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One Digital Health for more FAIRness

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Abstract

Background One Digital Health (ODH) aims to propose a framework that merges One Health's and Digital Health's specific features into an innovative landscape. FAIR (Findable, Accessible, Interoperable, and Reusable) principles consider applications and computational agents or, in other terms, data, metadata, and infrastructures) as stakeholders with the capacity to find, access, interoperate, and reuse data with none or minimal human intervention.

Objectives This paper aims to elicit how the ODH framework is compliant with FAIR principles and metrics, providing some thinking guide to investigate and define whether adapted metrics need to be figured out for an effective ODH Intervention setup.

Methods An integrative analysis of the literature was conducted to extract instances of the need—or of the eventual already existing deployment—of FAIR principles, for each of the three layers (keys, perspectives and dimensions) of the ODH framework. The scope was to assess the extent of scatteredness in pursuing the many facets of FAIRness, descending from the lack of a unifying and balanced framework.

Results A first attempt to interpret the different technological components existing in the different layers of the ODH framework, in the light of the FAIR principles, was conducted. Although the mature and working examples of workflows for data FAIRification processes currently retrievable in the literature provided a robust ground to work on, a nonsuitable capacity to fully assess FAIR aspects for highly interconnected scenarios, which the ODH-based ones are, has emerged. Rooms for improvement are anyway possible to timely deal with all the underlying features of topics like the delivery of health care in a syndemic scenario, the digital transformation of human and animal health data, or the digital nature conservation through digital technology-based intervention.

Conclusions ODH pillars account for the availability (findability, accessibility) of human, animal, and environmental data allowing a unified understanding of complex interactions (interoperability) over time (reusability). A vision of integration between these two worlds, under the vest of ODH Interventions featuring FAIRness characteristics, toward the development of a systemic lookup of health and ecology in a digitalized way, is therefore auspicable.

Keywords

- FAIR
- Information Science, Medical
- One Health
- Digital Health
- One Digital Health

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Introduction

Background

One Digital Health (ODH) aims to propose a framework that merges One Health's and Digital Health's specific features into an innovative landscape. FAIR (Findable, Accessible, Interoperable, and Reusable) principles consider applications and computational agents (or in other terms, data, metadata, and infrastructures) as stakeholders with the capacity to find, access, interoperate, and reuse data with none or minimal human intervention. Having an efficient and effective interaction between two knowledge management visions is essential. Understanding how ODH can trigger more FAIRness and reciprocally how FAIR can induce a sustainable practice of ODH, needs some awareness of each one separately.

One Health and Digital Health

Digital health deals with the development, implementation, integration, and use of information and communication technologies for health management and promotion purposes to improve wellness and reduce illness risk. At the same time, having an integrative understanding of human, animal, and environmental health is the challenge of One Health.[1,2] Thus, the deployment of interoperable systems is the key to efficiently supporting data collection, storage, and analysis, allowing the monitoring and generating of in-time alerts for decision-makers looking at human, animal, and environmental health as distinct fields or as a whole. In the health and environment contexts, this process is essential to prevent, respond, recover, and mitigate disasters from nano- to mega levels.[3]

One Digital Health

Standing at the crossroads of these fields, ODH aims to propose a framework—comprising two keys, three perspectives, and five dimensions—that merges their peculiar features into an innovative landscape. ODH intends to support the digital transformation of health ecosystems that is to support the improvement and enhancement of the whole quality of life and care ecosystems, wherein animals, plants, and other ecological components are called to build up a digitally enhanced web of interactions, thus allowing continuous monitoring and control.[4] Its core is therefore to look in a systematic and integrative way at the interactions between health and life sciences, digital technology, and environmental resource management. This is oriented to the realization, in the future, of near-real-time data-driven solutions to challenges related to systems medicine and ecology, as a whole. Further, a proper and evolutive framework, such as the ODH one, turns out to be essential to permit collecting heteroclite data to run analytics processes. This also means that, by definition, ODH concentrates on promoting and enhancing the synergy between One Health and Digital Health communities. It tends to help the health informatician community to address the intrinsic complexity of novel health and care scenarios in digitally transformed health ecosystems wherein citizens are called to play a central role in the management of their health-related data and resources. In this regard, to test and develop the inputs provided by the authors of the proposed framework,[4] both the European Federation of Medical Informatics and the International Medical Informatics Association supported the creation of as many ODH Working Groups. Memberships currently involve researchers and practitioners in health informatics, digital health, applied artificial intelligence and data science, human and veterinary clinical medicine, epidemiology and policy-making, citizen engagement, and smart city, emergency, and disaster management.

The FAIR Principles

The FAIR principles draw a framework to organize research outputs in such a way that they must be easily accessible, understood, exchanged, and reused. They address 21st century research requirements of "Findability," "Accessibility," "Interoperability," and "Reusability" of digital resources, such as datasets, code, workflows, and research objects.[5] Thus, relying on FAIR Data Principles[5,6] becomes critical to ensure mid- and long-term sustainable research outputs and provide up-to-date support to the decision-makers. FAIR principles consider applications and computational agents (or in other terms, data, metadata, and infrastructures) as stakeholders with the capacity to find, access, interoperate, and reuse data with no or minimal human intervention. They also recognize the importance of an automated process for computational support to deal with intensive data processes.[7]

ODH Intervention in a FAIRness Way

As previously stated,[4] the concept of ODH Intervention stems from the need to establish an interoperable digital health ecosystem capable of seamless, secure health data exchange and processing. An ODH Intervention is formalized as a set of digital functionalities[4] (digitalities) designed and deployed to:

- Support specific initiatives that address human, animal, and environmental systems' needs and challenges.
- Assess, study, and collect data on these systems' expected outcomes, unexpected outcomes, and effects.

Along with this, ODH-ness is introduced as an overall measure of how well the harmonization between the different digitalities works to address the needs and challenges mentioned above. Accordingly, on the one hand, assessing the FAIRness of an ODH Intervention stands as an unavoidable prerequisite for proper data management and stewardship of the whole set of data produced and exchanged within the Intervention itself. In the same way, developing an ODH-ness compliance analysis assessment involves the deployment of FAIRness Maturity models.[6] Therefore, the design and deployment steps of an ODH intervention imply[4] for the generated data at each step to be:

- "Findable," because the digitalities involved are part of the study and collection of all the data related to the interconnection between systems' needs.

- "Accessible" via standardized protocols, to leverage the available common substrates of data, information, and knowledge stemming from digital biodiversity.
- "Interoperable," as a consequence of the awareness to establish an ecosystem capable of seamless, secure health data exchange and processing, to deal with the shared risks between animal and human populations.
- "Reusable" to allow a systematic, continuous, and intelligent integration of big, smart, and multidimensional data exchanges by the digitalities involved.

One example of ODH intervention is the Optimal Evacuation Route for Animals (OPERA) project.[8] OPERA consists of an information system supporting environmental monitoring of the wooded areas at risk of fire in the "Mount Vesuvius' red zone" in South Italy. Its main objective is to determine the optimal evacuation route for animals in case of fire, for each of the reported animal species living in the mentioned area. With direct reference to the ODH framework, the project features the following: *perspectives*—individual health and wellbeing (of the animal species in case of evacuation), and ecosystem (red zone monitoring, and health guarantee for animals); and *dimensions*—environment (working out the evacuation route as an arborescence optimization problem), and health industry 4.0 (fires prevention via the deployment of a wireless sensors network). The OPERA project shows an example of a FAIR ODH intervention wherein the environmental monitoring systems are interconnected allowing data sharing in a findable, accessible, and interoperable way. Moreover, the models generated by OPERA are also built in such a way that they are reusable by other systems for other similar events.

Aim and Objective

Our leading aim, herein, is to take to the front the critical need of having ODH-related systems and platforms with a high FAIRness level even to increase the holistic features of systems medicine and ecological research to look at the humans' and animals' health and at the influences on their surroundings and vice versa. Therefore, the objective is to elucidate how the ODH framework can lead to more systems compliant with the FAIR principles and metrics. Our hypothesis is that the results we can provide below should help to draw some thinking guides to investigate and define whether adapted metrics need to be figured out for an effective ODH Intervention setup.[9] To this end, the compliance between the ODH framework's layers and the FAIR principles will be assessed in a synthetic and example-based way as a double-entry table (FAIR vs. ODH).

Methods

As briefly anticipated, the ODH "steering wheel" is built around two keys (One Health, Digital Health), three perspectives (individual health and well-being, population and society, ecosystem), and five dimensions (citizens' engagement, education, environment, human and veterinary health care, Healthcare Industry 4.0)[4] (►Fig. 1).

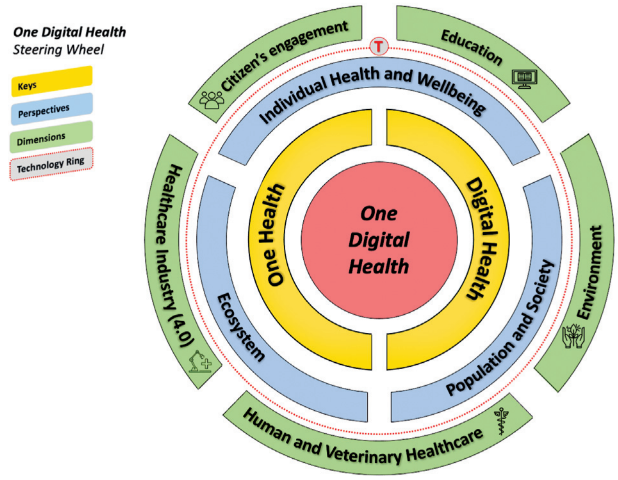

Fig. 1 The One Digital Health steering wheel conceptual framework (Adapted from Benis et al[4]).

The digitalities to be singled out and analyzed, toward the deployment of an ODH Intervention, aim to:

- Increase human wellness and animal welfare.
- Take into account "how" the humans/animals interactions reciprocally affect their health, and behaviors.
- Relate to how technology has been embedded in human experiences and activities.
- Support the management and governance of the complex interactions between humans, animals, and their ecosystems.

To achieve each one of those aims, it is critical to pursue a quality of data (e.g., according to the following components: availability, usability, reliability, relevance, and presentation quality; and according to the following data quality elements: accessibility, timeliness, authorization, credibility, definition/ documentation, metadata, accuracy, consistency, integrity, completeness, auditability, fitness, readability, and structure)[10] that must also feed with the FAIR principles. Thus, FAIR guiding principles spotlight the need to develop the capacities of computational systems to manage the monitoring, collection, processing, and stewardship of the digital resources to be evaluated, with a minimum of human interventions, due to the "big data" and "cloud computing" revolutions inducing an increase of data volume, velocity, and variability in the health and medicine arena.[11] To this end, an integrative literature review[12,13] was conducted to extract instances of the need—or of the eventual already existing deployment, explicitly reported or not—of FAIR principles with FAIR-enabling digital resources-like[14] (e.g., datasets, metadata, code, protocols, compute resources, data policies, identifier mechanisms, standards) for each of the three layers featured by the ODH framework. The review was processed by seeking for publications, on medical and engineering search engines (e.g., PubMed, IEEE Xplore, Science Direct), totally or partially related to the combinations of, at least, one FAIR principle and, at least, one of the ODH "steering wheel" features, for example, keys, perspectives, or dimensions (or synonyms). The included resources have been selected subjectively (i.e., as a shared opinion of the authors) according to their potential contribution to the aim and objective of this research.

The scope was to assess the extent of scatteredness in pursuing the many facets of FAIRness, descending from the lack of a unifying and balanced framework, which ODH actually is.

Results

FAIR-Enabling Digital Resources-Like for all the Layers of the ODH Framework

►Table 1 showcases a comprehensive overview of the findings of the integrative literature review that were then categorized according to the three layers of the ODH framework.

ODH FAIRness from an Interconnectivity Point of View

To provide an additional prospect to the mapping of the ODH and FAIR frameworks, in the following sections it is highlighted how different technological components existing in the different layers of ODH (keys, perspectives, dimensions) can also be effectively interpreted in the light of the FAIR principles.

Keys

The concept of One Health Informatics[15] first conveyed the idea of entwining One Health's widened framework—which looks at the inextricable interconnectedness between humans, animals, and the environment[16]—with the multiple features of Digital Health—that entail, for example, collecting and storing data, information, and knowledge to efficiently deliver health care, as well as pursuing goals related to health promotion, well-being, and efficient self-management. ODH's intrinsic propensity to facilitate and improve collaboration among practitioners from both communities provides a novel common ground to figure out aspects like (1) delivery of health care in a syndemic scenario; (2) digital transformation of human and animal health data; and (3) digital nature conservation by means of digital technology-based interventions.[4,17]

Perspectives

The shift from individual-level, predictive, personalized, preventive, and participatory health care[18] to a population level is not supposed to rely on a one-size-fits-all approach, as personalized health accounts for individuals' variability in terms of genes, environments, digital health literacy, preferences, and lifestyles. In a broader sense, the whole set of animals and humans, as well as software and robots, acting as autonomous and interacting agents to enhance decision support dynamics, make up an ecosystem capable of "digitally" responding to populations' impact and interactions.[19] Such digital biodiversity descends in turn from common substrates of data, information, and knowledge that need to be made accessible, available, and able to be analyzed in novel and innovative ways. Looking at the individual or at the population is pretty similar for dealing with data collection and storage. Thus, from a merged FAIR and ODH perspective handling individual data makes them available for population-level studies but the opposite is not always possible. This last possibility is less interesting in terms of ODH-ness due to the limited possibility of easy secondary use.

Dimensions

Digitalization and interconnectivity are meant to increasingly spread all over the facets of the health systems: this entails an equally growing challenge for collecting, storing, archiving, and analyzing a wide range of real-time data made available by several different kinds of connected organizations. As a consequence, many new paradigms need to be conceived to convey characters, features, and available technologies for each of the communities that (sometimes for the first time) find out new places of encounter with each other: it is the case of , for example, smart cities, citizen sciences, or welfare ecosystems. Similarly, the systemic thinking skills, underlying every research process, rising up in this new era are called to figure out the most suitable ways to get to and shape the new generations of practitioners. This occurs thanks to the deployment of well-known methods like project-based learning[20] and case-based learning,[21] which make it possible to have citizens capable of engaging with complex policymaking over time (i.e., for policies that are related to ethics, regulation, decisions on big smart data, and the shaping of social norms).

Discussion

Overview

The effectiveness of an ODH Intervention, although quantifying ODH-ness as a measure, also ideally provides its positioning within the Technology Ring that encompasses the set of digital functionalities the ODH framework relies on.[4] The FAIRification of an ODH Intervention, by extension, relies in the first place on the need to deploy timely solutions to enable the FAIRification of those technological resources the mentioned digital functionalities are meant to generate and handle.[22] On the other hand, an effective ODH-ness cannot be considered but as a sort of FAIR "meta-metric," since it has to deal with the assessment of the whole FAIR guiding principles set for each of the three areas (digital Human-ities, digital Animal-ities, and digital Environmental-ities) identified and comprised within the ODH Technology Ring. More specifically, these areas have to be intended, from an ontological viewpoint, as the projections of the upper-class "ODH Intervention" concept onto its interacting, constituent, classes of digitalities. Additionally, as FAIR Principles are aspirational (in that they describe a continuum of features, attributes, and behaviors that move a digital resource closer to a given goal[11]), a progressive, refined positioning of ODH-ness within the ODH Technology Ring will likely require a periodic normalization of the assessment steps, depending on the necessary changes impacting the resources involved. All this entails that, to be fully compliant with the ODH vision, each investigated digitality needs to be circularly evaluated: in other words, a FAIRification workflow for ODH Research demands the definition of timely

Table 1 FAIR-enabling digital resources-like for all the layers of the ODH framework

ODH "steering wheel's" layer	ODH layer feature/s	Findable	Accessible	Interoperable	Reusable
Keys	One Health/ Digital Health	Ecological (meta) data identification and registration (F3 +, F4 +)[25–28]	Retrievable and long-lasting accessible animal welfare data (A1 +, A2 +)[29]	Searchable resources endowed with metadata that make them recognizable in terms of nature and provenance, needed for conservation biology (I1–, I3–)[30]	Reusability of data in digital epidemiology (R1.3 +)[31,32]
Perspectives	Individual health and wellbeing	Deploying findability solutions applied to EHRs data (e.g., universal patient identifiers, for both humans and animals) can improve EHR's primary uses (F1 +, F2 +, F3 +, F4 +)[33–35]	Secure and robust access to patients' data are still challenging, for primary use (patient follow-up), in many countries (A1.2–)[36,37]	Allowing health care services customers to use different systems such as IoT-related tools and services for health self-management (I1 +, I2 +)[38–40]	The development of personalized follow-up and treatments is based on health monitoring big data collection and analysis (R1.2 +, R1.3 +)[41,42]
	Population and society	Deploying findability solutions applied to EHRs data (e.g., universal patient identifier, for both humans and animals) can improve EHR's secondary uses (F1 +, F2 +, F3 +, F4 +)[39,43,44]	Adoption and implementation of national initiatives and regulations to provide secure and robust access to healthcare data are scattered (A1.2–)[45,46]	EHRs' implementation strategies heavily rely on interoperable systems and platforms, which also account for IoT-related tools and services (I1 +, I2 +)[22,38,47–52]	Secondary use of health-related and environmental data (at the population level) allows the development of personalized follow-up and treatments (R1.2 +, R1.3 +)[41,42,53]
	Ecosystem	Ecosystems are all around and of different kinds; therefore, ecosystem data must look easily findable, in that each device is recording all the data generated or received from an external source (F1 +, F2 +, F3 +, F4 +)[8,54,55]	Accessibility of data generated in any kind of environment is limited in that the data are encoded and only usable via an Application Programming Interface, and regulated by policies such as General Data Protection Regulation (known as GDPR) (A1–)[56–58]	Interoperability of data generated in different ecosystems depends on the ways data are made accessible (I1 +)[57,59]	Reusability of ecosystem-generated data relates to its encoding, findability and accessibility, as defined for regulations and policies (R1 +)[56–58,60]
Dimensions	Human and veterinary health	Globally Unique Identifiers used for the European Platform on Rare Disease Registration (F1 +, F2 +)[61]	Safety protocols to be deployed for people and animals under risk of fire, based on Distributed Sensor Networks (A1.1–, A2–)[8]	HL7 FHIR used to achieve interoperability in patient health records (I1 +, I2 +, I3 +)[62]	A Semantic Deep Learning approach to get to reliable and reusable One Health knowledge (R1.2 +)[63]
	Healthcare industry (4.0)	The upcoming "European metrology cloud" will support the concept of a "Digital Single Market" that ensures secure communication and clear identification (F1–, F3–, F4–)[64]	Secure and trusted Telemedicine in IoT: sensors can only communicate with other-than Transmission Control Protocol /Internet Protocol (A1–, A2 +)[65]	A smart toy's ecosystem for pets has to interoperate with other smart devices for pets, within a smart home system (I3–)[66,67]	FAIRshake toolkit was developed to enable the establishment of community-driven FAIR metrics and rubrics paired (R1.2 +, R1.3 +)[68]

Table 1 (*Continued*)

ODH "steering wheel's" layer	ODH layer feature/s	Findable	Accessible	Interoperable	Reusable
	Citizen's engagement	The analysis of large Twitter datasets during main political events can help understand whether or not these practices shape political engagement (F4 +)[69]	Coronavirus tracking apps are playing critical roles to collect, gather, and share patient-generated health data via standardized communication protocols (A1 +)[70]	Open government data (OGD), although critical in the vision of a smart city, are still lacking (I1–, I2–)[71]	Data generated by Citizen Science (CS) groups are becoming important for scientists' communities, and are released via Creative Commons license (R1.1 +, R1.3 +)[72]
	Education	The FOSTER portal aimed at effectively collecting, indexing, and identifying learning objects in the field of Open Science (OS) via the creation of a taxonomy for the OS field (F4 +, F1 +)[73]	In higher and further education, students' accessibility preferences to use both eLearning contents and services can be adequately described in a machine-readable format via standardized communication protocols (A1 +, A2 +)[74]	Solutions like the Gamified Education Interoperability Language (GEdIL) provide accessible and shareable languages for knowledge representation (I1 +)[75]	Most libraries, archives, museums (LAM)'s data services lack information related to data reuse or license restrictions (R1.1–)[76]
	Environment	Environmental sequences, currently a major source of information, are usually accompanied by extensive and more uniformly collected metadata (F2 +, F3 +)[77]	TreeTalker (TT), IoT-based technology for tree monitoring, uses the LoRa protocol for data transmission (A1.1 +, A1.2 +)[78]	The Environment Ontology is a resource and research target for the semantically controlled description of environmental entities (I1 +, I2 +)[79]	The reuse of sequence data related to the COVID-19 pandemic is still limited by the lack of metadata submitted to genomic data repositories (R1.2–)[80]

Abbreviations: COVID-19, coronavirus disease 2019; EHR, electronic health record; FAIR, Findable, Accessible, Interoperable, and Reusable; IoT, Internet of Things.
Legend: (1) According to the FAIR Guiding Principles, To be Findable: F1. (meta)data are assigned a globally unique and persistent identifier; F2. data are described with rich metadata; F3. metadata clearly and explicitly include the identifier of the data it describes; F4. (meta)data are registered or indexed in a searchable resource; To be Accessible: A1. (meta)data are retrievable by their identifier using a standardized communications protocol; A1.1 the protocol is open, free, and universally implementable; A1.2 the protocol allows for an authentication and authorization procedure, where necessary; A2. metadata are accessible, even when the data are no longer available; To be Interoperable: I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation; I2. (meta)data use vocabularies that follow FAIR principles; I3. (meta)data include qualified references to other (meta)data; To be Reusable: R1. meta(data) are richly described with a plurality of accurate and relevant attributes; R1.1. (meta)data are released with a clear and accessible data usage license; R1.2. (meta)data are associated with detailed provenance; R1.3. (meta)data meet domain-relevant community standards.
(2) According to our analysis from the ODH viewpoint: + (*plus* symbol) means a satisfying/good/total compliance with FAIR Principles; – (*minus* symbol) means not adequate compliance with FAIR Principles.

metrics to assess whether a digital object, although complying with a specific aspect of FAIR within its specific area of the Technology Ring, shows a similar propensity/capacity to be FAIRed once stretched out toward one of the other two areas—or toward both of them, when it comes with a triality.

The main objective of this research was to provide to the different actors of the ODH landscape some indications about the "ODH keys, perspectives, and dimensions" compliance with the FAIR principles. On the one hand, the results of our analysis must lead to the development of FAIR metrics for implementing efficiently and effectively an ODH Intervention setup. Therefore, we assessed in a focused and example-based way the compliance of the ODH framework's layers with the FAIR principles and looked reciprocally at those latter to understand how they are implemented in the different components of ODH. Our results show the need to develop the ODH compliance to FAIR to allow streamlined monitoring and interactions between the different ODH perspectives and dimensions.

Strengths and Limitations

The power of ODH as a framework is to act as a bridge between worlds. In a broadly similar way, FAIR principles' upper aim is to facilitate data exchanges over time. Having an integrated view of the FAIR principles from the ODH viewpoint must straightly influence the development of collaboration between researchers and practitioners from fields previously not working together. Thus, showing that ODH is and must be "more FAIR" is an added value for the whole communities involved in one or more perspectives or dimensions of the framework. However, despite the efforts performed to deploy Open Science data stewardship, the comprehensive view that the ODH framework can provide is still lacking. Hence, the current effort of harmonizing digital resources of different sizes, scopes, quality, and utility is meant to develop along two complementary trajectories: on the one hand, a strong agreement will be requested as to the qualities (clear, realistic, discriminating, measurable, universal) that a FAIR metric should exhibit, to overcome differences such as those emerging for human and veterinary health[23]; on the other hand, already existing FAIR-driven communities are clearly called to keep strengthening their spiraling path to always refined FAIRness levels (it is the case of e.g., Education and Citizen Science Dimensions). The uneven results summarized in ►Table 1 tell us that the mature and working examples of workflows for data FAIRification processes currently retrievable in the literature,[7] only fit for the single slots/results, yet they provide a robust common ground to work such new aspects out from.

Implications for Public Health

ODH demands for the adoption of new kinds of data environments, technologies, and standards. The peculiar nature, in terms of both members and initiatives, of the abovementioned working groups also mean that different communities are called to pursue and create new networks of relationships with each other, to be compliant with the most intrinsic meaning of those aspects emphasized along with the two keys of the framework.

Analyzing these relationships is therefore expected to not only cater for novel insights, but also for supporting a systematic and syndemic decision-making process to learn coping with an upcoming large spectrum of events through a timely sequence of response, recovery, and mitigation steps.[24] In this regard, initiatives such as the FAIR4Health project encouraged the health research community to FAIRify, share, and reuse their datasets derived from publicly funded research initiatives. ODH pillars account for the availability (findability, accessibility) of human, animal, and environmental data allowing a unified understanding of complex interactions (interoperability) over time (reusability). In such a promising and prolific landscape that joins FAIR for global health as an interdisciplinary and unifying field by developing "fair" ODH interventions, (public) health policy-makers are strongly asked to account for this integrated approach in the development of research management up-to-date rules.

Conclusions

Having a clear view and understanding of the links and dependencies between the FAIR principles and the ODH framework layers is essential to build the next (eco)systems medicine as a whole, setting it up under the vest of ODH Interventions featuring FAIRness characteristics. The large set of examples provides elicited feedback from FAIR and ODH practitioners toward a vision of integration between these two worlds, for developing a systemic lookup of health and ecology in a digitalized way.

Conflict of Interest
None declared.

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