30\%$ influence unless validated through sensitivity testing.

This is why ranges like 0.7 $\times$ – 1.3 $\times$ are most commonly used. In public-health decision models, though, amplification beyond 1.25 $\times$ tends to distort rankings or prioritizations (Frazão et al. 2018; Trung 2022). In the present case, the relationship deals with FAIRness that amplifies ODH performance, but:

- FAIRness and ODH performance scales are conceptually orthogonal;
- FAIRness is not allowed to override the core ODH Intervention logic.
- Amplification should reflect data quality influences, not replace systemic multidimensional analysis.

This leads to the following scenario (Table 9):

Table 9: Feasible scenarios for implementing a multiplicative aggregation

Type of scenario	Amplification Range	Characteristics
Recommended Default	0.8× → 1.2×	• Safe • Defensible • Stable • Interpretable by stakeholders
Extended Range (if sensitivity analysis is conducted)	0.7× → 1.3×	• Acceptable for technical audiences • Adds more dynamic range • Still robust
Maximum Theoretical (but must be justified)	0.5× → 1.5×	• Only if explicitly validated • Risky in policy contexts • Could distort prioritisation

Therefore, although the best balance appears to be 0.7× → 1.3× since:

- Scientifically acceptable in MCDA literature;
- Robust enough to avoid dominance;
- Flexible enough to show the effect of FAIRness;
- Interpretable by evaluators, researchers, and policy makers;
- Transparent and easy to justify;
- Susceptible to a richer analytical behavior.

a safer yet effective choice is the 0.8× → 1.2× amplification interval.

3.4.3 Define Coupling Function

A coupling function $ODH_{amp} = \Phi(ODH_n, FAIR_n)$ is defined, which quantifies how FAIRness amplifies or limits an ODH performance. In this regard, a linear, multiplicative model can be worked out (Trung 2022; Mühlbacher and Kaczynski 2016; Wilkinson et al. 2016; Martínez-García et al. 2022; Bayón-Yusta et al. 2024; Băcescu Ene et al. 2025). The starting conditions are reported in (6):

$$\begin{cases} x = FAIR_n \\ y = f(x) = f(FAIR_n) = ODH_{amp} \in [0,8 * ODH_n; 1,2 * ODH_n] = \left[\frac{4}{5} * ODH_n; \frac{6}{5} * ODH_n \right] = \left[-\frac{ODH_n}{5}; \frac{ODH_n}{5} \right] \end{cases} \quad (6)$$

The Domain of the independent variable $D(x) \in [0;1]$. In addition, the model must address the following conditions, as expressed in (7):

$$f(x) = \begin{cases} -\frac{ODH_n}{5}, & x = 0 \\ \frac{ODH_n}{5}, & x = 1 \end{cases} \quad (7)$$

The linear model is setup as follows (Figure 2):

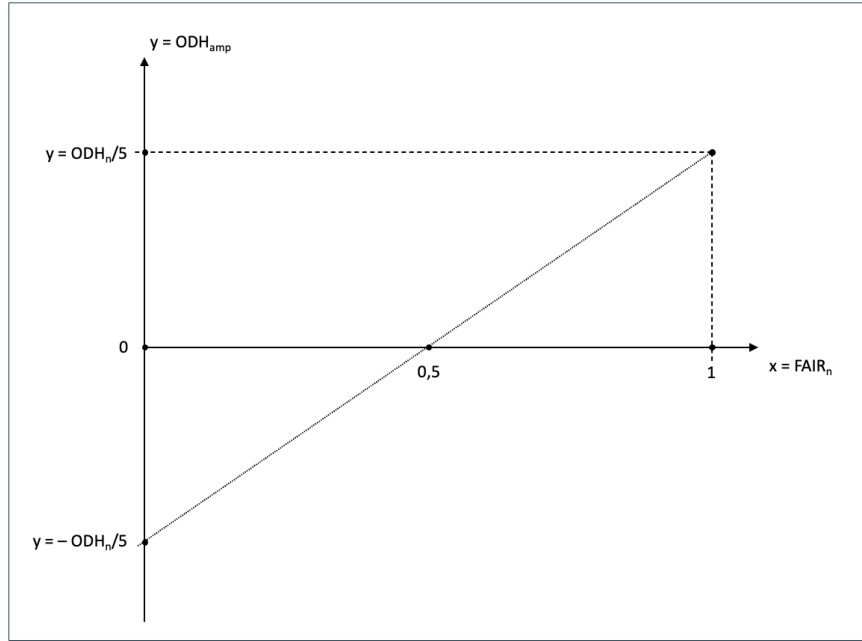


Figure 2: Linear model for amplification range

In (8) the coefficients of the model are calculated:

$$\begin{cases} y = mx \pm b \\ m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{ODH_n/5 - (-ODH_n/5)}{1 - 0} = \frac{2}{5} * ODH_n \\ b = -ODH_n/5 \end{cases} \quad (8)$$

Skipping the intermediate passages, the coupling function is expressed as in (9):

$$ODH_{amp} = \phi(ODH_n, FAIR_n) = \frac{ODH_n}{5} \cdot (4 + 2 \cdot FAIR_n) \quad (9)$$

3.4.4 Compute Integrated ODH–FAIR Score (IOF)

ODH_{amp} , as resulting from (8), has then to be rescaled back to a [0–5] range for interpretability (10):

$$IOF = 5 \times ODH_{amp} \quad (10)$$

Thus, $IOF \in [0,5]$ (integer values) expresses the *effectiveness of FAIR–ODH performance synergy* for the considered activity.

Since the ODH target graphic (see next Section) expects “smaller is better” (1 = center = best), it is necessary to convert IOF (0–5) into Target IOF (IOF_T), to maintain visual consistency (11):

$$IOF_T = 6 - IOF \quad (11)$$

where:

$$\begin{cases} IOF = 5 \Rightarrow IOF_T = 1 \text{ (best)} \\ IOF = 0 \Rightarrow IOF_T = 6 \end{cases}$$

IOF_T is clamped to $[1,5]$.

Table 10 provides an interpretation of the possible values resulting from performing the methodology (OECD et al. 2008; Walesiak 2018; Benis et al. 2021; Krishnan 2022).

Table 10: Interpretation Matrix

IOF_T Range	Interpretation	Description
0 – 1.5	Weak synergy	The Digital Object poorly supports the ODH intervention (low FAIRness or low ODH impact).
1.6 – 3.0	Moderate synergy	The compliance with FAIR principles partially enables ODH outcomes; improvements in accessibility/interoperability are needed.
3.1 – 4.0	Strong synergy	FAIRness of (meta)data of the Digital Object reinforces ODH goals effectively.
4.1 – 5.0	Excellent synergy	An elevated FAIRness level aligns with a high-impact ODH performance.

The implementation of such an overall design (i) ensures semantic alignment between the two frameworks (FDMM vs ODH), (ii) allows quantitative comparability for subsequent modeling or visualization, and (iii) is a standard, literature-supported procedure in composite index design, MCDA, and digital health systems integration. It therefore effectively aligns with the principles the ODH framework relies upon, and more specifically with the very premises of the concept of ODH Intervention.

3.5 One Digital Health Target

The ODH target (Figure 3) can be considered as a twin construct to the ODH framework, since it remains identified from the same Technology Ring standing within the ODH Steering Wheel (see Figure 1). More specifically, the ring serves as a catalyst among all the digital functionalities that the ODH framework relies on.

In the target, the area under the ring is divided into three circular sections, one per each of the Digitality Domains as introduced in the ODH Intervention table. The radii of the circumference enclosing the three sectors are the boundaries between the mentioned Domains. Within the target, the IOF_T s (dots)/relations/trialities are placed, depending on the number of health-related domains into which the DO(s) connected to each ODH Intervention's step fall/s – one, two, or three, respectively. More specifically:

- For single-domain dots: IOF_T is to be intended as the distance metric from the center;
- For two-domain segments (relations): an IOF_T is computed for each domain endpoint separately, as the necessary step before computing the strength of the relation.
- For three-domain segments (trialities): the same as for relations.

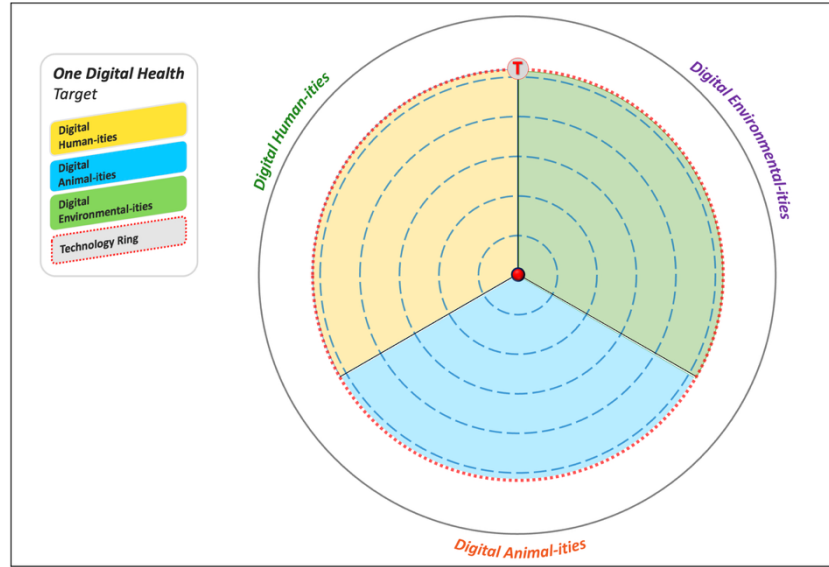


Figure 3: One Digital Health Target

Each of the three mentioned sectors/Domains can be in turn split into as many circular sub-sectors as the number of Specialities accounted for in the DOs developed for the ODHI. The width of each sub-sector is directly proportional to the number of Technologies deployed by the single Speciality. Then, the bisector of the angle at the center is identified for each sub-sector and represented by a dashed line.

Dots are located along the bisector, which pinpoint the IOF_T scores as emerged from the linear model described in the previous Section. As already said, the higher the value of IOF_T , the farther the dot is from the center of the target.

3.6 ODHness calculation

Once the single IOF_T scores are defined, if a DO falls into more than one Digital-ity Domains, the weight of a relation/triality results from the harmonic average (M_g) as expressed in (12):

$$M_g = \frac{N}{\sum_{i=1}^N \frac{1}{IOF_T}} \quad (12)$$

where:

- N = number of Specialities involved – 2 for a relation, 3 for a triality
- IOF_T is the Target IOF.

As already said, in case of a DO only falling in one Domain, the single Speciality (called “dot”) is interpreted as a fictive relation.

The values so obtained can be represented as vectors, oriented along the boundary lines between one Domain and another, as depicted in Figure 4. The module of each B_{XY} vector (where X and Y are two Digital-ity Domains) is the sum of the weights of all the relations insisting between the two Domains. If a triality is identified in the target, the module of each B_{XY} vector is incremented by the value of the triality’s weight – if no DOs exist that fall into some (X,Y) Domains couple, the module of that B_{XY} vector will only be equal to the weight of the triality. Eventually, since each dot is considered as a fictive

relation, its value will be split in two, since potentially a single dot may be involved in two different relations.

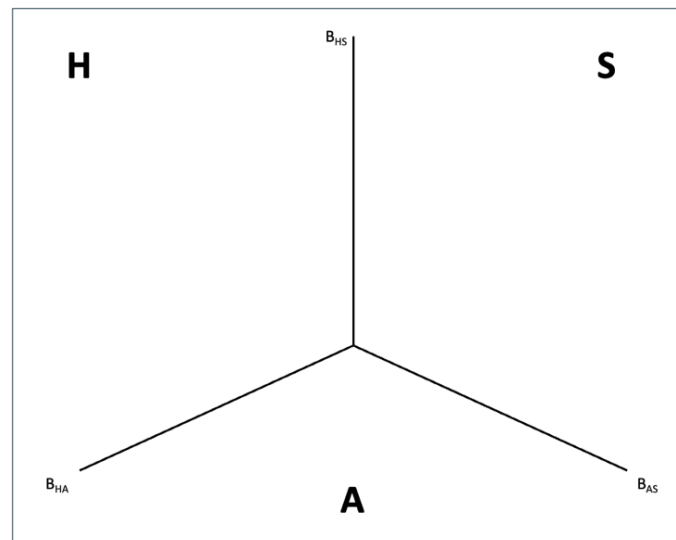


Figure 4: Vectors combining relations/trialities within the Technology Ring

The next step is performed as a typical sum of coplanar vectors: each one of the B_{XY} vectors can be associated to an imaginary y-axis, so that the corresponding x-axis remains identified, and the other two vectors result as rotated relative to the x-axis by an angle of $\pi/6$ degrees – from a trigonometrical point of view the choice of the y-axis is irrelevant to the result.

The coordinates of ODHness on the (x,y) plane are eventually the result of the algebraic sum of both the x-axis and y-axis components of the given vectors. Values are finally clamped to [1-5] range, to be placed within the ODH target. Figure 5 shows an example of how the ODHness is placed in the ODH target after being calculated in the (x,y) plane.

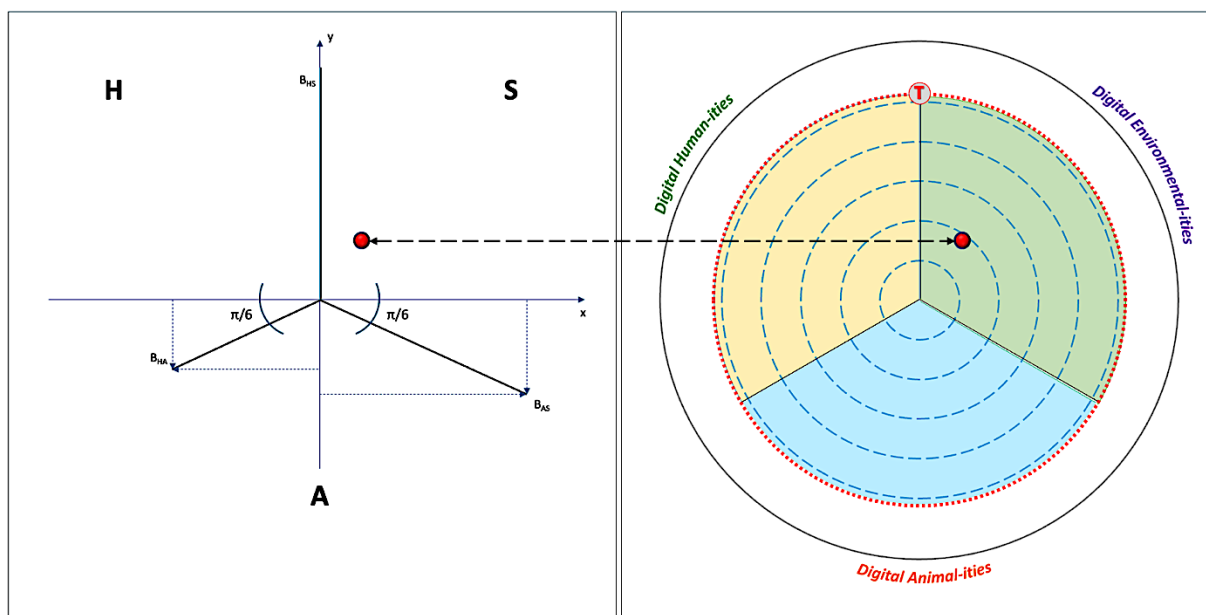


Figure 5: Vector sum and ODHness placement in the ODH target

4 Implementation of the One Digital Health Intervention in the OneAquaHealth project

The stepwise methodology described in the previous Section is now applied to analyze the entire OneAquaHealth project as a large-sized ODH Intervention, according to the project findings so far.

4.1 Use Case Definition

A combination of the approaches introduced in Section 3.1 was figured out, to get to a sort of “cascade effect” where the output of one approach becomes the input of the following one in the line. The main results of this step are summarized in Table 11.

Table 11: Integration of methods for transforming natural language text in a structured case study

Method	Main focus	Workflow	Structured output
Content Analysis	Highlighting key themes and grouping them into sections	- Text segmentation - Categorisation (similar concepts into broader categories) - Organisation into a diagram	Context: urban aquatic ecosystems in European research sites Problem: poor capacity to detect health risks Solution: standardised alert system Tools: indicators + DSS + CS app + city dashboard.
Grounded Theory	Generating emerging theory/narrative from data	<i>Open</i> coding (key concepts) <i>Axial</i> coding (connecting concepts to each other) <i>Selective</i> coding (narrative)	Key concepts: environmental monitoring, standardised alerts, predictive indicators, citizen science Relationships: tools → environmental monitoring ↔ digital indicators ↔ integrated digital ecosystem ↔ policy decisions Narrative: ODH integrates models, DSS and citizen science to manage health risks in urban aquatic ecosystems.
Use Case Modeling (Early Warning system)	Formalising operational interactions between actors and the system	- Identify actors - Define objectives - Describe main and alternative flows	Actors: Citizens (provide data via app); Policy makers (use dashboard/DSS); Researchers (select indicators) Preconditions: monitored ecosystem Scenario: Sensors collect environmental data; Predictive modelling selects indicators; Citizen science app integrates additional data; Dashboard displays interactive maps; DSS issues early warning. Post-condition: alert to decision-makers.

Method	Main focus	Workflow	Structured output
Case Study Protocol	Structuring a replicable and rigorous case study	- Context and questions - Unit of analysis - Evidence - Results	Context: urban aquatic ecosystems in European Research Sites Question: how does ODH improve early warning for emerging health risks? Evidence: indicators, DSS, CS apps, city dashboards, international standards for interoperability Expected results: improved risk detection and management, stakeholder involvement.

A series of core elements were then further distilled, and structured as follows according to the general narrative structure of the project submitted:

- *Drivers / Triggers:* emerging pathogens, environmental stressors, pollution, climate change;
- *Domains:* Human health — Animal health — Environment (ecosystems);
- *Actors:* Citizens, healthcare professionals (human & veterinary), researchers, public authorities, industry;
- *Intervention components (OHI):* Surveillance → Risk assessment → Response (clinical/public health/veterinary/environmental) → Policy;
- *Digital layer (ODHI additions):* Sensors & IoT; Citizen apps; Data pipelines & metadata; FAIRification; AI/DSS; Dashboards; Open Information Hub;
- *Outcome metrics:* incidence/prevalence, ecological/human health indicators, response time, policy uptake, interoperability/FAIR scores.

In a further step, contents were framed and mapped at high level according to the project organization in Working Packages:

- *Surveillance inputs:* sensor networks and ecological sampling across five sites (Coimbra, Benevento, Toulouse, Ghent, Oslo): WP2;
- *Data integration:* FAIRification central node: WP3; Open Information Hub: WPs 5/6;
- *Analytic layer:* predictive modelling and DSS: WP5; integration into surveillance platform: WP6;
- *Engagement & response:* citizen science: WP4; policy translation: WP7;
- *Cross-cutting requirements:* coordination: WP1; exploitation & sustainability: WP6.

Another refinement was made, by reorganizing the sequence of main activities, adding the 48-months' timeline and providing a first reference to the DOs selected for the analysis – according to what was stated in D3.4 – to be associated with the mentioned activities (Table 12). For each activity, the WP/s mainly involved was/were highlighted. All the Research Sites are intended to be involved to a different extent in every step. The DOs refer to activities performed roughly between M6 and M30 of the project.

Table 12: Use Case intermediate steps

Step	Description	Months	WP Lead	Digital Objects (DOs) produced
1	Context analysis, requisites definition, actors' activities baseline	M1–M6	WP1, WP2	—
2	Ecological + human/animal health data collection	M6–M24	WP2, WP3	▪ DO01: Dataset containing data on selected indicators ▪ DO02: Dataset containing selected indicators ▪ DO03: Dataset containing human health data from Research sites
3	(meta)data harmonization, data models	M10–M26	WP3	
4	FAIR Assessment (first iteration)	M12–M30	WP3	
5	FAIRification: PID, ontologies, standards, automation	M18–M34	WP3, WP5	—
6	Citizen Science: app, data validation, engagement	M18–M40	WP4	—
7	Predictive modeling and AI	M24–M40	WP5	—
8	DSS + city dashboard + maps + CS app integration	M28–M44	WP6	—
9	Early Warning System (EWS) testing FAIR Assessment (second iteration)	M36–M4	WP6	—
10	Policy uptake, guidelines, European-level scaling	M40–M48	WP7	—

4.2 From FDMM to ODH Intervention table

The (still intermediate) results of Table 12 were eventually reframed to fit with the structure of the ODH Intervention table, originally introduced in Table 5. This had to be slightly adjusted to include some specific features, such as the WP/s in charge of the single step (Table 13).

The names of the steps, along with the related time frames, resemble those temporarily introduced in Table 12. The three DOs produced and analyzed so far – in D3.4 and in (Tramontano et al. 2025) – emerge as correlated to the steps #3 and #4: in particular, as two DOs stem from the activities performed in step #3, the ODH_{score} – i.e., the ODH performance, or the compliance of the step with the Dimensions of the ODH framework – was calculated twice.

The ODH_{scores} for the identified DOs are the following:

- DO.01 = 2.2
- DO.02 = DO.03 = 1.6

For each DO the main Digital-ity Domain was identified, along with the related ones – in our case, only one related Domain was identified, therefore each of the DOs will be represented in the ODH target as a relation.

If a Speciality appears more than once in the table, its i -th index remains unaltered – e.g., “Public Health” appears as the sole Digital human-ity, therefore it was always associated with its synthetic form $H(S_1)$.

Among the Technologies deployed, notably Large Language Models stand out as AI-related instruments, along with the usage of Open Database Connectivity and Data Manipulation Tools.

The FAIRness levels of the DOs reported in the table are those calculated via the implementation of the FAIR Data Maturity Model introduced in D3.4.

Table 13: One Digital Health Intervention Table for OneAquaHealth

# Step	Timeframe (Months)	Step Name	Main Objective	Main Activities	WP Lead(s)	ODH Dimension(s) + Scores					Digital Objects (DOs)	FAIRness level	Main Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Data Linkage
						C	E	M	I	S			Specialities	Technology (ies)	Specialities	Technology (ies)	Specialities	Technology (ies)	
1	M1–M6	Baseline Definition & System Framing	Establish the conceptual, scientific, and technical foundations of OneAquaHealth; align the project vision with ODH and FAIR principles.	Review existing data ecosystems, define aligned framework and key indicators for aquatic ecosystem health; map stakeholders and data sources.	WP1, WP2						-								
2	M6–M12	Indicator Framework & Data Architecture Design	Develop a standardized environmental and health indicator set and interoperable data model.	Co-design the OneAquaHealth indicator framework; define metadata standards and API interoperability; prototype system architecture.	WP2, WP3						-								

# Step	Timeframe (Months)	Step Name	Main Objective	Main Activities	WP Lead(s)	ODH Dimension(s) + Scores					Digital Objects (DOs)	FAIRness level	Main Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Data Linkage
						C	E	M	I	S			Specialities	Technology (ies)	Specialities	Technology (ies)	Specialities	Technology (ies)	
3	M9–M18	Pilot Environmental Surveillance System (ESS) Design	Design and implement the first prototype of the ODH-based ESS for early warning and monitoring.	Develop architecture for the Environmental Surveillance System (ESS); integrate sensors, IoT nodes, and data collection pipelines; test FAIRification tools.	WP3; WP4	3	2	1	0	5	DO.01: <i>Dataset containing data on selected indicators (Biological Sampling)</i>	1,7	Ecology: S(S ₁)	LLM; Production Suite; Share space	Biology: A(S ₁)	LLM; Production Suite; Share space			S(S ₁) ⊕ A(S ₁)
						0	0	5	0	3	DO.02: <i>Dataset containing selected Public Health Indicators</i>	1,7	Public Health: H(S ₁)	LLM; Production Suite; Share space	Environmental Health: S(S ₂)	LLM; Production Suite; Share space			H(S ₁) ⊕ S(S ₂)
4	M12–M24	Citizen Science Tools and Engagement	Engage citizens in aquatic ecosystem monitoring through participatory sensing and feedback tools.	Co-design citizen science app; train local communities; integrate feedback loops into ESS; ensure ethical and legal compliance.	WP4	0	0	5	0	3	DO.03: <i>Dataset containing human health data from Research sites</i>	1,6	Public Health: H(S ₁)	ODBC; DMT; Production Suite; Share space	Environmental Health: S(S ₂)	ODBC; DMT; Production Suite; Share space			H(S ₁) ⊕ S(S ₂)

# Step	Timeframe (Months)	Step Name	Main Objective	Main Activities	WP Lead(s)	ODH Dimension(s) + Scores					Digital Objects (DOs)	FAIRness level	Main Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Data Linkage
						C	E	M	I	S			Specialities	Technology (ies)	Specialities	Technology (ies)	Specialities	Technology (ies)	
5	M18–M30	Decision Support System (DSS) and Predictive Modelling	Develop analytical tools for decision-making, risk assessment, and scenario simulation.	Build predictive models for hazard detection; create DSS dashboard with interactive maps; link models with ESS outputs.	WP3; WP5						-								
6	M24–M36	Integration and Open Information Hub (OIH)	Combine all components into a single ODH-aligned ecosystem for data sharing and cross-site analytics.	Integrate ESS, DSS, citizen science data into an open OIH; implement FAIR APIs; test for interoperability and usability.	WP3; WP5						-								
7	M30–M42	Evaluation and Policy Co-Creation	Assess performance, FAIR compliance, and policy implications of the integrated ODH ecosystem.	Conduct FAIRness evaluation, user feedback, and policy workshops; identify recommendations for sustainability and scaling.	WP6						-								

# Step	Timeframe (Months)	Step Name	Main Objective	Main Activities	WP Lead(s)	ODH Dimension(s) + Scores					Digital Objects (DOs)	FAIRness level	Main Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Related Digitality Domain (H/A/S)		Data Linkage
						C	E	M	I	S			Specialities	Technology (ies)	Specialities	Technology (ies)	Specialities	Technology (ies)	
8	M42–M48	Consolidation, Dissemination, and Replication	Ensure transferability, scalability, and long-term FAIR preservation of results.	Finalize replication guidelines; update digital assets in repositories; produce FAIR-compliant data packages for European uptake.	WP1; WP7						-								

H: Human Domain; **A:** Animal Domain; **S:** Surrounding Environment (Domain and ODH Dimension).

C: Citizen Engagement; **E:** Education; **M:** Medical (Human and Veterinary health care); **I:** Industry 4.0.

FAIRness: principles of (meta)data Findability, Accessibility, Interoperability, and Reusability.

4.3 Relevance of the Digital Objects

As introduced in the previous chapter, the relevance of the DOs identified was carefully assessed. The results are summarized in Table 14.

Table 14: Relevance of the DOs of the first iteration of the ODH Intervention for the OAH project

Digital Object		DO.01: Dataset containing data on selected indicators (Biological Sampling)		DO.02: Dataset containing selected Public Health Indicators		DO.03: Dataset containing human health data from Research sites	
Criterion category_Stage value		# of Criteria per category and stage value	Product between % of Criteria and stage value	# of Criteria per category and stage value	Product between % of Criteria and stage value	# of Criteria per category and stage value	Product between % of Criteria and stage value
F	# <i>Essential</i> criteria		4				
	1	Minimally fulfilled	2	0.5	1	0.3	0.3
	2	Partially fulfilled	2	1.0	3	1.5	1.5
	3	Totally fulfilled	0	0.0	0	0.0	0.0
	Sub-TOT Ess.			0.8		0.9	0.9
	# <i>Important</i> criteria		0				
	1	Minimally fulfilled	0	0.0	0	0.0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0.0
	Sub-TOT Imp.			0.0		0.0	0.0
	# <i>Useful</i> criteria		0				
	1	Minimally fulfilled	0	0.0	0	0.0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0.0
	Sub-TOT Usf.			0.0		0.0	0.0
	Sub-TOT F			0.3		0.3	0.3
A	# <i>Essential</i> criteria		2				
	1	Minimally fulfilled	1	0.5	1	0.5	0.3
	2	Partially fulfilled	1	1.0	1	1.0	0.5
	3	Totally fulfilled	0	0.0	0	0.0	0.0
	Sub-TOT Ess.			0.8		0.8	0.4
	# <i>Important</i> criteria		1				
	1	Minimally fulfilled	0	0.0	0	0.0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0.0
	3	Totally fulfilled	1	3.0	1	3.0	3.0
	Sub-TOT Imp.			1.0		1.0	1.0
	# <i>Useful</i> criteria		1				
	1	Minimally fulfilled	0	0.0	0	0.0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0.0

	3	Totally fulfilled	1	3.0	1	3.0	1	3.0
	Sub-TOT Usf.			0.4		0.4		0.4
	Sub-TOT A			0.6		0.6		0.5
I	# Essential criteria		0					
	1	Minimally fulfilled	0	0.0	0	0.0	0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Ess.			0.0		0.0		0.0
	# Important criteria		2					
	1	Minimally fulfilled	1	0.5	2	1.0	2	1.0
	2	Partially fulfilled	1	1.0	0	0.0	0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Imp.			0.5		0.3		0.3
	# Useful criteria		1					
	1	Minimally fulfilled	1	1.0	0	0.0	1	1.0
	2	Partially fulfilled	0	0.0	1	2.0	0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Usf.			0.1		0.3		0.1
	Sub-TOT I			0.1		0.1		0.1
R	# Essential criteria		2					
	1	Minimally fulfilled	0	0.0	1	0.5	2	1.0
	2	Partially fulfilled	2	2.0	1	1.0	0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Ess.			1.1		0.8		0.5
	# Important criteria		2					
	1	Minimally fulfilled	1	0.5	1	0.5	1	0.3
	2	Partially fulfilled	1	1.0	1	1.0	1	0.5
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Imp.			0.5		0.5		0.3
	# Useful criteria		0					
	1	Minimally fulfilled	0	0.0	0	0.0	0	0.0
	2	Partially fulfilled	0	0.0	0	0.0	0	0.0
	3	Totally fulfilled	0	0.0	0	0.0	0	0.0
	Sub-TOT Usf.			0.0		0.0		0.0
	Sub-TOT I			0.4		0.4		0.2
TOT Relevance			1.3		1.3		1.0	
			Intermediate		Intermediate		Low	

Despite the overall not-high score registered, it was considered to keep all the identified DOs for the setup of the ODH Intervention, as this was its first iteration and it will be as important to assess their R_i score after the FAIRification process – to be addressed in D3.6.

4.4 Model design

Table 15 summarizes all the passages introduced in Sections 3.3 and 3.4, thus spanning from the single ODH_{score} to the IOF_T s to be placed on the ODH Target, to the weight of the relations they originate. It is critical to highlight that, since each DO falls over two health-related Domains, the two endpoints of the relations will have the same ODH_{score} , e.g., $DO.01_1 = DO.01_2 = 2.2$; etc.

Table 15: Numeric results for the methodological steps

	DO.01_1	DO.01_2	DO.02_1	DO.02_2	DO.03_1	DO.03_2
ODH_{score}	2.2	2.2	1.6	1.6	1.6	1.6
ODH_n (base 5)	0.44	0.44	0.32	0.32	0.32	0.32
$FAIR$ score F_i	1.7	1.7	1.7	1.7	1.6	1.6
$FAIR_n$ (base 3)	0.57	0.57	0.57	0.57	0.53	0.53
$\Phi(ODH_n, FAIR_n)$	0.45	0.45	0.33	0.33	0.32	0.32
IOF	2.26	2.26	1.64	1.64	1.62	1.62
IOF_T (on the ODH Target)	3.74	3.74	4.36	4.36	4.38	4.38
Speciality (for Data Linkage)	S(S_1)	A(S_1)	H(S_1)	S(S_2)	H(S_1)	S(S_2)
N	2		2		2	
$1/IOF_T$	0.27	0.27	0.23	0.23	0.23	0.23
Weight of Relation	$t = 3.74$		$r = 4.36$		$s = 4.38$	

4.5 ODH Target

In Figure 6 the ODH Target is accordingly setup. The Digital Environmentalities Domain is split in two, as two Specialities – Environmental Health and Ecology – related to it have been identified in the analysis of the DOs; conversely, the other two Domains only feature one Speciality – notably, Public Health and Biology.

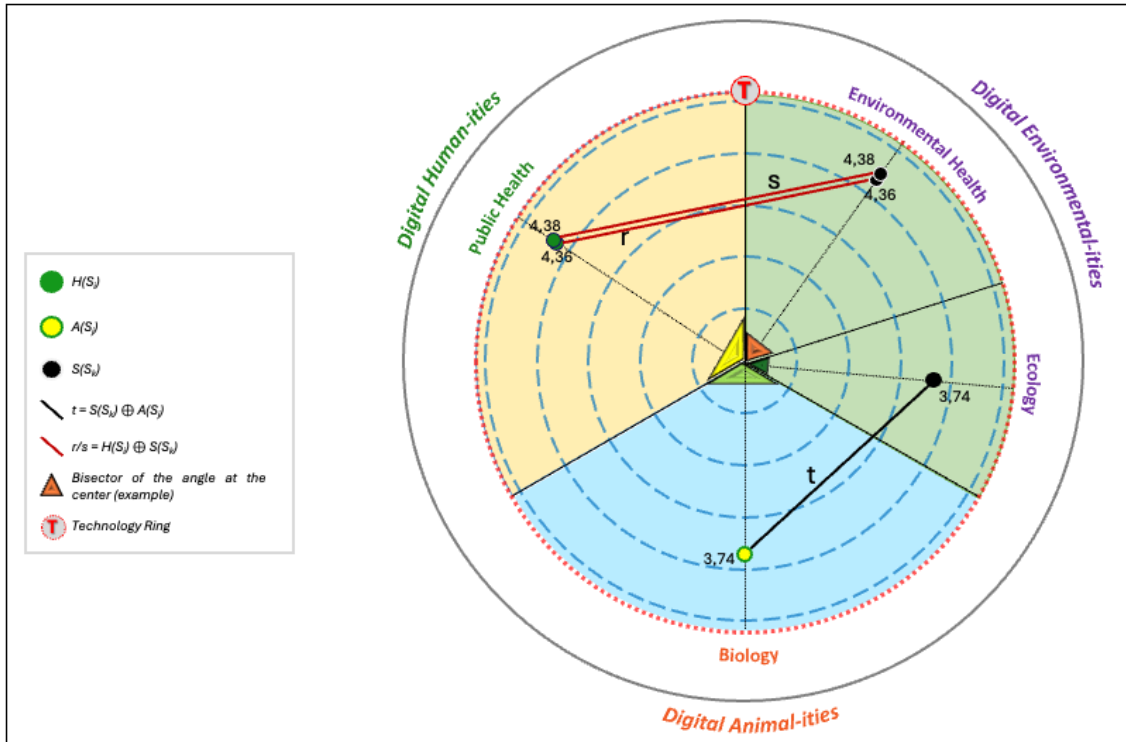


Figure 6: ODH Target for OAH

4.6 ODHness for OAH

For what concerns the translation of the values in a system of vectors, the B_{HA} vector is missing as either (i) no DOs fall between both Digital Human-ities and Animal-ities Domains, and (ii) no DOs only fall in the Digital Animal-ities Domain, so as to figure out fictive relations. Therefore, we have:

- $B_{HS} = r + s = 4.36 + 4.38 = 8.74$
- $B_{AS} = t = 3.74$
- $B_{HA} = 0$

The steps to calculate the coordinates of ODHness are as follows in (13):

$$\begin{cases} B_{HS,y} = B_{HS} \cdot \sin \frac{\pi}{2} = 8.74 \\ B_{AS,y} = B_{AS} \cdot \sin \frac{\pi}{6} = -1.87 \\ B_{HA,y} = 0 \end{cases} \quad (13)$$

$$\begin{cases} B_{HS,x} = B_{HS} \cdot \cos \frac{\pi}{2} = 0 \\ B_{AS,x} = B_{AS} \cdot \cos \frac{\pi}{6} \approx 3.24 \\ B_{HA,x} = 0 \end{cases}$$

It descends that:

- $ODH_y = 8.74 + (-1.87) = 6.87 \rightarrow 5$
- $ODH_x \approx 3.24$

According to what stated in Section 3.5, ODH_y value was clamped to [1-5] range, in order to be placed within the ODH target. The positioning of ODHness in the ODH Target for the OAH project is eventually depicted in Figure 7.

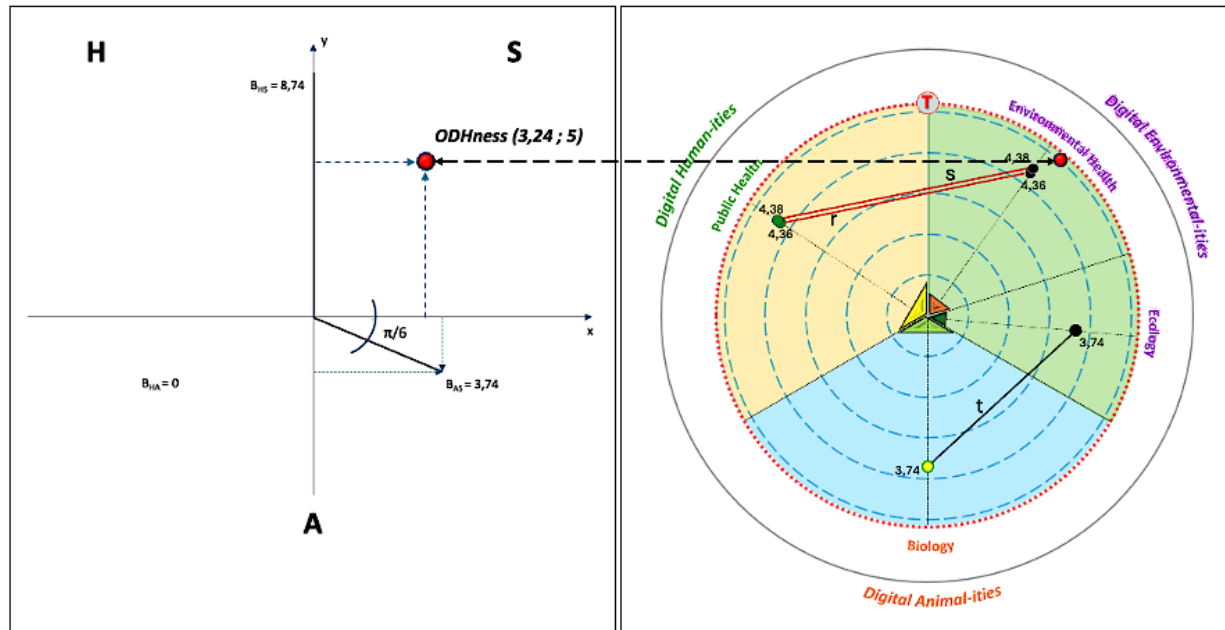


Figure 7: ODHness for OAH (first iteration)

5 Discussion

5.1 OAH as a structured ODH Intervention: advancing beyond the state-of-the-art

Many OHIs have been widely implemented over the last decades, prioritizing coordination mechanisms to achieve their goals, often emphasizing: (1) interdisciplinary governance; (2) environmental drivers of zoonotic and non-infectious outbreaks; (3) prevention at the population level; and (4) stakeholder engagement – see e.g., (Franco et al. 2014; Baum et al. 2017; Karimuribo et al. 2017; Nzietchueng et al. 2023; Thal and Mettenleiter 2023). However, even the most mature OHI models remain largely output-oriented narratives, thus lacking an explicit and formalized discussion concerning the setup and deployment of (FAIR) digital components.

The purpose of an OH Intervention is “by the book” to set in motion a series of actions capable of pursuing in a balanced way an improvement for either human, animal, and environmental health (Mumford et al. 2023; Mwatondo et al. 2023; Winkler et al. 2025), whereas an ODH Intervention is supposed to enhance an OHI by achieving a balance between the digital functionalities related to the mentioned health-related Domains.

According to the ODH Steering Wheel (cfr. Figure 1 and (Benis et al. 2021)), the combination of the two Keys is projected onto the three Perspectives, and then is operationalized through the Five dimensions via the Technology Ring that acts as a functional bridge between the layers. It descends that the Dimensions, to which the concept of ODH performance is strictly related, act as an “essential fabric of interconnections” among the activities to be performed in an Intervention, thus somehow echoing the “One Health” key of the framework. On the other hand, the critical role of FAIRness emerges as an enabler of impact for the digital technologies involved, because DOs’ compliance with the FAIR principles amplifies the ODH potential of any Intervention’s (tech-based) step. In this way the same Dimensions also embody the other logic sequence along the framework layers, which dates back to the “Digital Health” key of the framework. Similarly, the very premise the MCDA “philosophy” is built upon in finding out the righteous way to combine ODH_{score} and FAIRness, is justified and corroborated.

Hence, the shift from OH to ODH is substantiated.

The OneAquaHealth project is herein conceptualized and operationalized as a large-scale, ecosystem-driven One Health intervention with a digital backbone aligned to the One Digital Health framework. The present work proposes a conceptual and operational (r)evolution in intervention modeling: OneAquaHealth is not only analyzed as a OHI, but is also methodologically transformed into a digital use-case intervention workflow, where (i) a formal rationale for identifying and selecting Digital Objects is grounded in the core economy of research advancement, and (ii) a quantified harmonization of OH Intervention multidimensionality (ODH_{score}) and FAIR maturity (via the FDMM) are combined within a structured FAIR/ODH approach.

The novelty of the approach lies anyway on established scientific pillars (systems thinking, MCDA normalization frameworks, composite indicators, co-learning interventions), thus proving to be:

- more *coherent*, because it formalizes narrative-to-use-case transformation with systemic digital object anchoring across the 48 months of project lifespan;
- more *robust*, because it harmonizes two numerically orthogonal (and qualitative opposing) indices via justified inversion-normalization before aggregation, preserving ranking direction, interpretability, and semantic meaning within the ODH target;
- more *scalable and transposable*, because it provides minimal evidence requirements and reproducibility guidelines that can be adopted in future interventions within and outside the project.

The literature lacks references to interventions that a priori operationalize this multi-layer evidence centrality. In addition, existing frameworks only consider digital transformation of interventions – like a sort of “post-processing” phase –, but not the intervention-wide transformation power of digital objects themselves.

5.1.1 Digital Objects: choice, role, relevance

As seen in Table 13, the use-case intervention workflow can be articulated in several steps, each of which may be connected to one-to-many DOs – or even none. It cannot be though decided in advance how many DOs will be assigned to each step: as the chosen DOs are requested to act as quantifiable engines of systemic coherence during the project’s full lifespan, this means that a series of passages have to be implemented to work out the final number of DOs really needful to contribute to the ODH Intervention setup – and, accordingly, its ODHness:

- a periodic survey/identification of the DOs has to be performed, as (i) new DOs may arise in the project economy as it proceeds along the timeline, for their compliance to the FAIR principles to be assessed, and/or (ii) already existing DOs may need to undergo a FAIRification process to improve their FAIR-related status as the project's findings and exigencies increase;
- a choice may be made in advance as to the type of DOs to be considered for the project (as it was the decision for OAH to only focus on datasets) knowing that this may affect its final ODHness. This is anyway a subjective decision, which must be attributed to the P.I./project steering group;
- the relevance of the chosen category/categories of DOs must be defined – via e.g. the approach introduced in Section 3.3 and deployed in Section 4.3 – as a further decision may be requested to make about the quality of the DOs, to keep for the ODH Intervention setup.

In our case, the three DOs already identified in D3.4, despite their relevance as emerged in Table 14, have all been considered so far viable, mainly because this is still the first iteration of the ODH Intervention. In the next phases of the project, either eventual new DOs/datasets will be identified, and/or the previous ones are supposed to undergo a process of FAIRification. This will be discussed in the D3.6.

5.1.2 Implications for Public Health (Informatics)

As main result of the first iteration of the ODH Intervention on the OAH project, depicted in Figure 7, the ODHness lies on the upper right quadrant of the ODH target, thus seemingly over-reliant on environmental data and underdeveloped as to the animal side: this is mainly because (i) two DOs fall in the Human and Environmental Digital Domains, and (ii) the Animal Digital Domain is only connected to the Environmental Digital Domain. No relevant connections between the Human and the Animal Digital Domains seem to have properly emerged in the project, at least in the period under consideration – steps #3 and #4 roughly span between M9 and M30. More recent improvements of DO.03 are therefore not included in this analysis, as well as the setup and deployment of elements related to e.g., Citizen Science App, City Dashboards, DSS, or Environmental Surveillance System. This means that the DOs considered for this first iteration will have likely to undergo a FAIRification process, while a compliance with the FAIRness principles shall be performed for the next DOs to come – always keeping in mind that the only kind of DOs to be considered are datasets. Further iterations of the ODH Intervention approach shall therefore be performed to bring the ODHness as close as possible to the (0;0) coordinates in the ODH target.

This first overall scenario makes it possible to draw some lines. A robust evaluation of an ODH Intervention depends not only on adaptive leadership and capacity for learning, but also on governance arrangements that explicitly delimit the system of interest and the evaluation scope – decisions that must be reported transparently because they directly shape findings and transferability. The implementation of the ODH framework requires therefore both technical resources and sustained political and managerial commitment; without these, even well-designed digital interventions struggle to scale. Consistent with updated guidance for complex interventions, evaluators should treat development, feasibility, evaluation, and implementation as intertwined stages within an internally consistent approach: this perspective helps anticipate governance bottlenecks and highlights the need for participatory methods that secure multi-stakeholder endorsement early in project lifecycles (Skivington et al. 2021). Systems thinking reinforces the same message: interventions that aim to span human, animal, and environmental health are systemically embedded and therefore vulnerable to misinterpretation or misapplication if stakeholder roles, incentives, and power relations are not

explicitly addressed. Embedding reflexive methods and iterative co-design reduces these risks and improves the plausibility of scaling (Gadsby and Wilding 2024). Finally, mixed methods are essential: quantitative indicators (e.g., FAIRness metrics, ODH performance scores) provide comparability and benchmarking, while qualitative inquiry explains why interventions perform well in particular socio-institutional contexts. Together, these elements create a defensible pathway from pilot evidence to policy recommendations, while also producing the metadata and FAIR digital objects necessary for reproducibility and future benchmarking (Ji et al. 2021).

5.2 Limitations of the study

Some aspects to be mitigated mainly relate to:

- *subjectivity in ODH scores and FAIR assessment*: the ODH performance score – that is, the compliance to the ODH framework Dimensions – assigned to each of the steps of the use-case, as well as the compliance of the DOs to the FAIRness principles – from which their relevance index is also derived –, depend of course on the sensibility of the stakeholders. As to the latter, in particular, it was already expressed in D3.4 that it was considered critical for the OAH FDMM to pursue an educational purpose, since the compliance with FAIR principles is one of the five parts – namely: conceptual framework, data collection, data evaluation, data management and data application – in which the application of data literacy is supposed to be organized (Ridsdale et al. 2015). Such integration represents moreover a crucial step towards equipping future researchers (not only for computer science-related disciplines) with essential skills for navigating a data-driven approach (Gonzalez Soltero et al. 2024);
- *subjectivity in the choice of the DOs*: as said, it is critical to adopt a robust policy for what concerns the project leadership and overall organization. Getting to an idea as clear as possible about the DOs that the project may origin, although being a non-trivial decision-making activity, may be engineered by resorting to e.g., robust design-related techniques for complex systems. This anyway also lie in the very fundamentals of the MCDA discipline (Kalsi et al. 2001; Arvidsson and Gremyr 2008; Hisam et al. 2024);
- *MCDA aggregation approaches*: the multiplicative aggregation was chosen because it provides a strict non-compensability (each criterion's value does not necessarily affects the other one), and produces a scalable interaction effect, not just a passive aggregated indicator. Nonetheless, alternative approaches may turn out to be equally effective, among which:
 - additive aggregation (Weighted Linear Combination): this is widely used in public health, although it assumes some compensability – a low score in FAIRness could be offset by a good ODHness (or vice-versa).
 - geometric mean aggregation: as a non-linear model, it reduces compensability. It is also sensitive to low values, but less strict than full multiplication – still partially compensatory.
 - harmonic mean aggregation: very sensitive to the worst performing criterion, although it does not generate interpretable scaling factors for intervention design.
- *scale and contextual transferability*: a DO that works well for the OneAquaHealth urban sites may need adaptation in other ecosystems; replication guidelines and minimal metadata requirements should therefore be provided to ease transfer.

6 Conclusions

In the present document a novel, integrated approach for improving the concept of OH Intervention via the deployment of the ODH framework – going under the name of One Digital Health Intervention – was introduced, described, and implemented in the context of the OAH project.

To (1) support specific initiatives that address human, animal, and environmental system needs and challenges; (2) assess and study these systems' expected and unexpected outcomes and effects and collect related data; and (3) select timely metrics for the outcomes of multicriteria decision analyses, the Intervention tightly integrates a FAIRness maturity model with a quantified ODH Intervention coupling approach that (a) maps DOs to ODH target geometry, (b) computes IOF scores per intervention step, and (c) uses constrained multiplicative amplification to avoid dominance. The approach sits therefore at the intersection of One Health systems evaluation (Rüegg et al. 2018), FAIR maturity assessment frameworks (Wilkinson et al. 2016), and MCDA/composite indicator design (Mühlbacher and Kaczynski 2016).

By interpreting the entire 48-months OAH project as a large-size Use Case, the ODH Intervention proved also as capable to: (i) *address One Health-related challenges*, proving its capability in handling some among the main Digital outputs emerging from a multidisciplinary analysis of the delicate balance underlying urban freshwater ecosystems; (ii) *achieve One Health-related important and strategic outcomes* for clinical follow-up and practice, by highlighting an effective way (ODHness) to work out the balance between the digital functionalities related to the three health-related Domains, and (iii) *achieve FAIR uses of digital technologies*, providing the necessary connection between the potential of a One Health Intervention step (the Dimension-compliant data layer's systemic impact), and its digital facets (the FAIR-compliant data layer).

In the present work a first yet complete iteration of the ODH Intervention was run, which focused on the main elements produced up to roughly M30. The results of this work are the foundation of the next steps, as either the Digital Objects produced within the project will likely undergo a FAIRification process, or new Digital Objects will be produced, whose compliance for the FAIR principles will be assessed. The overall objective is to guide the next steps of the project in view of an improvement of the results of the next iterations of the One Digital Health Intervention.

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