UNESCO OPEN SCIENCE OUTLOOK 2023

Status and Trends Around the World

Contents

Acknowledgments

Foreword: The imperative for an inclusive and equitable open science

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Key Messages

Open science should serve to amplify access to knowledge by everyone for the advancement of science and society. It should also strive to promote opportunities for innovation and participation in the co-creation of knowledge and distribution of the resulting benefits.

- Open science has multiple potential benefits, ranging from cultural advancements, such as enhanced inclusion and trust in science, to practical gains, such as streamlined creation and reproducibility of scientific findings.
- Working openly can positively influence the investments in and outputs from science as well as the process and the impacts of science.

For open science to reach its full potential, it must be a truly global equitable phenomenon.

- Open science has the transformative power to reduce the existing inequalities in science, technology and innovation, hence to accelerate the progress towards the achievement of the Sustainable Development Goals and the fulfilment of the human right to science.
- The existing lack of equity in access to digital tools and physical equipment as well as the skills needed to use, manage and maintain them is one of the key barriers for accessing and sharing information and for collaborating at multiple scales in line with the requirements of open science.
- Taking into account the specific challenges of scientists and other open science actors in different countries, and in particular in developing countries, will be critical to ensure that open science reaches its potential and indeed reduces the digital, technological and knowledge divides existing between and within countries.

Growing evidence demonstrates the rapidly increasing adoption of open science practices around the world and across multiple disciplines. However, the existing open science assessments must be strengthened to address all aspects and values of open science.

- Preliminary attempts to assess the status and trends of open science have proven that standard approaches and existing indicators and bibliometrics are insufficient to understand and monitor the degree of openness across all the pillars of open science and across all the stages of the scientific cycle as defined in the UNESCO Recommendation on Open Science.
- A combination of qualitative and quantitative assessments, as well as innovations in understanding and managing change, will be needed for a representative monitoring system for open science that itself adheres to the values and principles of open science.

- There is a need to shift from monitoring outputs towards assessing the values and impacts of science and towards the people who are doing, engaging with and/or benefiting from science.
- Assessment is essential yet monitoring is significantly lagging for most of the pillars of open science namely open scientific knowledge beyond scientific publications, open engagement of societal actors, open dialogue with other knowledge systems and open science infrastructures.
- In general, access to scientific publications, collaborative research platforms, open repositories, open source software and hardware is on the rise with differences existing across disciplines and regions.
- Although half of scientific articles published in 2021 were released under a form of open access, based on openly available bibliometric databases, only a third of all scientific literature is under open access at present.
- Open science infrastructures now number in the thousands, with increasing calls for interoperability and attention to sustainability.
- There are indications of growing engagement with societal actors beyond the scientific community and in dialogue with other knowledge systems. However, the quality, nature or equity of engagement practices and exchanges between different knowledge systems is largely unknown.

The transition to open science requires a shift in the culture of science.

- Transformation to an open scientific system engaged with society requires both practical actions and systemic, cultural shifts grounded in mutual respect.
- Enacting such cultural change towards open science requires accessible infrastructures, strengthened capacities, aligned incentives and operational policies and policy instruments.
- At present, there is a lack of systematic and coherent approaches to open science that align with and operationalize values and principles of open science.
- The cultural shift to open science will only be possible with adequate monitoring of its impacts, including its possible unintended consequences for science and/or society (e.g. shift of costs from readers to authors; an increase in predatory behaviours; lack of clarity over ownership and intellectual property management in an open science context). If not addressed proactively, such unintended consequences may worsen inequities in science and in the distribution of its benefits.

Collective, collaborative and coordinated action and investment are needed to boost the transition to a truly global, equitable open science.

- Open science requires investment to thrive, and significant gains may be made through reallocation of existing resources.
- Incentive systems to promote open science urgently require alignment of the values and priorities used to assess scholars and institutions with the values and principles of open science.
- Innovation in international partnerships and co-funding for open science will be key for a meaningful equitable global transition to open science.

Introduction

Transitioning to Open Science: A Global Assessment of Progress and Challenges

In an increasingly digitalized world, where information can flow effortlessly across borders, open science has emerged as a powerful force driving the advancement of knowledge and innovation.

The transparency and collaboration that characterize open science are redefining conventional research practices, potentially sparking an era of inclusive and participatory science. Inclusion and participation are not automatic for all, however, particularly for those facing resource and capacity limitations. As the world undertakes the transition to open science, it has become crucial to undertake a comprehensive global assessment of open science to gauge its impact, identify challenges and lay the groundwork for future progress.

This publication is the first attempt at a global assessment of the state of open science, taking into account the priorities, values and principles set out in the 2021 UNESCO Recommendation on Open Science. This first edition of the global *Open Science Outlook* seeks to identify potential metrics or indicators and methodologies, both qualitative and quantitative, that can describe the status and progress of open science across geographic regions, actors and disciplines. It also highlights essential gaps in the available data and information, as well as the means to assess the impact of open science on the benefits of science for all.

The *Outlook* takes a global perspective and considers the broad range of open science practices as well as the broad range of actors involved in transforming science systems around the world. This snapshot of open science status and trends is intended to illuminate opportunities and provide a baseline against which the implementation of the 2021 UNESCO Recommendation on Open Science can be assessed over time.

Countries are obliged to report on their implementation of the 2021 Recommendation on Open Science every four years, beginning in 2025. In line with the provisions of the Recommendation, UNESCO has been working with Member States and experts across the regions to develop a monitoring framework with shared standards. Future editions of the UNESCO Open Science Outlook will incorporate the quadrennial national reporting facilitated by this agreed monitoring framework.

Open science has become its own field of research, with a growing body of scientific literature assessing practices and their impacts in multiple contexts. While detailed analyses are indispensable for the rigorous evaluation of specific research studies within the field of open science, a broader assessment presented in the UNESCO Open Science Outlook provides a panoramic view of the state of open science across its different pillars as well as across different regions and communities. It contributes to our understanding of the collective impact of open science initiatives on the global research landscape and to identifying overarching trends, challenges and opportunities.

This publication also explores the challenges faced by researchers, institutions and policymakers in embracing open science, such as concerns related to intellectual property and the need for adequate infrastructure and funding. It also highlights areas that require more attention and resources, aiding policymakers, funders and other leaders in setting strategic priorities for advancing open science.

As open science continues to reshape the research landscape, a comprehensive global assessment is essential in guiding its trajectory and maximizing its benefits for society as a whole.

The quantitative and qualitative open science assessment coupled with diverse examples of a variety of open science practices provided in this inaugural edition of the *UNESCO Open Science Outlook* are intended to inspire a more inclusive, transparent and collaborative scientific ecosystem that can pave the way for more open, equitable knowledge in service of society.

Chapter 1: Global commitment to open science

Summary

The world has made a global commitment towards open science, embodied in the 2021 UNESCO Recommendation on Open Science.

Open science has the potential to reduce disparities in science, technology and innovation while advancing global goals and the human right to science. It serves not only to amplify access to knowledge by everyone for the benefits of science and society but also to promote opportunities for innovation and participation in the co-creation of knowledge. In this context, open science offers cultural, social and economic benefits, including improved inclusivity and trust in science, increased impact, streamlined research and enhanced reproducibility. Open practices can make the scientific process more efficient, transparent and reliable, thereby strengthening evidence for decision-making and trust in science.

Each of the multiple actors and stakeholders in science and innovation systems has a role to play in the operationalization of open science—as well as benefits to gain. Cooperation and awareness among these actors can optimize investments, strengthen sustainability of scientific initiatives, address implementation challenges and mitigate possible unintended consequences of open science practices.

To be fully effective, open science must be embraced globally, involving a profound shift in the global scientific culture.

Chapter 1: Global commitment to open science

Science for the future

Open science has the transformative power to reduce the existing inequalities in science, technology and innovation, hence to accelerate the progress towards the achievement of the Sustainable Development Goals and the fulfilment of the human right to science. But for open science to reach its full potential, it must be a truly global equitable phenomenon.

Science, technology and innovation (STI) are considered vitally important to respond to complex and interconnected environmental, social and economic challenges for the people and the planet. STI can be harnessed to provide solutions to improve human well-being, advance environmental sustainability and respect for the planet's biological and cultural diversity, foster sustainable social and economic development and promote democracy and peace. STI is critical for the achievement of the United Nations' 2030 Agenda for Sustainable Development and all of its 17 Sustainable Development Goals (SDGs; UN 2015).

Science is also a human right. The right to participate in and benefit from science and its advancements was set out in the Universal Declaration of Human Rights (UN 1948) and in particular in its Article 27.

All human activities in the 21st century are profoundly impacted, shaped, driven and enabled by STI. Yet, considerable gaps exist between and within nations in their abilities to harness the potential of STI for human well-being and environmental sustainability.

At the present time, science is produced and paid for unevenly around the world, with the G20 countries accounting for nine-tenths of research expenditure, researchers, publications and patents in 2018 according to the *UNESCO Science Report* (UNESCO 2021a). The tools and infrastructures used to conduct research are similarly unevenly distributed.

Access to scientific findings is haphazard, costly or both. Large fractions of scholarly literature are only available to paying readers, even in subjects relevant to global goals and global crises and even though the majority of research is publicly funded (UNESCO 2021a, Paic 2021). Results or underlying data and related scholarly resources are shared primarily at the initiative of the requesting researcher, with the decision to share often made by case by case by individual authors. Lack of clarity over intellectual property rights for published research also presents a hindrance to sharing or collaborating (see Box 1.3).

Science as presently conducted is created primarily within formal institutions. Despite the proliferation of digital communication tools and avenues, contributing to the scholarly conversation can be challenging even for experts without institutional affiliations, such as citizen scientists, participatory research communities and those who face age, economic or geographic barriers to institutional participation. The creation of recognized scientific data and knowledge is largely restricted to those who have existing connections and technical skills or tools.

Achieving SDGs and overcoming global challenges require more efficient, collaborative and inclusive science that can lead to innovative and sustainable solutions stemming not only from scientists but also from the whole of society. There is need to democratize science and the entire scientific process and to make it more accessible, equitable, transparent and inclusive.

Scientists and non-scientists from all over the world are taking action in this direction by increasingly embracing a paradigm shift in science: the transition to open science. While paths towards open science differ in different parts of the world, reflecting the specific STI situations and capacity, open science requires a profound change in the scientific culture shifting from:

- competition to collaboration;
- science as a product to science as a process; and
- science for the selected few to science for all.

Many joined UNESCO in developing the Recommendation on Open Science, the first international framework on open science (Box 1.1, UNESCO 2021b). This framework aims to reduce the technological and knowledge divides between and within countries, to make science more accessible, inclusive, transparent, more connected to society and to its needs. It contains the first universal definition of open science and creates a chance for the global community to work towards shared goals.

Box 1.1: UNESCO Recommendation on Open Science

The first international standard setting instrument on open science, the UNESCO Recommendation on Open Science, was unanimously adopted by 193 Member States in November 2021 at the 41st session of the UNESCO General Conference.

The Recommendation provides an internationally agreed definition and a set of shared values and guiding principles for open science. It also identifies a set of actions conducive to a fair and equitable operationalization of open science for all at the individual, institutional, national, regional and international levels.

The Recommendation calls Member States to:

- promote a shared understanding of open science,
- set out diverse paths to achieving open science,
- develop an enabling policy environment for open science,
- invest in infrastructure and activities that contribute to open science,
- invest in training, education, digital literacy and capacity-building to support open science,
- foster a culture of open science, supported by incentives that make it easier to use open science,
- promote innovative approaches for open science at all stages of the scientific process, and
- encourage international and multi-stakeholder cooperation in the context of open science to reduce gaps in technology and knowledge.

Member States committed to reporting on their progress in implementing open science every four years.

Central to the Recommendation is a set of pillars holding up a global open science system: open scientific knowledge, open science infrastructures, open engagement of societal actors and open dialogue with other knowledge systems, in combination with science communication. Broader than many previous conceptions of open science, these pillars structure an open approach not only for the availability of the results or end products of science but also in terms of the tools, perspectives and stakeholders involved during the creation and application of science.

Open practices are intended to be applied within all scientific disciplines and aspects of scholarly practices, including basic and applied sciences, natural and social sciences and the humanities.

Figure 1.1. Elements of open science. *(UNESCO 2021b)*

Future of Science

Open science serves to amplify access to knowledge by everyone for the advancement of science and society. It also strives to promote opportunities for innovation and participation in the co-creation of knowledge and distribution of the resulting benefits.

According to the internationally agreed definition in the 2021 UNESCO Recommendation, open science:

- increases scientific collaborations and sharing of information for the benefits of science and society;
- makes multilingual scientific knowledge openly available, accessible and reusable for everyone; and
- opens the processes of scientific knowledge creation, evaluation and communication to societal actors beyond the traditional scientific community.

The transformation from the conventionally 'closed' to open science requires a profound shift in the way science is produced, accessed, governed and used (Table 1.1).

Open Science

Open and equitable global science system	Open access to scientific knowledge	Open science infrastructures	Open engagement of societal actors	Open dialogue with other knowledge systems
An open science culture in an enabling policy environment with sustained resource commitments increases collaboration for the benefit of science and society.	All scholarly outputs are published in a fully open access outlet or posted in an open repository, with free, immediate readership rights.	Sustainable community-led open infrastructures, both physical and digital, are available to all, regardless of location, language or ability.	Multiple entry points enable engagement. External actors contribute to design, creation and application of scientific knowledge.	Diverse knowledge bases spark innovation and equitable decision-making, in a rights-based framework.
A culture of open science is fostered with effort to align incentives for open science. Investments are made in human resources, training, education, digital literacy and capacity building for open science.	Data, software and other outputs are FAIR and openly shared, linked with publication outputs.	Platforms permit usership for all. Digital architectures begin to facilitate use in different languages and accessibility needs.	Capacity for societal engagement is integrated into project design and institutional plans.	Capacity for ethical, open dialogue is integrated into planning and implementation at project and institutional levels.
Innovative approaches for open science are promoted at different stages of the scientific process	All scholarly outputs are made freely available to read, in a journal or an open repository, after an embargo of no more than 6 months.	Open infrastructures are available to those who having existing access or commit to specified partnerships.	Societal actors have a few, defined, points of contact with scientific processes.	Dialogue is built into policies, creating time, opportunities and incentives for dialogue.
International and multi-stakeholder cooperation is initiated with a view to reducing digital, technological and knowledge gaps.	Scholarly outputs are shared without clear licensing or copyright.	Infrastructure sharing is opportunistic.	Stakeholder engagement is opportunistic.	Dialogue is facilitated in one-off events, with uneven expertise.
There is no common understanding of open science and its benefits.	Scholarly outputs are not published or are published under restrictive copyright.	Digital gaps and subscription costs hinder the use of scientific infrastructures.	Science is separate from "outreach". Science communication is one-way, outwards.	Other topics or communities are research subjects or recipients of "outreach".

Closed Conventional Science

Table 1.1. DRAFT. Transformation to open science. *Adapted from SPARC and PLOS (2014), CC BY*

There are multiple actors and stakeholders involved in open science and the overall STI ecosystem. The collaborative and inclusive characteristics of open science allow new social actors to engage in scientific processes, including through citizen and participatory science. These actors have the freedom to participate fully in open science regardless of their nationality, ethnicity, gender, language, age, discipline, socio-economic background, funding basis and career stage or any other grounds. Each of them has a role to play in the operationalization of open science—as well as benefits to gain (Figure 1.2).

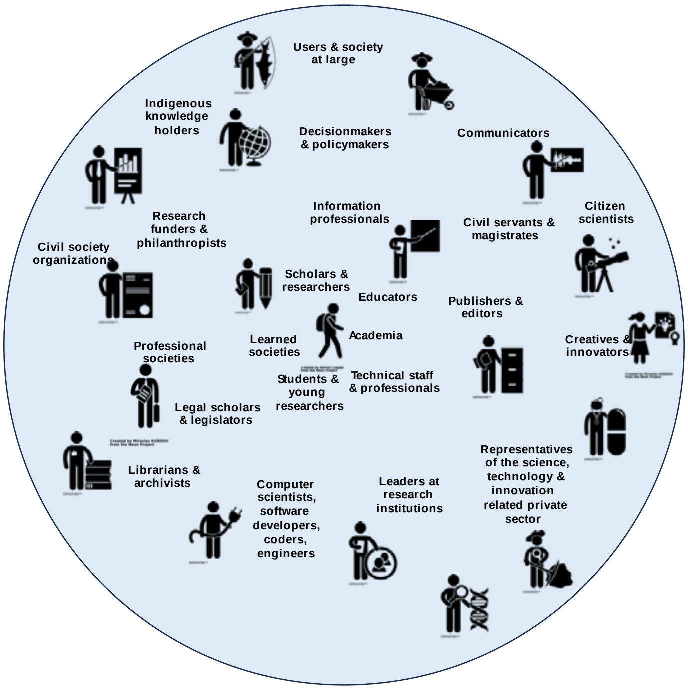


Figure 1.2. Examples of open science actors. *Icons: Gan Khoon Lay, Miroslav Kurdov, Adrien Coquet, Wynne Nafus Sayer, courtesy of The Noun Project, CC BY 3.0*

The benefits of open science range from cultural advancements, such as enhanced inclusion and trust in science, to practical gains, such as streamlined creation and reproducibility of scientific findings (Figure 1.3).

Working openly positively influences not only the investments in and outputs from science but also the process of science. More open, transparent, collaborative and inclusive scientific practices, coupled with more accessible and verifiable scientific knowledge subject to scrutiny and critique, create a more efficient enterprise that improves the quality, reproducibility and impact of science, and thereby the reliability of the evidence needed for robust decision-making and policy and increased trust in science.

Greater openness throughout the scientific process helps to maintain high quality and integrity of research as it facilitates review, replication and reproduction of scientific findings. Coupled with the rapid advancement in artificial intelligence (AI) techniques and tools, vast amounts of open scientific literature, data and information can be promptly discovered and analyzed, accelerating the pace of discovery but also its transparency and accessibility (Box 1.2).

Box 1.2: Adopting the values and principles of open science for ethical artificial intelligence (AI)

Modern technologies equip scientists to find, use, re-use, analyze, visualize and integrate knowledge at a faster pace than ever before. Advanced computing techniques, such as natural language processing (NLP) and machine learning permit rapid processing of extensive scientific literature and datasets. Machine learning and artificial intelligence (AI) tools enable fast and large-scale data collection, analyses, visualization and interactions. AI tools can also be used to cross-check open data and results, improving the reliability of research outputs. Advantages reach from data management and findabilty to enhanced verifiability, multilingualism and increased collaborations through AI-powered collaboration platforms.

However, access to these tools remains uneven, and there are important ethical considerations regarding their creation and application, including their responsible use, transparency and openness. The 2021 UNESCO Recommendation on the Ethics of Artificial Intelligence (UNESCO 2021c) sets the international norms and standards to ensure that AI technologies are used responsibly and transparently. In addition, transparent and ethical AI could be strengthened by adopting the values and principles of open science, including efforts towards ensuring access to ethical and responsible AI for all.

There are also environmental implications of using large datasets and intensive AI processing. The increased demand for bandwidth and server space to store and manipulate terabytes of data comes with an expanded carbon and energy footprint. In line with the 2017 UNESCO Recommendation on Science and Scientific Researchers (UNESCO 2017), scientists should be aware of the need to manage resources efficiently and sustainably, with due regard for the impact of science on future generations.

Greater access to scientific processes and outputs can improve the effectiveness and productivity of scientific systems by reducing duplication costs in collecting, creating, transferring and reusing data and scientific material, allowing more research from the same data. This greater access also increases the social impact of science by multiplying opportunities for local, national, regional and global participation in the research process as well as opportunities for wider circulation of scientific findings. Better access to research-derived knowledge can boost innovation and value creation by enabling actors outside the research community to find new areas of application.

The main benefits that researchers have personally experienced from making data available are collaboration and higher citation rates, with few noting tangible financial benefits (Van den Eynden et al. 2016). While there is lack of comparable data on actual use of open science outputs in a way that would allow identification of economic impacts (Fell 2019), benefits of open science further include opportunity for new scientific discoveries, enhanced cross-disciplinary co-operation, economic growth through synergies with intellectual property regimes and better opportunities for innovation (Box 1.3), increased resource efficiency, improved transparency and accountability regarding disbursement of public funds, better return on public investment, securing public support for research funding and increasing public trust in research in general (Paic 2021).

Box 1.3: Managing intellectual property in an open science context

Open science and intellectual property (IP) regimes share the same fundamental policy goal of promoting innovation for the social, scientific and economic development of everyone everywhere.

IP rules and frameworks can sometimes be complex to understand. Yet, they are important to many elements of open science, including in relation to the output of scientific research that may lead to academic articles or original databases which can be protected by copyright or lead to inventions that can be protected through patents and other forms of IP.

Open science and IP are not exclusionary regimes. They complement one another, as they operate on different levels depending on the desired outcomes for the parties concerned.

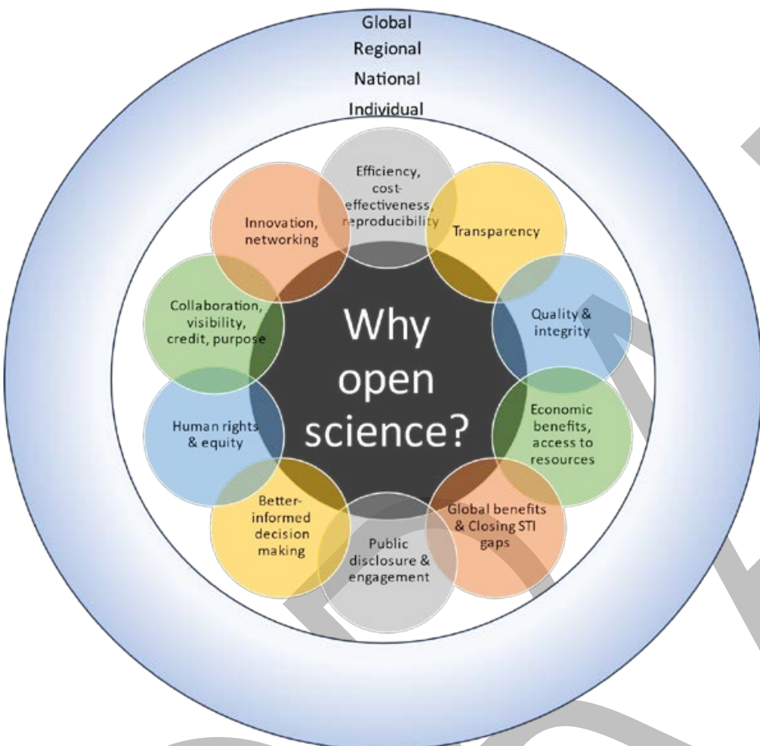
Innovation and creativity benefit from the rich access to existing information, knowledge and data. The IP system takes this "need for access" into account and internalizes many values that are also the basis for open science. For instance, both open science and IP management benefit from a well-defined scope of protection (for instance, ideas and raw data are not protected); the principle of territoriality for patents, and by extension, the ability to use patented technology not protected in a particular jurisdiction; the limited term of protection; and the difference between access and possibility of re-use (for example, disclosure obligation). In addition, limitations and exceptions may allow for certain non-commercial re-uses in the field of research.

Importantly, thanks to IP rights, researchers and inventors can freely determine who and on what terms third parties can gain access and re-use the results of their intellectual activities. These features guarantee that IP and open science can be used in harmony towards the same goals.

Open science relies on the exchange of information across communities of researchers and innovators to enhance and accelerate innovation. These models require a clear set of rules that enables information to flow and build upon. IP rights are at the very core of these models, allowing broad and enforceable sharing of results. For example, many open access initiatives, repositories or collaborative projects function on the basis of clear IP licensing frameworks. These models leverage input from a community in exchange for making the outputs broadly available.

There are no one-size fits all solutions in the field of promotion of science and technology. Ad-hoc and multilayered assessments are needed. IP rights are flexible enough to support granular and nuanced licensing schemes that underpin countless open science models (such as open repositories, patent pools and collaborative software development) and eventually be customized to also guarantee some sort of economic reward and/or control of commercial exploitations by third parties.

Contributed by Mahmoud Dif, Paulo Lanteri and Victor Owade (World Intellectual Property Organization)



Open science can also help address inequalities among regions. Open practices and tools can facilitate more inclusive science, and open assessment of scientific systems can support greater understanding of patterns in investment in and capacity for science.

The benefits of open science also include societal, education and governance benefits. Data on such benefits are not systematically measured nor readily available and are highly dependent on the open science actors considered.

Figure 1.3. DRAFT. Examples of the benefits of open science, relevant at multiple scales. *Adapted from National Open Science Cloud Initiative of the Republic of North Macedonia (https://www.nosci.mk/?page_id=26) and Pinnock (2019) CC-BY-SA 4.0*

Future Priorities and Pathways

Taking into account the specific challenges of scientists and other open science actors in different countries, and in particular in developing countries, will be critical to ensure that open science does not exacerbate but indeed reduces the digital, technological and knowledge divides existing between and within countries.

To ensure a global, equitable, fair and just transition to open science in line with the values of science as a global public good, due consideration must be given to the existing disciplinary and regional differences in open science perspectives.

The consultations held by UNESCO during the development of the 2021 UNESCO Recommendation on Open Science revealed regional differences in the level of understanding, capacities, infrastructures, policy environments, funding availabilities, incentives and priorities with regard to operationalization of open science and its different pillars and elements (Table 1.2; UNESCO 2020a,b,c). These differences need to be taken into account moving forward on the path to open science.

Region	Priorities
Western European and North American States	• Aligned incentives for open science, reviewing the current systems of scientific evaluation and rewards based on the principles of open science; • Innovative forms of collaboration, including with societal actors beyond the scientific community; • Respect for bibliodiversity; • Harmonization of data protection policies; and • Investment in shared and co-ordinated infrastructure to facilitate open science, taking into account regional and disciplinary specificities
Eastern European States	• Alignment of national initiatives on open science on the basis of good practices from other regions; and • Addressing the unintended consequences of transitioning to open science, such as high article processing charges for individual researchers or their research institutions, the publication of data and knowledge without proper quality control and the oversimplification of science.
Latin American and Caribbean States	• Development of a comprehensive and globally co-ordinated approach to open science that addresses the structural needs of emerging and developing economies and ensures that the benefits of open science are fairly shared among all nations, building on their long history of open access publishing; • Sustainable access to infrastructure and compatibility with national priorities, regulating the commercialization of open data; • Strong multilingual engagement; and • Fair and equitable inclusion of historically marginalized knowledge-holders.
Asian and Pacific States	• Development of a common vision of open science; • A coherent regional policy framework and practical guidelines on different elements, practices and policies in relation to open science; and • Strengthened regional co-operation, including through the establishment of a regional platform for open science accompanied by regional capacity-building programmes.
African States	• Investments in connectivity and infrastructures, such as computer hardware and software; • Development of institutional capacity for science, technology and innovation and an enabling policy environment; • More efficient scientific collaboration and networking, including the sharing and scaling up of good practices in regional collaboration, in order to generate new knowledge and attract more substantial research funds at the regional level.
Arab States	• A cultural shift from a competitive to collaborative mode for the practice of science; • Development of policies and the technical capacity to manage intellectual property rights in relation to open science; • Establishment of infrastructure and regional repositories; • Greater awareness of open science as a key enabler of innovation and prosperity; • Strengthening of research systems to ensure research output is accessible, of quality and subject to a fair evaluation; and • Greater transparency and stronger links between research and societal impact.

Table 1.2. Regional priorities for the transition to open science. Information: UNESCO 2020(b)

Chapter 2: Status and trends of open science: Global overview and regional trends

Summary

While there is clear evidence of growth in open science practices worldwide, there is significant variation in the interpretation, adoption and data availability for open science metrics.

Progress in each of the elements of open science as defined in the 2021 UNESCO Recommendation on Open Science is essential for the transition to a global, equitable system of open science. Yet at present the intensity of practice of and investment in these different elements varies substantially.

Open engagement of societal actors does not yet feature among mainstream practices considered in open science activities, although the last decades have seen a rise of interest in scientific projects incorporating societal engagement. Similarly, assessing knowledge flows and exchanges between different knowledge systems as well as contributions from conventionally marginalized scholars is still lagging.

Open access to publications is a commonly assessed metric, with a third of all scholarly literature currently under some type of open access. This share has been rapidly growing in recent decades, with half of the articles published in 2021 under some type of open access. However, regional and disciplinary differences exist in open access approaches.

Practices related to sharing open research data and software/code are also expanding but monitoring in these areas is in its early stages. Open science hardware is also rapidly evolving. With the growth in the number of open science repositories and other open infrastructures, the focus is now shifting to interoperability and sustainability of shared services.

More comprehensive assessments that consider the values, as well as all actors and aspects of open science are needed for a multicultural and globally representative system of monitoring. Now is an opportune moment to transition to a more people-focused and purpose-based framework of assessment in the context of open science.

Chapter 2: Status and trends of open science: Global overview and regional trends

Building the pillars of openness to advance values and principles of open science

Open science is not an end in itself, but a means towards fairer, more equitable, diverse and inclusive research systems that are better geared towards the production, dissemination and use of scientific knowledge that helps address societal challenges with benefits for all. It is therefore important to understand and monitor the degree of openness not only of the outputs of science but also across all the pillars of open science and across all the stages of the scientific cycle. A combination of qualitative and quantitative assessments, as well as innovations in understanding and managing change, will be needed for a monitoring system for open science that itself adheres to the values and principles of open science.

The growing interest in open science—and the requirement to monitor progress towards the implementation of the 2021 UNESCO Recommendation on Open Science—creates new demands for assessment of the status, trends and impacts of open science practices. Progress in each of the elements of open science as defined in the 2021 UNESCO Recommendation on Open Science is essential for the transition to a global, equitable system of open science.

To date, there is no comprehensive global monitoring framework for open science. The interpretation, extent of use and data availability for key metrics of open science vary widely around the world. In some regions, open science is a relatively new phenomenon, whereas other regions are building on decades of experience in opening various aspects of the scientific process.

For some elements of open science, assessing changes and measuring progress can be aided by the use of indicators and data sources. In addition to being accurate, efficient and reproducible across regions and disciplines, these indicators and sources need to respect the core values and principles of open science as identified in the 2021 UNESCO Recommendation on Open Science.

However, there is a real risk that assessments of specific quantifiable open science practices or outputs may distract from the overall need to monitor a comprehensive transformation to open science and its impacts on the science, technology and innovation (STI) ecosystem and on society.

Hence, the aspects of open science that do not lend themselves to numerical indicators must not be ignored (Box 2.1). By contrast to a system of rankings that lends itself to opportunistic behaviours and unbalanced competition, open science needs a system fostering analytical insights which can lead to a scientifically sound understanding of effective actions in specific contexts, to identify choices favouring the widespread adoption of truly transformative open science.

Box 2.1: Monitoring openness and opening monitoring

Monitoring open science raises fundamental questions: What culture of monitoring is desirable to promote open science? Who is involved in this monitoring? How can the activity of monitoring itself be opened and used as a tool for engagement through participatory, transparent multistakeholder approaches?

To take full advantage of the adoption of the 2021 UNESCO Recommendation on Open Science, transparent and representative monitoring must be put in place to drive and support the intended change, and to identify effective actions and priority gaps.

A coherent approach to monitoring…

Member States are required to report back on their implementation of the 2021 UNESCO Recommendation on Open Science every four years, beginning in 2025. UNESCO with its partners and the support of a broad international open science community is working towards the development of a global Open Science Monitoring Framework, building upon existing resources and identifying key gaps in the information needed to support decision-making. With a global perspective, this exercise will help identify new and existing monitoring criteria, strengthen existing metrics and monitoring tools and develop new monitoring approaches as required.

According to the 2021 UNESCO Recommendation on Open Science, the monitoring of open science should be explicitly kept under public oversight, including the scientific community, and whenever possible supported by open non-proprietary and transparent infrastructures.

… leaving no one behind

Considering science as a global public good, it is important not to reduce open science to a few standardized metrics monitored in a top-down approach. Masking variations, particularly those between and within countries, may undermine the transition to a genuinely open science, accessible to all and with benefits for all. Inclusion of scholarly outputs pertinent for all disciplines and practices of science is essential, given the existence of a multiplicity of formats, languages and modes of distribution of scientific knowledge.

…..aware of the risks of the 'streetlight' effect

Indicators can be considered in terms of their technical validity as well as their political value and value as steering instruments to draw—or distract—attention and resources. The variety of open science practices does not easily lend itself to assignment of overarching indicators, which might engender the risk of certain indicators being mistakenly interpreted as standards of good practices. The risk of "over-standardization" is twofold. Firstly, there may be overestimation and thus reinforcement of "mainstream" open science practices against potentially interesting, yet less widespread ones. Secondly, this could lead governments and institutions to disregard less diffused practices with a consequent loss of diversity and thus decrease of the potential of open science.

…..conscious of the major gaps

Multiple aspects of open science are not yet assessed using standardized metrics or indicators. Major monitoring gaps include ways to assess trends in the openness of scientific culture, open engagement with societal actors and dialogue with other knowledge systems. The development of monitoring systems, potentially including metrics and indicators, for these two pillars of open science is a priority for tracking the implementation of the 2021 UNESCO Recommendation on Open Science.

Open engagement of societal actors

Enabling open engagement of societal actors

Open engagement of societal actors is an essential element of open science, as defined in the 2021 UNESCO Recommendation on Open Science. Multiple expert and non-expert publics are, or could be, engaged in science through co-creation, communication and consumption of scientific knowledge. Here, the term 'engagement' is used in its broadest sense, with practices ranging from participatory and citizen science to scientific volunteering, science communication, university extension, crowdfunding and crowdsourcing, among others.

The involvement of various publics can occur in or throughout multiple stages of the scientific process, with three major aspects or phases of engagement:

- public understanding of science (typically framed as outreach from a scientific expert to others);
- public creation of scientific knowledge (creation or co-creation, co-design, scientific volunteering, participatory science, citizen science), which may or may not be led by communities outside of research institutions; and
- public involvement in the management of science (co-design of research projects or research agenda, prioritization of research themes).

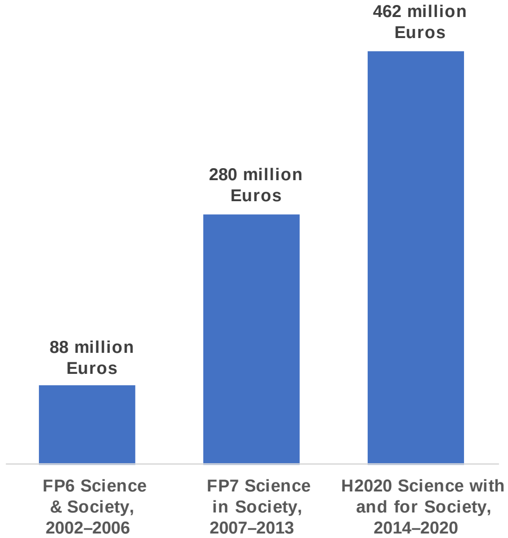
Open access to technical scientific content may not by itself substantively increase engagement. Transformation to a scientific system engaged with society requires both practical actions and systemic, cultural shifts grounded in mutual respect. Facilitating and equipping such efforts involves the commitment of resources, including time and financial investment. It also requires assessment and monitoring of engagement practices, processes and outputs, as well as their impacts on the scientific process and broader society.

Assessing trends in open engagement

Open engagement of societal actors does not yet feature among mainstream factors considered in research evaluations, for individuals or institutions. Many engagement activities, even within research institutions, are neither formal nor formally identified and reported. A large variety of engagement activities occur through many different channels, including through informal interactions. In this context, it is difficult to conceive a standardized monitoring framework and normalized ways of tracking progress.

Broadly speaking, the last decades have seen a rise of interest in scientific projects incorporating societal engagement. There has been an increase in funding directed towards societal engagement in science (Figure 2.1); a rise in the recorded numbers of citizens engaging in scientific projects or producing data (Figure 2.2); a rise in the number of scientific publications mentioning citizen science (Figure 2.3); and growth in the number of engagement projects available for participation. As examples, volunteers made 2.4 million data contributions in 2022 to the 1,500 projects on the Scistarter portal, and over two million registered volunteers have contributed to over 700 million classifications on the Zooniverse citizen science platform as of 2023. The Sensor.Community outcompetes every official measurement station in terms of the number of air quality data points at a given data standard, using low-cost sensors operated by volunteers without external funding.[1]

[1] See: https://maps.sensor.community/



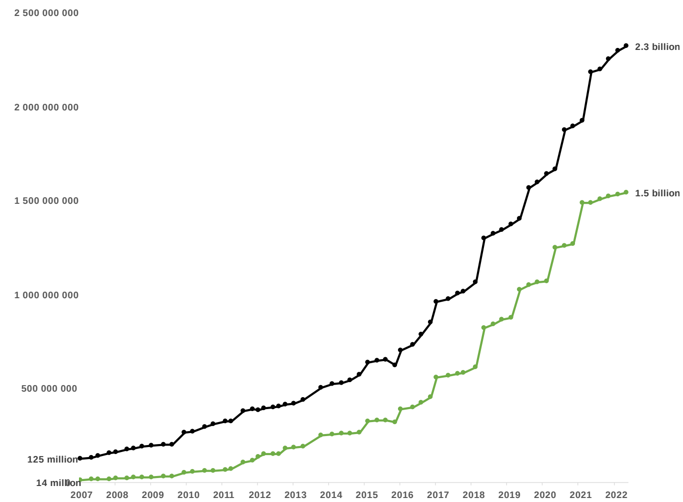


Figure 2.1. Research funding directed towards societal engagement by the European Commission, 2006–2020.
Data source: European Commission (2020)

Figure 2.2. Number of species occurrence records registered on the Global Biodiversity Information Facility, total and derived from citizen science efforts, 2007–2022. By 2018, half of GBIF records were citizen science observations, although with lower diversity at only 20% of the genera observed by professional scientists. *Data source: John Waller, GBIF*

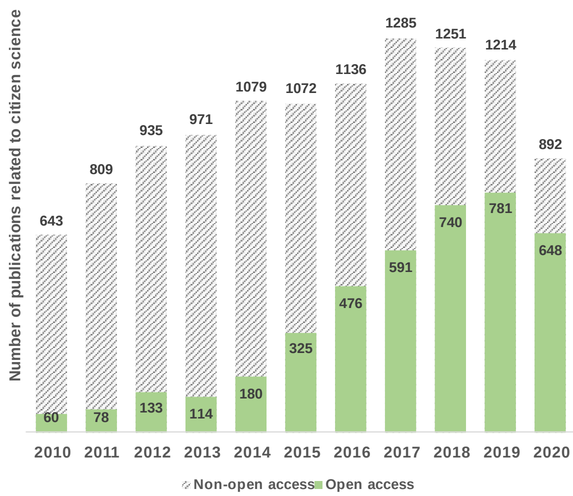


Figure 2.3. Number of publications related to citizen science overall and under open access, 2010–2020. In 2019, 39.1% of citizen science publications were open access. *Data derived from the Scopus (Elsevier) database. Data source: Álvarez (2020)*

Engagement can be led or initiated within or outside of traditional institutions. For example, there is a long and powerful tradition in Latin America of university extension, i.e. educational activities for persons who are generally not full-time students, which has discussed in detail the relations between university and society and has reached a significant level of conceptual and practical development (CLACSO 2020).

However, with the lack of a standardized definition of societal engagement and in the absence of a common monitoring framework, it is quite difficult today to quantify the full breath and impacts of open engagement of societal actors on the advancement of science and the benefits to society.

Simply quantifying the number of projects that claim to involve societal engagement will not identify meaningful change in the scope or quality of such efforts, nor of their impact. Using the partly available numerical proxies—such as the number of citizen science projects, the number of funded projects incorporating societal engagement or the amount of funding directed towards such projects—bears the risk of suggesting that an increase in numbers reflects growth in terms of effective engagement practices and outcomes.

Furthermore, because most of these indicators refer to citizen science projects, there is also a risk of perpetuating an assumption that open engagement is wholly represented by citizen science. That said, the progress made with monitoring the implementation and impacts of citizen science, which includes attention to process indicators, may serve as a useful example for impact assessments of other societal engagement (Wehn et al. 2021).

Finally, reliance on metrics of 'standard' scholarly outputs (data and/or publications) for non-scholarly endeavours, or for scientific practices that may not prioritize the production of those outputs, should be treated and interpreted with caution. While there is value in having some indication of the degree of collaboration with non-academic actors in the formal literature because it illustrates temporal and regional trends, measuring the number of publications does not assess the quality of engagement and the values represented.

Whereas mainstream science monitoring frameworks are data-centric, there is opportunity with open science monitoring for a more people-focused and purpose-based framework of assessment (Box 2.2).

Box 2.2. Moving to a people-centred monitoring framework

Current mainstream science monitoring frameworks are predominantly data-centric and mainly focused on scientific inputs and outputs. While there is value in numerical indicators, there is opportunity with open science for a more people-focused and purpose-based framework of assessment.

There is a need to shift the attention from quantity and rankings to the values and impacts of science, the process of doing science and the people who are doing, engaging with and/or benefiting from science. In this context, the diversity in approaches is essential, and the use of quantitative proxies may not always be possible or appropriate.

Working with the values and principles of open science and sharing tools associated with the aims of the 2021 UNESCO Recommendation on Open Science creates an opportunity for innovative methods of monitoring engagement of societal actors in science. A number of proposed proxies could be used to assess, in part, trends in societal engagement, such as:

- actions and initiatives taken by countries and institutions to support or implement open engagement of societal actors (e.g. specific policy instruments; strategic frameworks or action plans as well as processes used to build engagement or engagement skills; community research institutes or community publishers in collaboration with academia, with consideration of the type of entity leading the initiative);
- actions and initiatives taken by countries and institutions to recognize and reward activities involving societal engagement, with attention to who is initiating and leading the engagement;
- platforms and entities promoting societal engagement, including institution-led and community-led engagement as well as trends among disciplines;
- level of funding allocated to scientific practices involving open engagement of societal actors;
- level of investment in increasing the capacity of societal actors to create scholarly knowledge;
- number of people engaged in open science, along with basic demographics.

Innovative efforts are already underway. The Ibero-American Manual of Linkage Indicators of the University with the Socioeconomic Environment, or Valencia Manual (RICYT & OCTS-OEI 2017), was designed to assess the engagement of universities with societal actors outside of the academic institution. The manual sets out how to collect this information in a regular, standardized process, working with institutions at three levels. This approach examines institutions and considers only engagement activities led by or hosted within universities.

The International Union for the Conservation of Nature is developing a measurement and reporting system based on indicators of management effectiveness in protected areas for the purposes of biodiversity conservation. Rather than a uniform system, users adjusted and elaborated the core tools as required to build national relevance.

The OECD Water Governance Principles present an example of how collaboratively agreed principles for governments (OECD 2015) can be accompanied by a multi-stakeholder based monitoring framework (OECD 2018) which itself has been built using collaborative approaches. This framework is implemented using multi-stakeholder approaches within countries to take stock of progress towards the various principles.

Demonstrating the impacts on science: the case of the SDGs

Another way of monitoring open engagement is by assessing the impacts of open engagement of societal actors on knowledge generation for finding solutions to pressing societal challenges from local to global levels.

For example, the United Nations has recognized citizen science as a potential source of data that may contribute to the achievement of the UN Sustainable Development Goals (SDGs) of the *Agenda 2030* (e.g. UN 2018). Through a systematic review of the metadata and work plans of SDG indicators, Fraisl et al. (2020) showed that citizen science projects have already been contributing to the monitoring of at least five SDG indicators: SDG 9.1.1, 14.1.1, 15.1.2, 15.4.1 and 15.5.1. They show that greatest contributions of citizen science (current and potential) to the SDG indicator framework could be in SDG 15 Life on Land (64%); SDG 11 Sustainable Cities and Communities (60%); SDG 3 Good Health and Wellbeing (56%); and SDG 6 Clean Water and Sanitation (55%), including 76 indicators, which, together, equates to around 33% of all the SDG indicators (Fraisl et al. 2020; Figure 2.4).

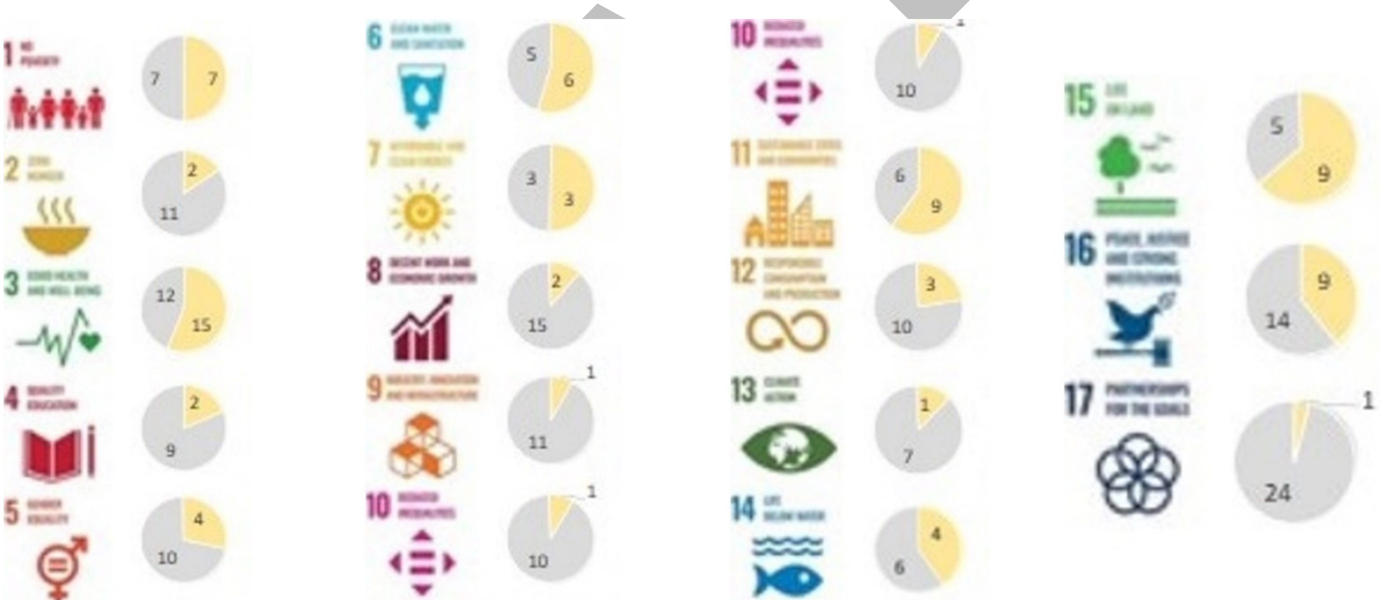


Figure 2.4. DRAFT. The indicators for each Sustainable Development Goal where citizen science projects could contribute (in yellow) or where there is no alignment (grey). *Adapted from Fraisl et al. (2020)*

Open dialogue with other knowledge systems

Promoting inclusiveness and diversity of knowledge holders and systems

Open dialogue between different knowledge holders and across knowledge systems is an essential element of open science, as defined in the 2021 UNESCO Recommendation on Open Science. The communities involved in this dialogue are diverse, ranging from traditionally marginalized scholars and hard to reach communities, to traditional and Indigenous knowledge holders.

Enhanced dialogue among scientists and knowledge holders beyond the traditional scientific community can enhance inter-relationships and complementarities between diverse epistemologies and advance knowledge-based solutions best fitted for specific local environments and communities.

There is increasing recognition that broader engagement and dialogue are essential for a science-based approach to meeting the SDGs and tackling global challenges, such as the climate and biodiversity crises. Both the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) are creating mechanisms for broader knowledge input to their science-based analyses and reporting, including inputs from Indigenous Peoples and local communities.

From a policy and institutional management perspective, dialogue across knowledge systems—as well as monitoring thereof—is often viewed as separate from the work of research-performing organizations. Yet assessing knowledge flows and exchanges between different knowledge systems as well as contributions from conventionally marginalized scholars will be critical for our understanding of the impacts of open dialogue on the advancement of science in line with the values and principles of open science.

Understanding openness in different knowledge systems to track desired outcomes

For open science to fully reach its potential, it is critical to assess the impacts of openness and open science practices on all knowledge holders to ensure that it does not repeat the mistakes of the conventional 'closed' science and that it does not exacerbate or amplify disparities in knowledge production and circulation.

Engaging with other knowledge systems requires a broader understanding of what that knowledge is, how it is created and how it is shared among different cultures and communities. Open access to knowledge may not always be the desired result of an open dialogue across knowledge systems. According to the Open and Collaborative Science in Development Manifesto (OCSDNet 2017) and in line with the exceptions to openness identified in the 2021 UNESCO Recommendation on Open Science, the degree of openness of knowledge produced from research is dependent on the kinds of research being performed, who drives the research agenda and, importantly, for whom the research is being performed. Thus, openness is situated and highly conditional on the conditions of knowledge production (Chan et al. 2019).

Several other factors need to be taken into account when engaging in and monitoring open dialogue with different knowledge holders and across different knowledge systems (Figures 2.5 & 2.6). Any assessment or monitoring of open dialogue will need to be done taking into account these principles and the values of open science as identified in the 2021 UNESCO Recommendation on Open Science.

Figure 2.5. Elements of the research cycle (inner), open science initiatives (middle) and open and collaborative principles defined in the Open and Collaborative Science in Development Manifesto. *Graphic: OCSDNet (2017)*

Figure 2.6. The CARE Principles define Collective benefit, Authority to control, Responsibility and Ethics and their relationship to engagement with and for secondary use of Indigenous data. Graphic: Research Data Alliance Interest Group (2019)

Assessing the spectrum of engagement and dialogue

The use of quantitative indicators and proxies to monitor open engagement and dialogue is currently limited and may not be the most appropriate way to reflect the diversity of approaches that can contribute to open dialogue.

Measurement based on scientific articles, including attempts to identify those articles co-authored with or benefiting from the knowledge of marginalized scholars, Indigenous Peoples and other communities, including vulnerable and hard to reach communities and people outside of the academic mainstream, is a challenging task and can only reflect a part of the desired dialogue and the resulting impacts. At present, there is no systematic way to assess whether knowledge or a related output is co-created on an equitable footing.

Alternative approaches are necessary in this regard. An approach is to assess the type and/or quality of engagement. In the particular context of engagement with Indigenous knowledge holders, the spectrum of engagement can range from no engagement to full Indigenous engagement centred in Indigenous value systems with community members having authority over the research process (Figure 2.7). Taking the case of climate-related research, the majority (87%) of global climate studies published between 1995 and 2016 relating to Indigenous populations and/or Indigenous knowledge and analyzed by David-Chavez and Gavin (2018) according to this scale were found to "practice an extractive model in which outside researchers use Indigenous knowledge systems with minimal participation or decision-making authority from communities who hold them".

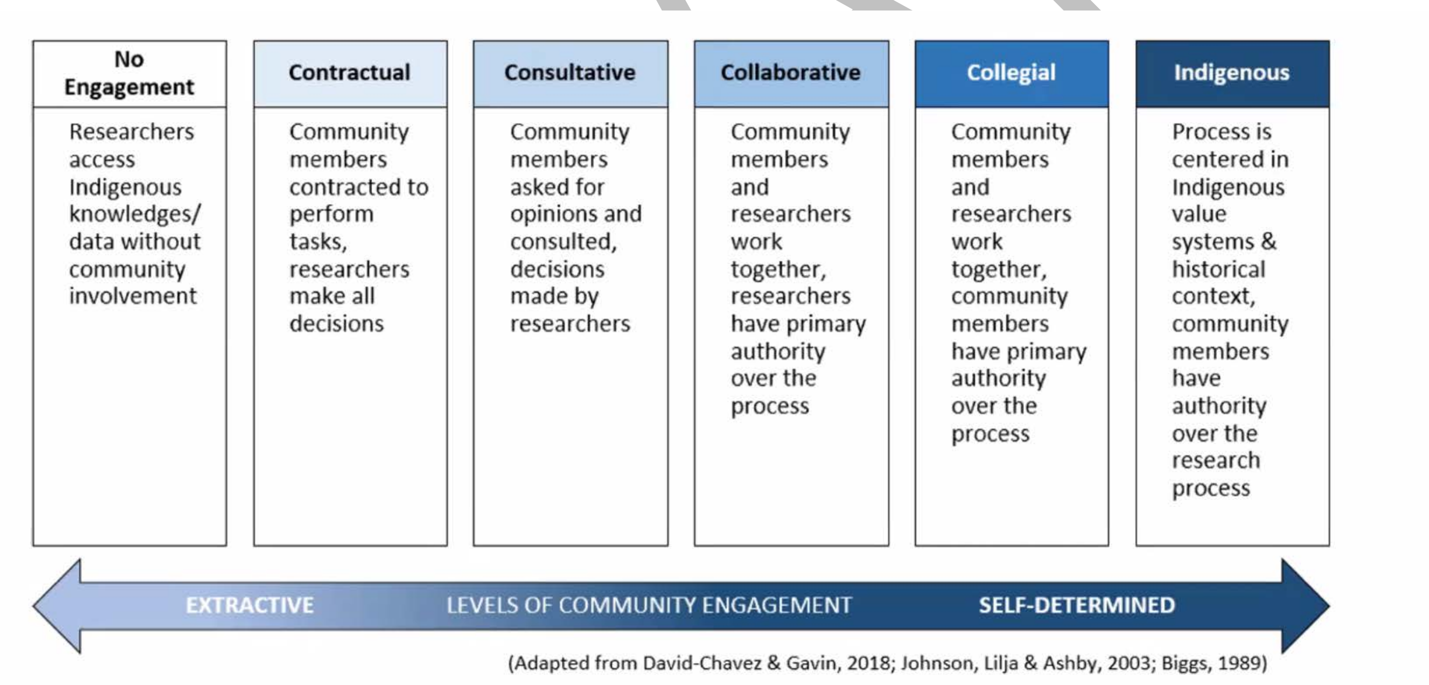


Figure 2.7. Spectrum of engagement in scientific research. *David-Chavez (2022), adapted from David-Chavez & Gavin (2018), Johnson et al. (2003) and Biggs (1989)*

Another approach is to track trends in the development and implementation of policies and practices, including funding that facilitate or require dialogue across knowledge systems.

As an example, Aotearoa New Zealand is beginning to monitor the number of Māori researchers and the amount of funding directed towards Māori principal investigators. The National Research Information System in New Zealand now tracks Māori researchers and Māori research processes.

Efforts to develop indicators useful to assess and support open dialogue might consider:

- transparency of Indigenous rights and interests in datasets;
- transparency around access to funding for Indigenous Peoples and other knowledge systems;
- policies promoting CARE Principles;
- policies requiring disclosure of Indigenous Peoples' rights, interests or provenance; and/or
- presence of frameworks for free, prior and informed consent or other constructive mechanisms by which Indigenous Peoples opt to engage or not engage in certain forms of research and data sharing;
- presence of frameworks to acknowledge origin of knowledge and to acknowledge ownership, including regulation of commercial and/or proprietary use of collectively produced knowledge;
- presence of funding schemes and/or incentives that equitably reward the different actors in knowledge production and sharing.

Open scientific knowledge

Based on the 2021 UNESCO Recommendation on Open Science, open scientific knowledge refers to open access to scientific publications, research data and metadata, open educational resources, software, and source code and hardware that are available in the public domain or under copyright and licensed under an open license that allows access, re-use, repurpose, adaptation and distribution under specific conditions, provided to all actors immediately or as quickly as possible regardless of location, nationality, race, age, gender, income, socio-economic circumstances, career stage, discipline, language, religion, disability, ethnicity or migratory status or any other grounds, and free of charge. It also refers to the possibility of opening research methodologies and evaluation processes.

Open scholarly literature

The most common metric used to monitor open science today is the extent of open access to scientific publications.

Only a third of all scholarly literature is currently under some type of open access, even though a growing proportion of scholarly literature is available free to readers, under multiple mechanisms (Box 2.3). The Directory of Open Access Journals (DOAJ), which hosts a community-curated list of open access journals, contains more than 19,000 open access journals as of May 2023, growing from 300 open access journals when it was launched in 2003.

The extent of open access publications varies in the different regions, disciplines and for different research subjects. However, a substantial portion of scholarly literature still remains behind paywalls or is made available to readers by creating price barriers for authors or authoring institutions.

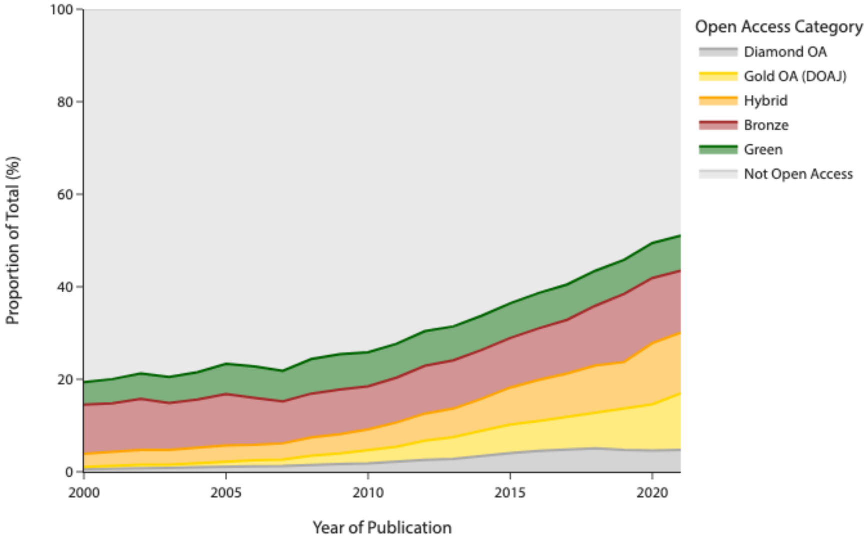


Figure 2.8. Share of scientific articles by access type in their year of publication, 2000–2021. *Categories based on Paic (2021). Data provided by the Curtin Open Knowledge Initiative (COKI) from a dataset which combines OpenAlex, Unpaywall, the Research Organisations Registry and Crossref*

The share of scientific publications in open access has been rapidly growing in recent decades, with half of the articles published in 2021 under some type of open access (**Figure 2.8**). About 42% of all indexed scholarly articles over the past decade (2012–2021) are now openly available, up from 24% of articles published during 2002–2011.The categories of open access are constantly evolving. In 2020, Diamond OA journals, with no fees for readers or for authors, composed 69% of the journals in the Directory of Open Access Journals but published only 35% of the articles (Crawford 2021). Between 2017 and 2019, 17,000 to 29,000 Diamond OA journals published 8% to 9% of all scholarly journal articles and 45% of open access articles (Bosman et al. 2021).

Box 2.3: What is open access to scientific publications?

Open access (OA) research outputs are commonly understood as scientific outputs that are available online to read and reuse without charges. Under the pillar of open scientific knowledge, the 2021 UNESCO Recommendation on Open Science defines open scientific publications (including, among others, peer-reviewed journal articles and books, research reports and conference papers) that may be disseminated by publishers on open access online publishing platforms and/or deposited and made immediately accessible in open online repositories upon publication, that are supported and maintained by an academic institution, scholarly society, government agency or other well established not-for-profit organization devoted to common good that enables open access, unrestricted distribution, interoperability and long-term digital preservation and archiving.

There are multiple approaches to open access to scientific publications, making it important to consider when and how a scientific publication is made open access. For instance, access may not be granted immediately: an embargo period of varied duration is used by some publishers and in certain contexts. In addition, corporate, non-profit, society, academic and other publishers use a variety of models to meet their income needs and publishing service costs. Some journals charge an article processing charge (APC) to authors of scholarly articles during the publication process, shifting the burden of journal production costs (such as editing, peer review, hosting, archiving and preservation) to authors from readers. This fee may be paid by the author, the author's institution or their research funder. Unfortunately, high and growing APCs are causes of inequality for the scientific communities around the world, particularly for authors from developing countries or less-funded research fields or institutions which can find themselves thus excluded from open access publishing. APCs are therefore currently one of the most prominent unintended negative consequences of open science.

In this context, a range of categories exist to describe the exact type of open access (summarized by Paic 2021):

- *Diamond:* Article published in an open access (only) journal without an article processing charge; in other words, the publication is immediately available free of charge for the author(s) and for the reader(s).
- *Gold:* Article published in an open access (only) journal that includes article processing charges, is part of a read and publish subscription or there is insufficient information to confirm that there are no author side charges to cover the cost of publishing.
- *Green:* Pay-to-access articles with an existing free copy in an open repository.
- *Hybrid:* Free to read articles under an open license in a pay-to-access journal.
- *Bronze:* Free to read on the publisher's website, but with no identifiable license or a license other than a Creative Commons license.

Nearly all (95%) of Latin American OA journals use the Diamond model, whereas a little over half of African and Western European OA journals are Diamond OA (Bosman et al. 2021). The same trends appear when examining open access articles by publication type (Figure 2.9). Nearly 40% of the indexed openly available articles published in the last decade by authors in the Latin American and Caribbean region were published under the Diamond model. By contrast, only 8% of OA articles are published using the Diamond model by authors in Western Europe and North America. The largest proportion of fee-based open access publishing (Gold model) is seen in Africa.

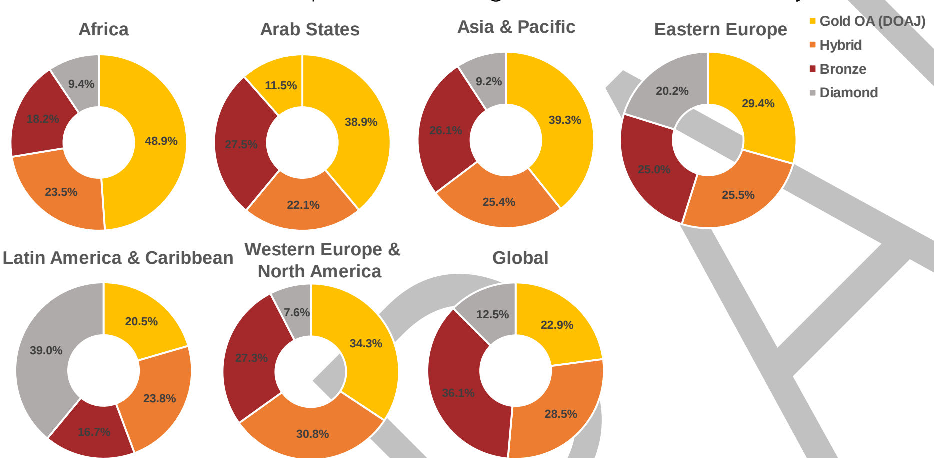


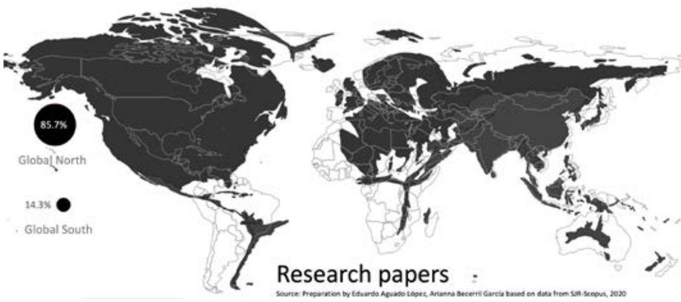
Figure 2.9. Share of articles, published between 2012 and 2021, under open access by category of open access (Box 2.3). *Data provided by the Curtin Open Knowledge Initiative (COKI) from a dataset which combines OpenAlex, Unpaywall, the Research Organisations Registry and Crossref*

Diversity of languages in scholarly publishing is an important aspect of open science and linguistic diversity in scholarly publishing may serve as one indicator of openness. According to the Curtin Open Knowledge Initiative, for 2020 publications registered with Crossref digital object identifiers (DOIs), over 85% are in English, followed by German (2.9%), Portuguese (2.2%), Spanish (2.0%) and Bahasa Indonesian (1.3%). These numbers are weakened by not including information on articles with other registration agencies, particularly relevant for Chinese but also other East Asian languages in countries with their own registration agencies.

Diamond OA models appear to dominate the landscape for fully open access journals published in non-English languages (COKI 2022). Between 2020 and 2022, 21% of English-language articles in DOAJ journals were in journals without APCs, while this percentage was 86% for articles in languages other than English (COKI 2022).

Regional differences exist in the extent of open access publications. It is important to note that different countries and regions, namely from the Global South, are under-represented in the commonly used literature databases, such as Scopus and Web of Science. Using those mainstream metrics, the scale and impact of scholarly output from these countries and regions may be vastly underestimated (Figure 2.10).

A)



B)

Figure 2.10. (A) Weighted cartogram of Scopus-indexed publications by region, 2020. (B) Co-authorship in Diamond open access journals by region, 2022. *Source: Eduardo Aguado López and Arianna Becerril Garcia using data from (A) SJR-Scopus and (B) Redalyc*

Different scientific fields and disciplines present a wide variety of open access publication practices. The share of free-to-read publications from the past decade indexed in the OpenAlex database ranges from 21% in history to 52.6% in biological sciences (**Figure 2.11**). The proportions of openly shared articles in the fields of biology, economics, environmental sciences, geography, mathematics, medicine, philosophy and sociology exceed the average for scientific publishing overall.

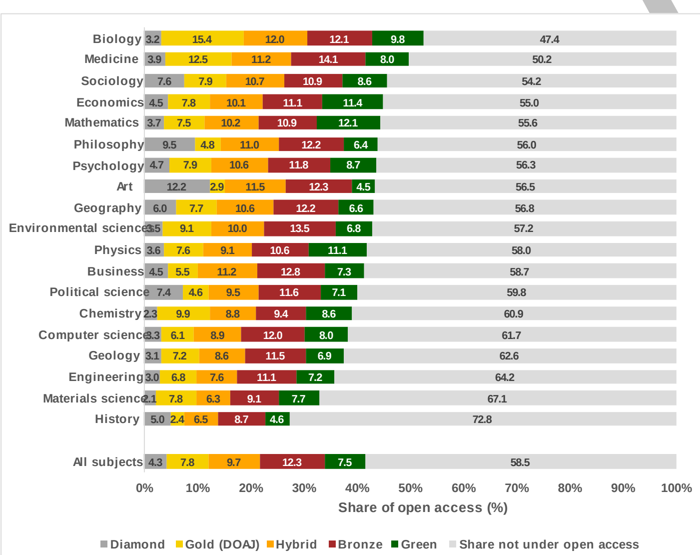
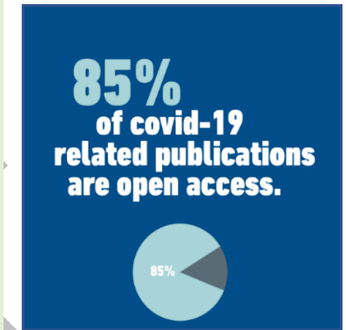


Figure 2.11. Share of publications by access type and by discipline, 2012–2021. The overall value for all disciplines combined is shown in the bottom row. Disciplines are defined using the OpenAlex Level0 concepts. *Data provided by the Curtin Open Knowledge Initiative (COKI) from a dataset which combines OpenAlex, Unpaywall, the Research Organisations Registry and Crossref*

Different subject areas are differently represented in open access publications. The extent of open access varies by subject, with COVID-19 related publications presenting one of the best open access practices (**Box 2.4**).

Box 2.4. The Covid-19 pandemic changed the global scientific publishing landscape



The Covid-19 pandemic has shown that the scientific community is able to come together and beat paywalls in order to share science to urgently overcome a global crisis. Some 85% of COVID-19 related articles are available in open access, in sharp contrast to under 40% of scientific articles overall, based on the Dimensions database.

Several institutions created openly accessible databases to allow users to find relevant articles, such as the global research database created by the World Health Organization[2] or LitCOVID created by the National Library of Medicine of the US National Institutes of Health. Major publishers also released related content. Examples include Elsevier and Springer Nature, each of which enabled free access to more than 60,000 research publications.

The longevity of these initiatives is unknown. In many cases, publishers provided selected articles for free reading without applying an open license, theoretically allowing them to reinstate a paywall at any time.

Unfortunately, this is not the case for many other subjects. Taking the example of the SDGs, broadly half (50.8%) of all SDG-related articles indexed in OpenAlex for the years 2010 to 2020 are currently available in open access (Figure 2.12), ranging between 38.2% (SDG 7 on affordable and clean energy) and 61.4% (SDG 3 on good health and wellbeing).

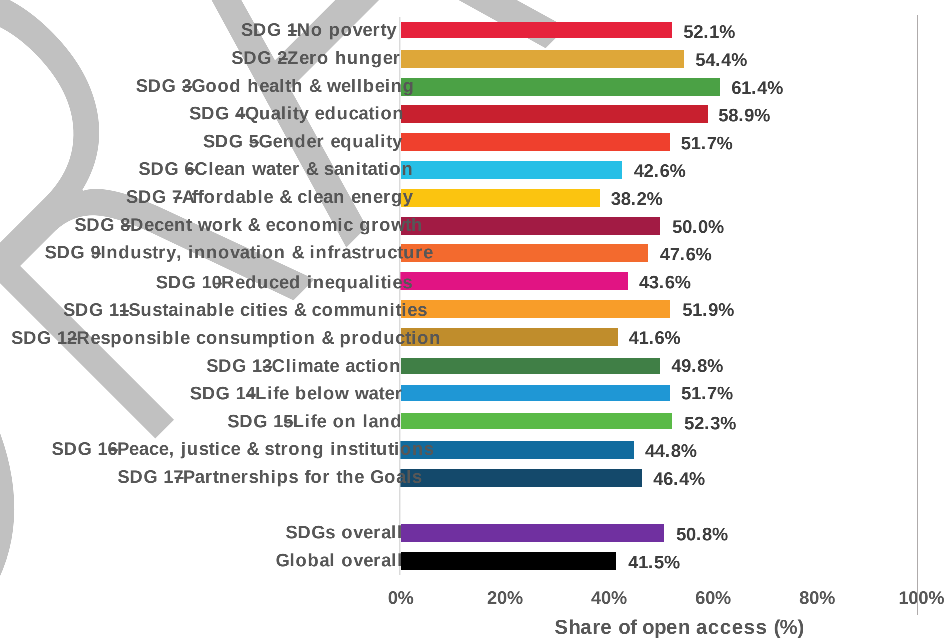


Figure 2.12. Share (%) of SDG-related scientific articles in open access, 2012–2021. The bottom black bar shows the share of all articles in open access. *Data provided by the Curtin Open Knowledge Initiative (COKI) from a dataset which combines OpenAlex, Unpaywall, the Research Organisations Registry and Crossref*

[2] See: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/global-research-on-novel-coronavirus-2019-ncov

Open research data

Sharing of open research data is a growing practice with new requirements and tools, including community principles. According to the 2021 UNESCO Recommendation on Open Science, open research data include, among others, digital and analogue data, both raw and processed, and the accompanying metadata, as well as numerical scores, textual records, images and sounds, protocols, analysis code and workflows that can be openly used, reused, retained and redistributed by anyone, subject to acknowledgement.

Broadly speaking, monitoring of open research data sharing is in its early stages and it is not yet possible to estimate the proportion of open research data. Assessments today can show the trend of effort, but no current data on this topic are comprehensive or fully representative. Existing assessments are also almost wholly restricted to English language datasets or data-sharing repositories or rely on natural language processing with its own restrictions.

The number of datasets or dataset "size" are not always useful metrics. The number of data points within a dataset is highly variable by discipline. Neither number nor size of datasets is an entirely satisfactory proxy of quality or impact, and both are strongly affected by sharing practices such as collation of relevant data versus publication of single units.

Potential proxies to support assessments of the practice of research data sharing include policies and policy instruments, presence and coverage of data-sharing infrastructures and repositories, registration of data identifiers such as DataCite DOIs and trends in community-led data sharing practices. These assessments are limited to date in that researchers are in the early stages of adoption of tracking tools and of characterization of data or datasets.

Emerging trends in data management and sharing include the development and growing adoption of community-developed principles, such as the FAIR principles (Wilkinson et al. 2016), the CARE Principles for Indigenous Data Governance (Carroll et al. 2020) and the TRUST principles for digital repositories (Lin et al. 2020).[3]

In addition, a growing number of countries and institutions are developing open data policies. As one illustration of this trend, 200 institutional mandates addressing data had been registered on the Registry of Open Access Repositories list of Mandatory Archiving Policies as of May 2023.[4] The level of compliance and effectiveness of research data sharing policies is, however, poorly known. Policies need to be backed up by training, data stewardship support and incentivization (Paic 2021).

Questions remain about the scale and impact of data re-use, which might vary among disciplines and communities. Key questions to consider include: Are open data being used? How do the costs of open data management compare against the usage and benefits accrued?

Open educational resources

Open educational resources (OER) provide opportunities to enhance the experience of learners and educators, as well as benefit educational communities and broader society by providing access to educational resources and teaching methodologies that can be adapted according to the needs of each context, either cultural or situational. The UNESCO Recommendation on Open Educational Resources (UNESCO 2019), adopted at UNESCO's 40th General Conference in November 2019, is the first international normative instrument to embrace the field of openly licensed content and technologies in education.

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[3] FAIR: Findable, Accessible, Interoperable and Re-useable; CARE: Collective benefit, Authority to control, Responsibility and Ethics; TRUST: Transparency, Responsibility, User focus, Sustainability and Technology

[4] See: https://roarmap.eprints.org/

The 2019 UNESCO Recommendation on OER aims to support Member States in the development and sharing of openly licensed learning and teaching materials, benefitting learners, teachers and researchers worldwide. It aims to encourage actions in five areas: (i) building capacity of stakeholders to create, access, re-use, adapt and redistribute OER; (ii) developing supportive policy; (iii) encouraging inclusive and equitable quality OER; (iv) nurturing the creation of sustainability models for OER; and (v) facilitating international cooperation.

The 2019 UNESCO Recommendation on OER calls, in particular, for embedding OER policies into national policy frameworks and strategies and aligning them with other open policies and guiding principles, such as those for open data and open source software. It also calls for leveraging open licensed tools, platforms with interoperation of metadata, and standards (including national and international) to help ensure OER can be easily found, accessed, re-used, adapted and redistributed in a safe, secure and privacy-protected mode.

The first consultation on the UNESCO Recommendation on OER was held in 2023 and reflected the high level of interest of Member States in operationalizing OER to support the sharing and creation of knowledge globally. In preparation for this first reporting process, some 75 UNESCO Member States from all regions, including 44 Member States from Africa and 14 from Small Island Developing Member States, participated in consultations on regional and national implementation of OER activities. These consultations and the preliminary results of the first consultation of the UNESCO Recommendation on OER (being finalized at the time of writing) highlighted that OER is used widely in all UNESCO regions in line with the Action Areas of this normative instrument.

Open science software and source code

According to the 2021 UNESCO Recommendation on Open Science, open source software is software for which the source code is made publicly available, in a timely and user-friendly manner, in human- and machine-readable and modifiable format, under an open license that grants others the right to use, access, modify, expand, study, create derivative works and share the software and its source code, design or blueprint. In the context of open science, when open source code is a component of a research process, enabling reuse and replication generally requires that it be accompanied with open data and open specifications of the environment required to compile and run it.

Broadly speaking, open source is already widespread across digital infrastructures, with 92% of applications today containing open source components (Tidelift 2018). More than 69% of developers using GitHub, a popular repository hosting service that enables open co-working, self-reported participating in open source projects—including but not limited to projects for scientific research—in 2021, up from 63% in 2020.

Open software used for research purposes is a subset of open software, and there is a growing demand to recognize software/code as scholarly contributions by individual researchers and institutions.

Open sharing of software and code for research purposes is not systematically tracked or reported. One option for assessment is the use of persistent identifiers[5] which holds promise for future assessments of open source software and code developed for scientific research. The non-profit DataCite provides persistent DOIs for data under a fee structure. The Open Researcher and Contributor ID (ORCID) is free to individuals and allows for the self-reporting of software as a publication type. Today, these datasets are by no means complete, but the number of reported software/code contributions has grown rapidly since 2016 (Figure 2.13).

[5] Persistent identifiers (PIDs) are unique and permanent digital references that make it possible to find, access, reuse and cite digital information objects of any type on the Internet, regardless of a change in its location.

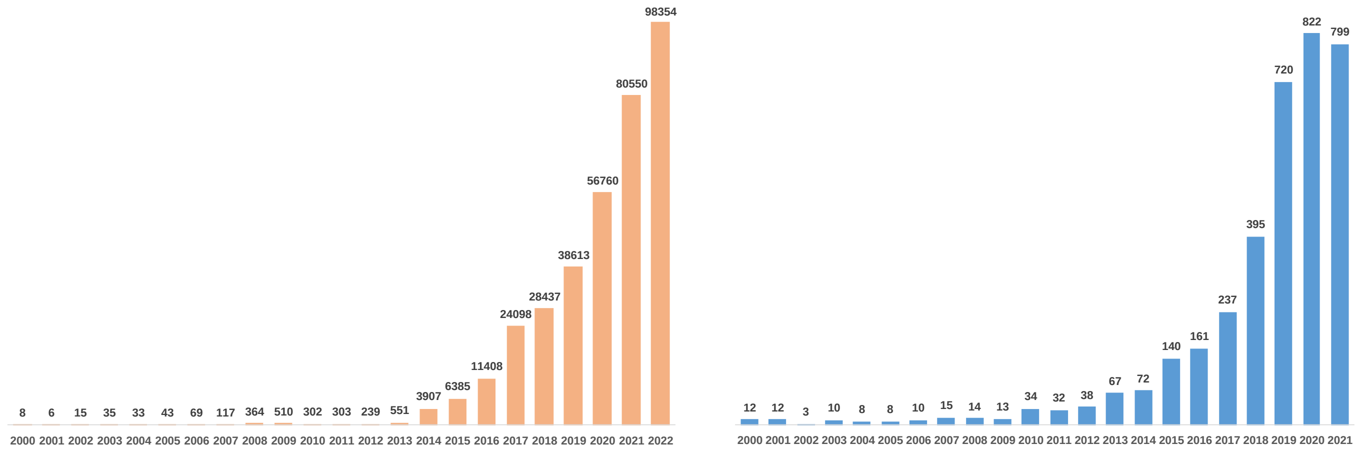


Figure 2.13. Number of software contributions recorded in the DataCite collation (left) and associated with ORCID researcher profiles (right), 2000–2022. *Prepared by Rodrigo Costas Comesana using DataCite and ORCiD data*

The body of openly shared software and source code used for research purposes is largely unknown. Few open source software programs have an associated unique identifier, hindering the use of DOIs to identify software contributions (Di Cosmo et al. 2018). Community standards are emerging that could boost both the reporting and monitoring of software as a research output.[6]

Yet numbers are not enough. Simply quantifying software contributions is insufficient to assess software and source code in the context of open science. In the context of open science and its values and principles, it is also important to consider the diversity of users and contributors to the software and source code used to create and conduct science. Although systematic and reproducible ways of monitoring this diversity are lacking, there have been some first attempts to identify the geographic and gender representation among software contributors.

Software contributions remain dominated by developers in Europe and North America (over 50% of contributions), although the geographic diversity of contributors to open source software has been slowly and steadily increasing since the early 1990s (Rossi and Zacchiroli 2022). Women have been historically underrepresented as software authors, reaching 10% of all contributions for the first time in 2019 (Zacchiroli 2021).

We are still far from understanding who is contributing to open source software for science and what impact these knowledge products have on society.

Open science hardware

Physical hardware is an essential part of the research equipment that many scientists and science users rely on to measure, explore and innovate. Open science hardware is an emerging practice and discipline and an important part of the scientific infrastructure. It allows design, manufacture and use of scientific instruments to support the development of accessible, affordable and reproducible science, thus playing an essential role in enabling the conditions for globally equitable science.

As stated in the 2021 UNESCO Recommendation on Open Science, open science hardware includes physical objects whose design specifications are licensed in such a way that said object can be studied, modified, created and distributed by anyone, providing as many people as possible with the ability to construct, remix and share their knowledge of

[6] For example, see the efforts of the Software Citation Working Group of the Journal Article Tagging Suite for Reuse: https://jats4r.org/software-citations/#recommendation

hardware design and function. A community driven process for contribution, attribution and governance is required to enable reuse, improve sustainability and reduce unnecessary duplication of efforts.

The scientific community collaborates on open science hardware in different ways, including for example through:

- the Gathering for Open Science Hardware (GOSH), one of the most prominent international networks of open science hardware practitioners and advocates;
- the Internet of Production Alliance, a global organization convening groups like GOSH together with other community organizations;
- the Open Source Hardware Association (OSHWA), which supports the iterative drafting of a definition and shared set of principles for open source hardware.

Open science hardware has yet to be recognized in mainstream assessments of scientific output and there is lack of a systematic monitoring framework for its development, uptake or impact.

A quantitative proxy for open hardware evolution is the number of open hardware certifications. The Open Hardware Certification Program was launched in 2016 by OSHWA, with 85 hardware certifications in 14 countries in the first year. In 2022, the number of certifications grew to 224 from nearly 60 countries on every continent except Antarctica (Figure 2.14). The peak in 2020 might be explained by increased attention to certification, whether for new or existing hardware, as an activity possible to complete even during COVID-19 pandemic-related lockdowns. A peak in certifications may or may not mean an increase in actual hardware development.

Over 75% of the certifications derived from Europe and North America, followed by the Asia-Pacific (10%) and Eastern European (7%) regions, but the diversity among developers remains unknown. The USA alone represented more than half of the contributions from Europe and North America.

Unfortunately, at this stage, there is no information about the portion of these certifications for hardware created for scientific uses, nor the diversity of contributors and/or beneficiaries. However, community standards are emerging that would allow a more systematic and coherent self-reporting or monitoring of open science hardware efforts and their impacts.

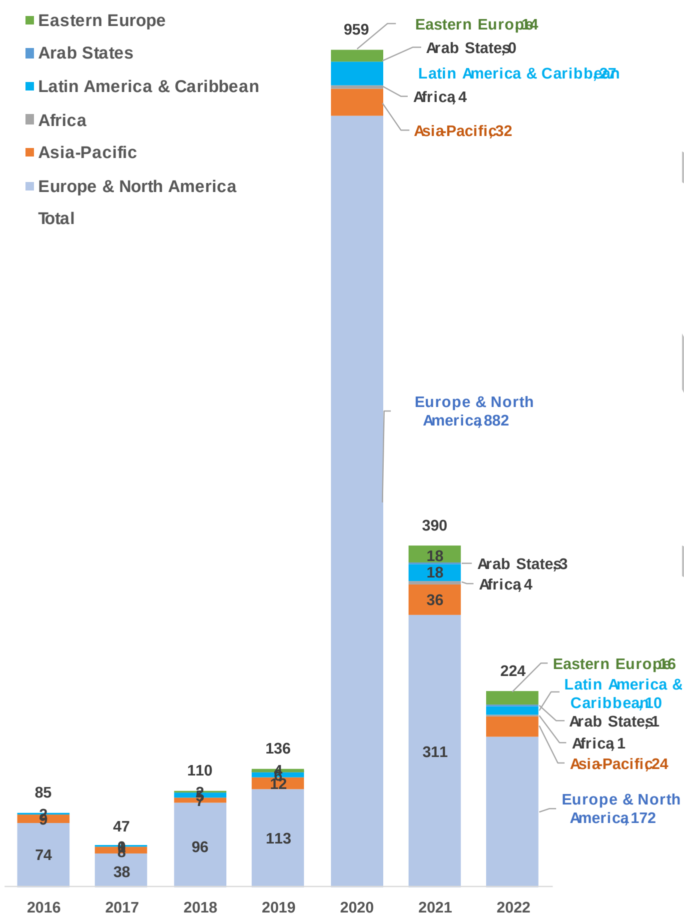


Figure 2.14. Certifications of open source hardware, 2016–2022.
Source: OSHWA, accessed 16 May 2023

Open science infrastructures

Open science infrastructures are shared research infrastructures that support open science and serve the needs of different communities. Infrastructures are increasingly recognized as foundational for many types of scholarly research.

They can be physical, digital and hybrid, include repositories, equipment and other infrastructure, and serve different purposes, regions, disciplines, communities and stages of the scientific process. Together with open digital tools, infrastructures are a growing part of standard scientific practice for scientists worldwide and a growing area of investment attention.

The number of repositories holding scientific publications and/or datasets has grown rapidly. However, the number of repositories as an indicator for trends in open science infrastructures should be used with caution. Increasing the number of repositories does not necessarily increase the number or share of openly available materials or their accessibility to users. Increasing the capacity for repository services and increasing the deposition of materials for sharing are primary goals, only partly proxied by the number of stand-alone repositories. Community-led efforts are ongoing to characterize trustworthy data repositories.

With that caveat, the number of open access repositories holding scientific publications has more than tripled over the past decade, from 1,597 repositories in 2010 to 6,035 in May 2023, based on indexing in the Directory of Open Access Repositories (OpenDOAR).[7]

In mid-2023, 3,117 data repositories (holding or describing datasets) were indexed in the Registry of Research Data Repositories database. More than half contain data that are openly available; the remainder use a range of measures, such as registration (29%) or embargo (15%), that may permit free access when conditions are met.

Western Europe and North America account for nearly 85% of all the open access repositories (Figure 2.15) and open data repositories (Figure 2.16) while Africa and the Arab region account for less than 2% and 3%, respectively.

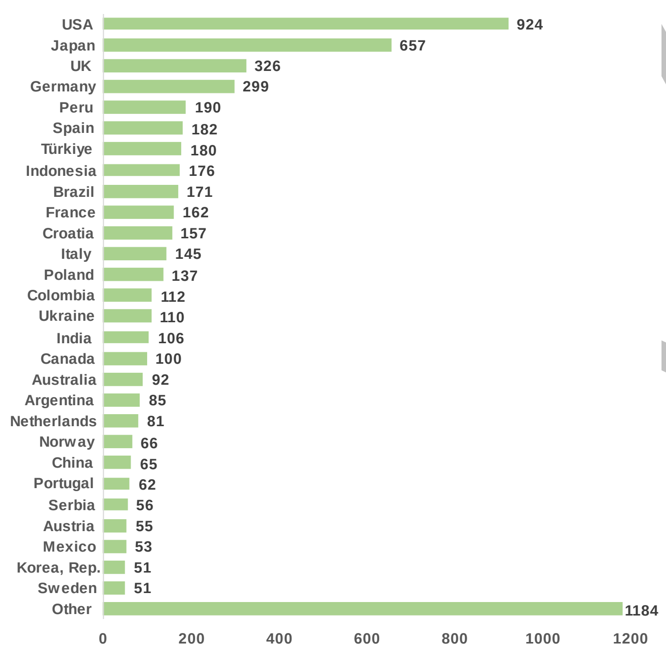


Figure 2.15: Open access repositories by country, among countries with at least 50 publication repositories. A total of 6,035 repositories were indexed. *Source: OpenDOAR (accessed 30 May 2023), CC BY-NC-ND 4.0*

[7] See: https://v2.sherpa.ac.uk/opendoar/

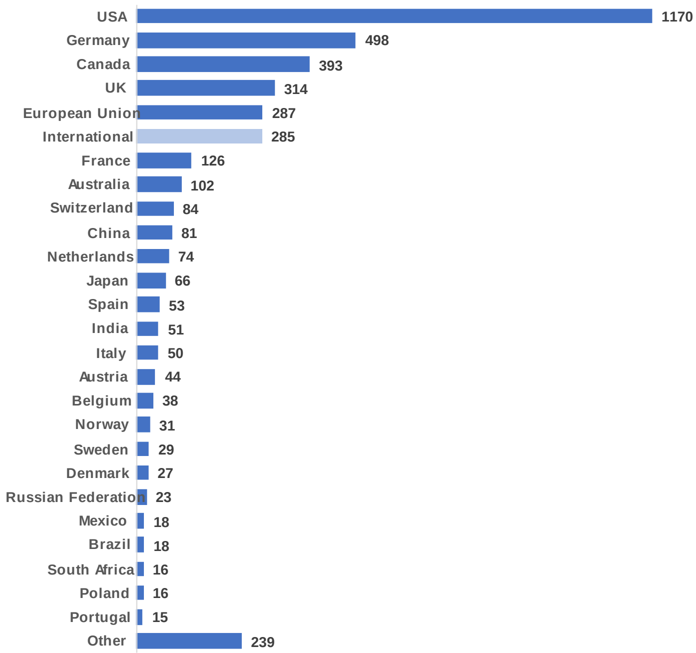
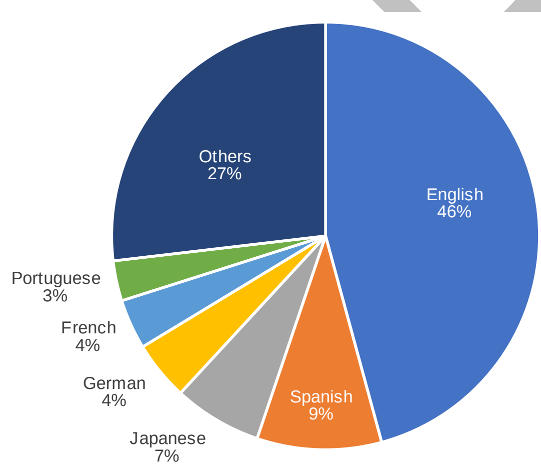


Figure 2.16: Open data repositories by host country, among countries with at least 15 data repositories. International repositories are created or hosted by multiple countries and may contribute to their respective country totals as well; some repositories are exclusively labelled international. A total of 3,117 repositories were indexed. *Source: Registry of Research Data Repositories – re3data.org, https://doi.org/10.17616/R3D (accessed 30 May 2023), [CC BY 4.0](#)*

Complementary indicators of infrastructure trends with relevance for open science may include diversity in citing objects hosted on different repositories; trends in the accessibility of digital and physical tools or infrastructures to users by geographic region or discipline; and the diversity represented in the infrastructure, such as multilingualism.



English-language open access publication repositories dominate but other language options are available (Figure 2.17). Similarly, of the 3,117 data repositories, the majority of data repositories indexed in the Registry of Research Data Repositories use English, followed by German (9%), French (9%), Spanish (4%), and Chinese (3%); other languages are used in less than 16% of the indexed data repositories.

Figure 2.17. Total number of open access repositories indexed in the Directory of Open Access Repository by main language *Data source: OpenDOAR (accessed April 2022)*

A growing number of free-to-use digital tools and infrastructures are available, with many actors involved in their creation, noting among others the key role played by libraries in developing repositories and interoperable archiving systems. However, the presence of a free-to-use tool in one part of the world does not mean that it is accessible or functional in all locations. While the creation of digital tools remains concentrated in the Global North (Bezuidenhout & Havemann 2021), recent mapping exercises are revealing the landscape of digital research repositories in other regions. For example, Bezuidenhout et al. (2020) mapped the repositories in African countries and found that South Africa (40) and Kenya (32) hosted the most repositories (Figure 2.18). Eight languages were represented in the dataset, including Arabic, Amaranth, English, French, German, Portuguese, Spanish and Swahili.

With the growing number of calls to ensure equal access and equitable community governance for open science tools, the key questions that need to be considered going forward include: Are open science infrastructures truly accessible and fit for purpose? Are policies helping to increase availability, accessibility and compliance to help ensure infrastructures further the implementation of open science?

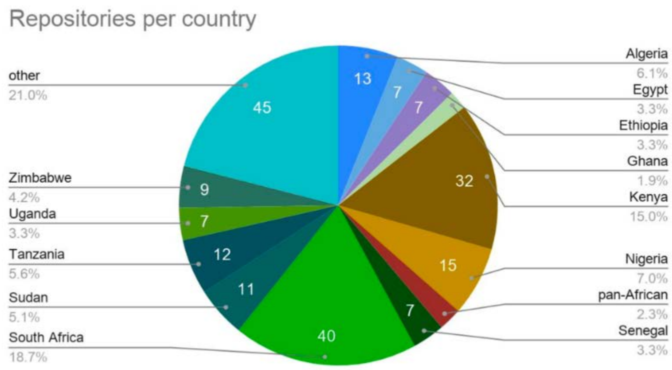


Figure 3: Number of repositories per African country and percentages. 'Other' countries entail those with 0-3 repositories present,

Figure 2.18 Number of repositories per African country and percentages. *Source: Bezuidenhout et al. (2020)*

Chapter 3

Key factors enabling the cultural shift to open science

Summary

The analysis of the current open science practices and the status and trends of open science across the world shows there are still barriers to openness in research and a lack of equity and inclusion in open science.

The central challenge for open science today is to account for equity when adopting open science practices, within local contexts. Addressing this challenge will require both practical actions and systemic, cultural shifts to operationalize the values and principles of open science.

Enacting the cultural change towards open science requires accessible infrastructures, strengthened capacities, aligned incentives and operational policies and policy instruments. Adequate investment to sustain open practices is also key.

The transition towards open science can only be successful through diligent monitoring of its consequences, encompassing potential unintended outcomes for both the scientific community and society at large. These unintended consequences might include shifts in financial burdens from readers to authors, a rise in predatory behaviours as well as uncertainties regarding ownership and intellectual property management in the context of open science. If not proactively tackled, such unintended consequences might exacerbate disparities in access to science and in the equitable sharing of its benefits.

As demonstrated in the examples presented in this chapter, actions in these priority areas are ongoing in varied contexts in all geographic regions, involving and initiated by a range of open science actors.

The need for a cultural change towards open science

As it challenges traditional norms and practices of 'science', the transition to open science requires a true shift in the culture of science.

Open science is grounded in the values of collective benefit, quality and integrity, equity and fairness, diversity and inclusiveness. It challenges traditional notions of how scientific research should be conducted, disseminated and rewarded. It further challenges who should be involved in and contribute to research, who can access it and who should benefit from it.

The central challenge for open science today is not to replicate the errors of conventional 'closed' science and to ensure equity when adopting open science practices. At present, access and contributions to, as well as benefits derived from open science remain unequally distributed. In addition, attention remains uneven among the different pillars of open science, with engagement with societal actors and dialogue with other knowledge systems still largely absent from the plethora of open science practices.

Addressing these challenges will require innovation in the way concepts and practices of 'collaboration', 'participation', 'dialogue' and 'partnerships' are perceived, defined and realized by a wide range of actors and stakeholders in the science, technology and innovation (eco)systems across the globe.

Transformation to a scientific system open to all and for all therefore requires a systemic cultural change and calls for structural support, practical actions and pragmatic tools to shift behaviours.

The novel approaches that will foster alignment with and operationalization of fundamental values and principles of open science will need to be embedded into systemic interventions targeting the key factors that enable cultural change to open science, such as infrastructures, capacities, incentives and policies.

While diverse paths and incremental progress will be a welcomed part of the journey, the cultural shift to open science will only be possible with adequate funding and innovative monitoring of its impacts (see Chapter 2), including its possible unintended consequences for science and/or society (Figure 3.1).

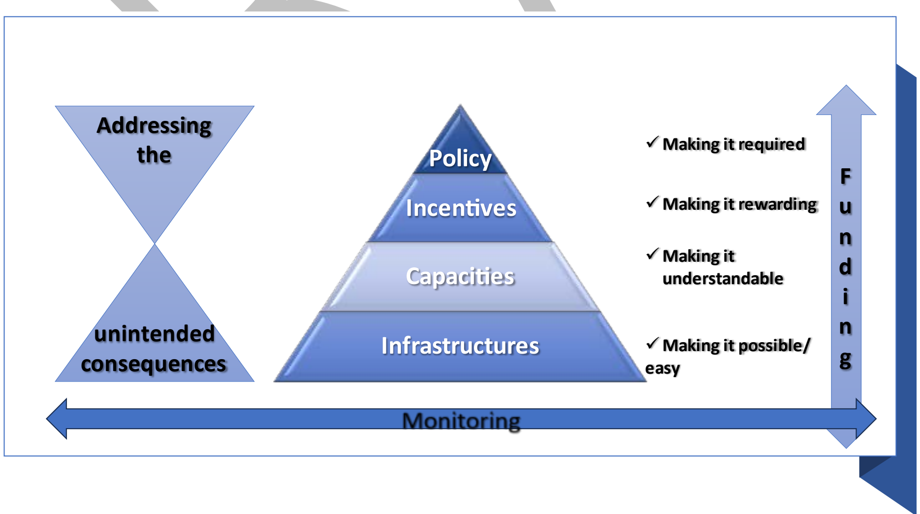


Figure 3.1. DRAFT. Key factors enabling the cultural shift to open science. *Based on an adaptation of the theory of research culture change, developed by the Center for Open Science (Shaw et al. 2022)*

Adequate infrastructures

Open science infrastructures are essential for conducting open and transparent high-quality research, fostering collaboration, addressing complex scientific challenges and promoting innovation. Both physical and digital infrastructures, including a reliable internet connection, are key to open science and the provision of standardized services to manage and provide access to scientific knowledge and processes.

Equity in access to the digital tools and physical equipment, as well as the skills needed to use, manage and maintain them are a key prerequisite for sharing information and collaborating at multiple scales, from individual to international levels. To meet their full potential, open science infrastructures need to take into consideration local contexts and the needs of diverse communities, which also allow them to enable meaningful engagement and dialogue among researchers and other open science actors.

Open science infrastructures not only foster enhanced sharing of scientific knowledge among scientific communities but also need to promote inclusion and exchange of scholarly knowledge from traditionally underrepresented or excluded groups (such as women, minorities, Indigenous scholars, scholars from less-advantaged countries and those using low-resource languages) and contribute to reducing inequalities in access to scientific development and capabilities among different countries and regions.

With varied needs and demands from different disciplines and communities, those using open infrastructures—and the related services—are best able to inform the functionality, design and implementation of those services. Community-developed tools and standards are a growing part of open science and of resourcing, funding and harnessing open science infrastructures.

Without adequate open infrastructures, there can be no open science. Yet, infrastructures remain for many an invisible foundation.

Key challenges facing open science infrastructures today include accessibility gaps, heavy demands for archiving, the need for interoperability, challenges in tracking research objects and knowledge products, community governance and lack of adequate investments resulting in lack of sustainability and risk of commercialization.

A number of initiatives have been successfully developed to address these issues. Some examples are presented below; many others also exist around the world.

Increasing the traceability of research outputs using persistent identifiers

Bolstering the traceability of research objects and knowledge products helps to ensure their effective re-use while building trust and integrity across infrastructures. Digital identifiers are a way to maximize the benefits of knowledge sharing while identifying the contributions by knowledge creators.

Assigning a unique, persistent identifier (PID) permits users to trace the product throughout the research cycle and over time. Examples include archival resource keys, digital object identifiers (DOIs) including DataCite DOIs for datasets, ORCiDs for people, ROR IDs for organizations and research activity identifiers (RAiD) for research projects (Figure 3.2). The LocalContexts project is developing identifiers for knowledge owned in community; for example, Traditional Knowledge and Biocultural Labels establish cultural authority and governance over Indigenous data and collections by adding provenance information and contextual metadata, protocols and permissions for access, use and circulation.

While PIDs increase findability, some models of PID implementation themselves create accessibility challenges. A range of mechanisms support the management and use of such persistent identifiers, some of which rely on a subscription model. To avoid the cost of DOI registration, the archival resource key of the Argentine Center for Scientific and

Technological Information (ARK-CAICYT) is a persistent identifier that is free of charge and has been adopted by over 70 Argentine scientific journals (see: http://id.caicyt.gov.ar/issn/).

The Africa PID Alliance led by Helix Analytics Africa and Training Centre in Communication (TCC-Africa) is intended to operationalize FAIR sharing using PIDs (Ksibi et al. 2023). The project will start with a survey on the continental level, including on the potential for a DOI Registration Agency tailored to the continental context and for a specific prefix for Africa.

At the global level, the Research Data Alliance established a National PID Strategies Working Group, which has produced a strategy Guide, Case Studies and Checklist to assist in this rapidly developing area.

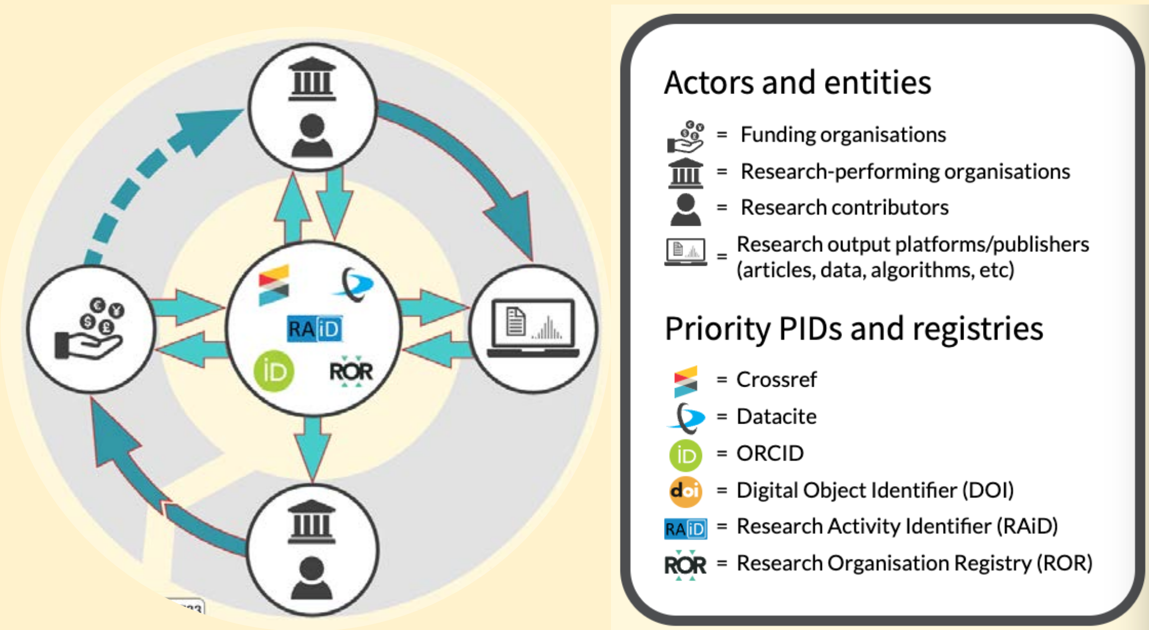


Figure 3.2. An example of a research cycle optimized with the use of persistent identifiers. Ideally, multiple actors, including funding agencies, research performing organizations, research output platforms and contributors to the research, are involved at multiple stages using PIDs to link inputs and outputs. *Image: MoreBrains, see https://resources.morebrains.coop/pidcycle/*

For more information, please contact Chris Erdmann (Michael J. Fox Foundation), Joy Owango (TCC-Africa), Shawna Sadler (ORCID) and Natasha Simons (Australian Research Data Commons; RDA National PID Strategies Working Group)

Mapping infrastructures to build synergies and avoid duplication

Creating a strategic framework of open science infrastructures informed by owners and users can support action at the national level. A consultative process can help to identify existing activities and priority needs.

Brazil is expanding the usage of existing investments with a registry. In 2020, the Ministry for Science & Technology inaugurated the National Platform of Research Infrastructure (https://pnipe.mctic.gov.br/), intending to consolidate Brazil's research infrastructure under one digitally accessible portal. This platform allows institutions to register their infrastructures and make them available for others, enhancing the visibility of resources across the country, inviting collaboration from public and private sectors and facilitating the management and monitoring of shared usage via report generation on the platform. The numerous potential benefits including encouraging inter-institutional collaboration, optimizing the use of costly equipment and expanding the accessibility of resources to researchers nationwide. The initiative can even allow institutions to join forces: for instance, users can register infrastructures that are not currently operational, as a need for maintenance might be filled by other users with the resources or installed capacity for it.

The Republic of Korea has invested in digital open science infrastructure with multiple national programs. Since 2008, the National Science & Technology Information Service (NTIS, https://www.ntis.go.kr) has served as a major digital government platform in which national R&D information and related data are publicly released. NTIS has been financially supported by the Korean government according to the Framework Act on Science and Technology. The framework is applicable to other countries. In fact, Costa Rica benchmarked a Korean framework on NTIS and established its own science and technology information service (SINCYT, https://sincyt.go.cr). NTIS has been awarded by diverse entities, including 2012 United Nations Public Service Award. Another example of open science infrastructure is a digital platform run by a public research institution. For instance, Korea Institute of Science and Technology (KISTI) has set up a multi-layered digital platform and provided digital services; the platform incorporates at least three types of services, which are AccessOn (for open access publications), DataOn (for research data-sharing) and ScienceOn (a one-stop portal connecting AccessOn, DataOn and other related online information services in the field of science and technology, https://scienceon.kisti.re.kr/).

For more information, please contact André Brasil Varandas Pinto (Leiden University) and Eunjung Shin (Science and Technology Policy Institute, Republic of Korea)

Archiving open software as human heritage

Access to the source code of research software is essential for open science: as a product of human creativity, software contains a growing part of scientific and technical knowledge. Archiving and referencing research source code is also an essential condition for the reproducibility of research results in all fields of study.

Software Heritage (https://softwareheritage.org) has the mission to collect, preserve and make accessible the source code of all software that is publicly available. An international non-profit initiative led by Inria (the French national research institute for digital science and technology) in partnership with UNESCO, Software Heritage provides an infrastructure shared between research, industry and public administrations which makes it possible to pool costs, avoid the dispersion of efforts and standardize user training.

Software Heritage is based on a cost-sharing model, at several million euros per year, and is supported by the contributions of a network of international actors. For example, France participates through the national Fund for Open Science and the contribution of several research organizations and universities. A national open science prize for research software was launched in France in 2021. With its second national plan for open science, France is encouraging the distribution of source codes for research software under an open source license, which allows unhindered reuse, and recognition of the contributions to the development of quality research software, in all their forms, as part of the career evaluation of researchers and engineers. The collaboration between Software Heritage and the open archive of HAL publications in France allows researchers and engineers to contribute with the least effort to the construction of a catalogue of research software production, equipped with quality metadata.

The Software Heritage archive contains over 16 billion unique source files, drawn from more than 250 million distinct sources as of August 2023. This includes publicly accessible projects on the most well-known forges but also the long tail of platforms maintained and used by research organizations (see https://archive.softwareheritage.org). Simple actionable guidelines are available at https://www.softwareheritage.org/howto-archive-and-reference-your-code/ for researchers worldwide to archive and reference software source code that they use or produce. This includes the possibility to explicitly request the archiving of a software project at https://save.softwareheritage.org: more than 500,000 requests have been made since the service opened in 2019.

For more information, please contact Laurent Romary (Inria) and Roberto Di Cosmo (Software Heritage)

Global cooperation on FAIR data policy and practice for interoperability

Interoperability refers to the ways in which data is formatted that allow diverse datasets to be used together, merged or aggregated in meaningful ways. Interoperability frameworks, based on coherent standards, are considered essential for both established domains and emerging cross-domain research areas of global importance (European Commission 2018a).

Coordinated by CODATA (https://codata.org/), with the Research Data Alliance association as a major partner, the WorldFAIR project (https://codata.org/initiatives/decadal-programme2/worldfair/) is intended to advance implementation of the FAIR data principles, in particular those for interoperability, and to develop a set of recommendations and a framework for FAIR assessment in a set of cross-disciplinary research areas. The two-year project launched in 2022, funded by the European Commission through its Horizon Europe Framework Programme. The project is a collaboration between 19 partners from 13 countries including research institutions and scholarly organisations from Africa, Australasia, Europe and North and South America.

The project will explore features of an emerging Cross-Domain Interoperability Framework with 11 case studies from the physical, social, agricultural and environmental sciences and the cultural heritage sector, and prepare FAIR Implementation Profiles appropriately adapted to each (cross-)discipline area. This will lead to, and help inform, a fuller mapping of current best practices and emerging solutions and initiatives for FAIR data in these domains.

The Global Open Science Cloud initiative and other activities in the ISC CODATA Decadal Programme 'Making Data Work for Cross-Domain Grand Challenges' are addressing topics around large-scale data interoperability across domain and institutional boundaries.

For more information, please contact

Collaborative creation of major science infrastructures to enhance inclusion

For some scientific fields, the requisite infrastructure would be nearly impossible to create, host and maintain by one nation alone. There are examples of shared physical scientific infrastructure in different parts of the world, promoting scientific collaborations and diplomacy while expanding usership, including:

- The High-Altitude Water Cherenkov Gamma Ray Observatory (HAWC, https://www.hawc-observatory.org/) — a gamma-ray and cosmic ray observatory located on the flanks of the Sierra Negra volcano in the Mexican state of Puebla at an altitude of 4100 meters. HAWC is an international collaboration among over thirty universities and scientific institutions from eight countries.
- Square Kilometer Array Observatory (SKA, https://www.skao.int/) — the largest intergovernmental international radio telescope project, being built in Australia and across Africa. Organisations in 16 countries are currently taking part in the SKA project at government or national-coordination level or are represented as observers. Eight African partner countries are involved in coordinated action to support the future expansion of the SKA project in Africa. The project has paid particular attention to inclusion and societal impact. For instance, Wajarri Elders and heritage experts, alongside others, walked over 400 km of the proposed construction area in Australia to identify priority sites for preservation.

- Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME, https://www.sesame.org.jo/) — following the example of CERN (the European Organization for Nuclear Research), SESAME is the first synchrotron light source in the Middle East and neighbouring countries and the region's first major international centre of excellence. Situated in Jordan, it has eight Member States: Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine and Turkey. Between July 2018 and February 2020, experiments were conducted for 62 proposals from 12 different countries, many of them collaborative projects.

For more information, please contact:

Building an inclusive and global network of next generation and open repositories

Repositories represent critical infrastructure for collecting and providing access to research outputs. As the number of infrastructures multiplies, there comes a need to ensure visibility and functionality across systems. Interoperability and federation help to boost their value and mitigate risks of knowledge loss.

The Confederation of Open Access Repositories (COAR, https://www.coar-repositories.org) is an international association with over 150 members and partners from 50 countries around the world, representing libraries, universities, research institutions, government funders and others. COAR works to define interoperability standards through identifying common behaviours, protocols and technologies, allowing the development of value-added services on top of the content contained in the network.

The COAR Community Framework for Good Practices in Repositories (https://doi.org/10.5281/zenodo.7108100) aims to assist repositories to evaluate and improve their operations based on a set of applicable and achievable good practices. COAR also promotes innovation across the ecosystem through the Next Generation Repositories and COAR Notify Initiatives, positioning repositories as the foundation for a distributed, globally networked infrastructure for scholarly communication—integrated with other value-added services such as peer review—making the system more research-centric, open to and supportive of innovation, while also collectively managed by the scholarly community.

In line with the UNESCO Recommendation on Open Science, COAR is developing best practices for collecting multilingualism and non-English content in repositories. It has published guidance (https://www.coar-repositories.org/news-updates/what-we-do/multilingual-and-non-english-content/) for improving the discovery of repository content in a variety of languages, along with implementation guidance for the repository community aiming to couple the effort to boost multilingual engagement and knowledge sharing with adequate infrastructures and a commitment to disseminating research for the benefit of society.

For more information, please contact Kathleen Shearer (COAR)

Human and institutional capacity

Open science requires investment in capacity building and human capital, both on individual and institutional level, and for different actors at different career stages, from early career to leadership positions. The necessary skills range from sharing open scientific knowledge to building collaborations and societal engagement and dialogue with actors beyond the scientific community.

Identifying capacity needs and priorities must involve scientists as well as a range of other actors involved in open science (see Figure 1.2), taking into account strong variation within and among geographic regions and disciplines.

There are advantages to building capacity and creating learning exchanges among the multiple communities of open science within and outside the conventional academic institutions.

To take advantage of the opportunities offered by open science, research projects, research institutions and civil society initiatives need to call on broad comprehension of the open science values and principles as well as technical skills and capacities in digital literacy, digital collaboration practices, data science and stewardship, curation, long-term preservation and archiving, information and data literacy, web safety, content ownership and sharing, as well as software engineering and computer science, among others.

In addition, building capacity of scientists and non-scientists for effective open engagement of societal actors beyond the conventional scientific community and for promoting dialogue with other knowledge systems is central to the open science concept and practice.

Building the capacity of young scientists for open science, both through formal and informal training opportunities and peer networks, is of particular importance as the early career researchers are key for scientific knowledge production and sharing. They are also highly impacted by evaluation and incentive systems in place that may or may not support open science practices.

Open science capacity building programmes in general and those addressing engagement with societal actors and other knowledge systems in particular, are still largely piecemeal and opportunistic. In many institutions, open science activities are driven by individual researchers, librarians, data stewards and others from the bottom up. While these efforts are laudable and highly appreciated, long-term sustainability of open science requires institutional support and systemic investment in well planned, coherent and comprehensive open science capacity building plans and strategies.

At present, **the key challenges for building capacity in open science include the lack of a defined framework or set of skills and competencies and the strong variability in awareness and capacity among actors and across elements of open science, as well as across different regions. Another challenge is the lack of long-term, well-funded comprehensive training programmes for the implementation of open science practices for scientists and other relevant open science actors.**

Valuable examples of effective actions to adopt or strengthen open science capacity building exist in various contexts. Some of these are presented here below.

Framing digital skills and knowledge for open science

In the Recommendation on Open Science, Member States are encouraged to consider agreeing on a framework of open science competencies aligned with specific disciplines for researchers at different career stages, as well as for actors active in the private and public sectors or in civil society, who need specific competences to include the use of open science products in their professional careers. Member States are encouraged to consider developing recognized skills and training programmes in support. A core set of open science skills should be regarded as part of the foundational expertise of all researchers and incorporated into higher education curricula.

Building upon an existing digital skills framework, Ligue des Bibliothèques Européennes de Recherche – Association of European Research Libraries (LIBER Europe) compiled a set of open science skills essential for librarians and researchers (https://doi.org/10.5281/zenodo.4727592). These skills were then mapped to key frameworks including Digcomp 2.0 (https://data.europa.eu/doi/10.2791/11517), the FOSTER+ learning resources (https://www.fosteropenscience.eu/resources) and the LIBER Open Science Roadmap focus areas (https://doi.org/10.5281/zenodo.1303001), to provide structure and context by categorising the skills. While open science skills include behavioural competencies such as communication, negotiation, teaching, etc., for reasons of practicality and scope, the final list was limited to the digital core areas of open science skills and knowledge needed to practice open science.

In further developing a framework of competencies and in building capacity for open science, in general, efforts must be directed towards ensuring regional balance and inclusivity in prioritizing and providing training, in line with the values and principles of open science.

For more information, please contact liber@libereurope.org

Early career researchers and others advancing open science in China

The Chinese Open Science Network (COSN; https://open-sci.cn/) is a grassroots network for promoting open science practices and awareness of reproducibility in the Chinese-speaking community, led by and aiming to serve early career researchers. Since its inaugural event in 2016, COSN has organized three in-person workshops, 55 journal club sessions, 58 talks, 16 tutorials and 2 hackathons and has translated 15 English articles and blogs pertaining to open science into Chinese.

With close collaboration with the Center for Open Science and other open science communities, as well as national and subnational open science platform providers in China such as the National Science Library of Chinese Academy of Sciences (NSL-CAS), COSN is building an online Chinese-speaking open science community, so that early career researchers in China can engage more in open science practices alongside their international counterparts. As of 2023, the COSN's official WeChat account had more than 26,000 subscribers; more than 1,000 researchers and students actively participate in the discussions on open science.

These efforts growing within a context of multiple actions at national and subnational level to advance open science practices. For example, the National Science Library of Chinese Academy of Sciences (NSL) has organized annual events such as China OAWEEK (initiated in 2012) and China Fair Use Week (2014) and has established essential open knowledge platforms like IR grid (2009), GoOA (2013), and ChinaXiv (2016). The IR grid (http://www.irgrid.ac.cn/) seamlessly integrates over 100 institutional repositories within CAS. GoOA (http://gooa.las.ac.cn) facilitates access to over 19,000 OA journals and more than 12 million OA papers globally. ChinaXiv is a preprint platform for open scholarly exchange, widely recognized as the most authoritative preprint platform for scientific papers in China.

The Smart Education of China Platform (http://www.smartedu.cn) recently won the UNESCO ICT in Education Prize. The Platform is a digital education resource centre for public services, both for learning and for educational administration. The training materials held on the Platform have reached millions of learners. The English version of the platform attracts learners from more than 160 countries on six continents, and other language versions are set to go live in 2023.

For more information, please contact Hu Chuan-Peng (Nanjing Normal University, COSN) and Jinxia Huang (National Science Library of Chinese Academy of Sciences)

Partnering to develop open science in institutions of higher education

In 2022, the non-profit trust Training Centre in Communication (TCC Africa, https://www.tcc-africa.org/), based in the University of Nairobi, Kenya, officially partnered with the Association for African Universities (AAU) and the not-for-profit open science publisher Public Library of Science (PLOS, https://plos.org/). This builds on the 2021 agreement between PLOS and TCC Africa (PLOS 2021). Aiming to support leaders, including leaders in African institutions, the joint initiative is being used to identify challenges to the adoption of open science while simultaneously supporting effective implementation.

The results (TCC 2023a) were released in March 2023 of the first two of four regional policy workshops (PLOS 2022a) aimed at Presidents, Vice Chancellors, Rectors, Deputy Vice Chancellors, Directors of Research and Libraries in African institutions for higher education. The workshops aimed to increase awareness of the benefits of open science, to support development and implementation of open science policies and promote the adoption of open science practices. In April 2023, a 3rd regional workshop was held in South Africa, which included the governments of South Africa and Namibia (TCC 2023b).

Joint approaches are also progressing open science policy at the regional and national level. In 2022, the East African Science and Technology Commission (EASTECO), PLOS and TCC Africa announced their collaboration for the implementation of open science and open access principles for EAC Partner States, namely Burundi, Democratic Republic of Congo, Kenya, Rwanda, South Sudan, United Republic of Tanzania and Uganda (PLOS 2022b). A regional launch meeting has been followed by the first national level meetings in Tanzania and Kenya in 2023.

Other initiatives are also building supportive communities of institutional leaders. The Higher Education Leadership Initiative for Open Scholarship (HELIOS, https://www.heliosopen.org/) is a cohort of over 95 US colleges and universities committed to collective action to advance open scholarship. HELIOS workstreams, led by member campus representatives, are focused on making open scholarship easier for researchers and institutions that support them; aligning incentive structures like hiring and reappointment, promotion, and tenure (RPT) to properly reward open activities; stimulating infrastructure that supports open scholarship; and coordinating with like-minded activities in the government, philanthropic, and professional society sectors.

For more information, please contact Roheena Anand (PLOS), Caitlin Carter (HELIOS) and Joy Owango (TCC Africa)

Forum for Open Research in MENA

The Forum for Open Research in MENA (FORM, https://forumforopen.org/) is a non-profit membership organisation supporting the advancement of open science policies and practices in research communities and institutions across the Arab region by facilitating the exchange of actionable insights and the development of practical policies.

A catalyst for positive action, FORM works with key stakeholders to develop and implement a pragmatic programme designed to support the transition towards more accessible, inclusive and sustainable research and education models across the Arab region. In pursuit of this, FORM is developing a library of localised resources and hosts regular free online community development activities, providing practical insights and guidance on key aspects of open science for higher education stakeholders.

In addition, the Annual Forum (held in a different Arab State each year) provides an arena for librarians, researchers, funders, government policy makers, universities and international experts to discuss and debate key themes and issues relating to the development and implementation of open science policies and practises in Arab research communities and research institutions. Any research institution or research community based within the Arab region that wishes to support the mission can become a member. Membership is free.

For more information, please contact Emily Choynowski (FORM)

Alignment of incentives

Key to the cultural shift towards open science are adequate incentives aligned with the values and principles of open science.

Motivations and incentives are inherently connected to research evaluation and assessment. The current research assessment system, which determines career progression, funding and recognition, mainly rewards researchers for publishing their work in high-impact journals, most of which are either not open access or charge prohibitive open access publishing fees for authors. However, the impact of scientific activities extends far beyond the number of ranked journal articles produced. There is a need to shift evaluations from focusing on outputs to processes, from impact factors to impacts, from individual to collaborative achievements and from individual to collective benefits.

In most cases, there is no tangible reward for time, resources and efforts associated with open science practices, especially those which cannot be automatically converted into traditional academic output, such as publications, but which nevertheless can have a significant impact on science and society. Existing scientific evaluation practice can, in some cases, even create disincentives for open science.

The current research assessment system does not provide appropriate incentives for collaboration among researchers or for broader engagement and dialogue with actors and knowledge holders beyond the conventional scientific community. Societal engagement and open dialogue do not yet feature among indicators used to monitor research, for individuals or institutions. Training for such scientific practice is still piecemeal and opportunistic for the majority of science students and researchers.

In order to avoid unresolvable tensions on scholars, **the most fundamental challenge for the advancement of open science today is the need to align the values and priorities used to assess scholars and institutions, for the purposes of funding or career progression, with the values and principles of open science as defined in the 2021 UNESCO Recommendation on Open Science.**

There are several movements across the globe to address the need for reform of the research assessment and evaluation. In the spirit of open science, it is imperative to have globally harmonized scientific assessment grounded in the same system of values for all scholars.

Committing to global reform in research assessment: DORA

The Declaration on Research Assessment (DORA, https://sfdora.org/) recognizes the need to improve the ways in which the outputs of scholarly research are evaluated. Developed in 2012 during the Annual Meeting of the American Society for Cell Biology in San Francisco, it has become a worldwide initiative covering all scholarly disciplines and all key stakeholders including funders, publishers, professional societies, institutions, data providers and researchers. Over 2,800 organizations and over 20,000 individuals in 161 countries have signed the Declaration as of 2023.

Through community engagement, resource development, partnership, advising and convening, the DORA team aims to advance practical and robust approaches to research assessment globally and across all scholarly disciplines.

Reformed assessment is intended to establish greater equity and reward practices that are fit-for-purpose within context, recognizing variations relating to geographies, communities and scholarly disciplines. Schmidt (2022) illustrates a wide variety of academic achievements and outcomes that could be considered "impactful", using a model that visualizes "impact" along a scale of contributions' influence and extent of reach to new types of audiences (Figure 3.3).

Tools to Advance Research Assessment (TARA, 2021–2023) is a project to facilitate the development of new policies and practices for academic career assessment. It will help DORA identify, understand, and make visible the criteria and standards that institutions, particularly universities, use to make hiring, promotion and tenure decisions. This information will be used to create resources and practical guidance on research assessment reform for academic and scholarly institutions.

Figure 3.3. Building blocks for impact. *Graphic by Ruth Schmidt, adapted from Schmidt (2022)*

For more information, please contact Haley Hazlett (DORA)

Assessing the state of research evaluation systems

In their 2023 synthesis the *Future of Research Evaluation*, the Global Young Academy (GYA), the InterAcademy Partnership (IAP) and the International Science Council (ISC) Centre for Science Futures Scoping Group discuss recent actions, responses and initiatives taken by different stakeholders around the world. The authors suggest that organizations work with UNESCO to help shape national research evaluation commitments under the Recommendation on Open Science. For a summary of the issues identified, actions taken and remaining open questions based on the report, see Figure 3.4.

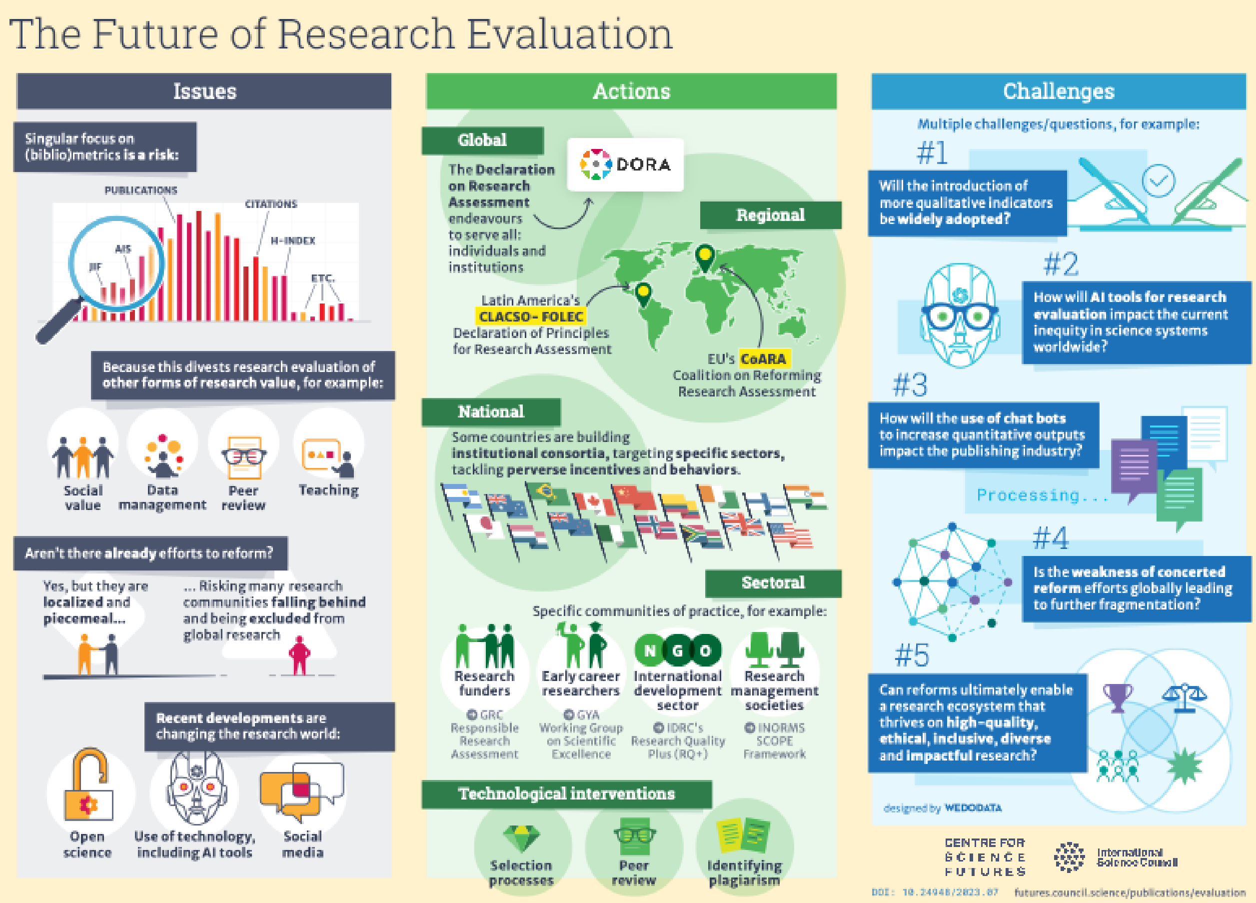


Figure 3.4. Illustration of key issues, actions and challenges for research evaluation. *Graphic by ISC Centre for Science Futures, https://doi.org/10.24948/2023.06*

Collaborative action on research assessment in the context of open science: Introducing CoARA

A dominant barrier to establishing open science as the norm lies in research assessment. Reconfiguring research assessment is a crucial endeavour for research organizations and funding bodies as well as for individual researchers, particularly those in the early stages of their careers. This priority ranks as a key action item within the European Research Area Policy Agenda for 2022–2024.

Drawing upon the initiatives of DORA and crafting time-bound commitments, the Coalition of Reforming Research Assessment (CoARA, https://coara.eu/) sets forth a unified path for the reform of research evaluation while upholding organizational autonomy, across Europe and on a global scale. Started in 2022, CoARA convenes over 500 research-performing entities, research funding institutions, policy influencers and research infrastructure bodies across more than 40 countries.

By means of a worldwide coalition comprising research funding organizations, research-performing institutions, national and regional assessment authorities, agencies, associations and learned societies, signatories of the CoARA Agreement (https://coara.eu/agreement/) are committed to effecting systemic transformation grounded in shared principles and within an agreed timeframe. Additionally, signatories commit to fostering the exchange of information and mutual learning.

Signatories pledge to disclose their progression in evaluating or constructing criteria, tools and procedures, aligned with the core Commitments and following an action plan with milestones defined by the community, by the end of 2023 or within one year of Agreement endorsement. Further, signatories commit to showcasing their advancements by the close of 2027 or within five years of signing the Agreement, a juncture by which they would have completed at least one cycle of reviewing and advancing their assessment criteria, tools and procedures.

Bearing in mind the inherently universal and transnational essence of research, which thrives on the movement of scholars and ideas, instituting a systemic transformation necessitates the active participation of research and research-affiliated institutions on a broad and all-encompassing scale. Consequently, broadening the membership of the Coalition across Europe and beyond, and formulating just policies and practices that serve the greater good, stands as a strategic focal point for CoARA.

For more information, please contact Erzsébet Toth Czifra (CoARA Secretariat)

Assessing research for social relevance in Latin America and the Caribbean

Since 2019, the Latin American Forum for Research Assessment (FOLEC, in Spanish, https://www.clacso.org/en/folec) from CLACSO has been promoting a transformation in research assessment in Latin America and the Caribbean. The Declaration of Principles (CLACSO 2022), which has more than 270 institutional and individual signers, stated "the need to incorporate new research assessment practices that encourage open access in diamond journals and repositories, since they do not exclude authors for economic reasons, and allow peer review to focus more on the quality of the research than on the journal where it is published".

The Declaration also promotes the creation and use of (open) databases which reflect both the production disseminated in international repositories as well as that which is included in regional and local databases, while encouraging the recognition and reward of multilingualism in publications. Multilingualism is seen to favour the development of socially relevant research and contribute to sustaining cultural diversity.

CLACSO, an international non-governmental institution with UNESCO associate status, brings together more than 856 research and postgraduate centres in 55 countries in Latin America and the Caribbean and other continents. The organization has a long trajectory in the promotion and enforcement of Diamond open access (without charges to authors) in the region: network institutions publish approximately 400 journals and more than 3,000 books in open access with peer-review and open licenses. In alliance with Redalyc-AmeliCA, CLACSO publishes a joint collection of 1,025 Social Science and Humanities quality journals in Diamond open access. CLACSO's research assessment recognizes and rewards that, at least, 30% of CLACSO's working groups members (a total of 87 with 4,584 participants from 44 countries) are social movements, policy makers, advocacy leaders and/or non-governmental organizations. Thus, the network encourages vigorous social engagement with knowledge production and circulation, through different forms of participatory science.

For more information, please contact Pablo Vommaro, Dominique Babini, Laura Rovelli and Ana Luna González (CLACSO-FOLEC), with the advice of Fernanda Beigel

Policies

As open science gains momentum across different scientific and non-scientific communities, the groundswell of action can benefit from the guidance and support provided by the development of relevant policies, ranging from community to institutional, national and regional to international policies.

Open science policies can be defined as a set of guidelines, rules, regulations, laws, principles or directions to put open science values and principles into practice. By providing a strategic framework and a roadmap for coordination of efforts, resources and priorities for open science practices, open science policies are critical in fostering the cultural change to open science and developing science, technology and innovation systems which contribute to making research more efficient, trusted, impactful, inclusive and responsive to societal needs.

While national governments drive the creation of policies and/or policy instruments at the national level, open science policies can be developed by different open science actors in the country, including research-performing institutions, research funders or scientific publishers. There is therefore a need for a public, transparent and concerted effort to harness shared expertise for the range of actions and actors involved in the development of open science policies and policy instruments.

At the national level, a growing number of countries have policies that pertain to at least one aspect of open science. There is a pattern of starting with an open access policy addressing publications and/or research data (e.g. Mexico, 2002 and 2014; New Zealand, 2010; El Salvador, 2011; Spain, 2011; Argentina, 2013; Peru, 2023; Ecuador, 2014; India, 2014; Poland, 2015; Cyprus, 2016; Germany, 2016; Lithuania, 2016; Czechia, 2017; Norway, 2017; Belgium, 2018; Ethiopia, 2019; Chile, 2020; Iceland, 2020; Malta, 2021; USA, 2022), then transitioning to a more comprehensive open science policy (e.g. Serbia, 2021; Austria, 2022; Cyprus, 2022; South Africa, 2022; Venezuela, Botswana, in preparation), national action plan (Slovenia, 2015; Netherlands, 2017; Romania, 2018; Montenegro, 2020; Bulgaria, 2021; France, 2021; Italy, 2022; Ukraine, 2022) or national strategy (Albania, 2017; Slovenia, 2017; Denmark, 2018; Romania, 2018; Slovakia, 2019; Latvia, 2022; Spain, 2023) or roadmap (Croatia, 2014; Finland, 2014; Latvia, 2016; Ireland, 2019; Canada, 2020; Cote d'Ivoire, Kenya, Lesotho, Mozambique, Nigeria, Somalia, Tanzania, Uganda, under development).

Several countries are also incorporating the values and principles of open science in their existing science technology and innovation policies (e.g. China, 2018; Japan, 2020; Estonia, 2021; Ghana,2023; Sierra Leone, 2022; Cambodia, under preparation) thus ensuring that open science is an integral part of science.

There is also growing interest from regional, and sub-regional bodies in particular in Africa, to harmonize open science efforts through development of sub-regional open science policy frameworks (e.g. European Union; Southern African Development Community; Economic Community of West African States; East African Science and Technology Commission) and shared infrastructures such as open science clouds (e.g. European Open Science Cloud (EOSC)) or research and education networks (e.g. West and Central African Research and Education Network African (WACREN); Arab States Research and Education Network (ASREN); Ubuntu Alliance).

Latin American government efforts have focused on open access to publications and to a lesser extent on open research data, but there are around a dozen and almost a dozen international and regional declarations, respectively, that call for promoting a transition towards the principles of open science (Babini & Rovelli 2020). There is an incipient movement towards supporting collaborative dimensions of open science. A key focus in Latin America and the Caribbean is the approach to knowledge as a public good. To this is added a perspective that emphasizes the design of open science policies contextualized not only in global research and scientific policy agendas but also in the emerging needs in the local research and development agendas (for example, see the Panama Declaration on Open Science 2018).

Institutional policies and in particular open access mandates are also on the rise, including mandates from funding agencies and research organizations and institutions requiring or strongly encouraging researchers and/or publishers to make their scientific publications available in open access. From 2010 to 2021, the majority (78%) of open access mandates and policies indexed in the Registry of Open Access Repository Mandates and Policies[8] were put in place by

[8] See: https://roarmap.eprints.org/

research organizations (875 mandates), followed by science funders (84). The majority (over 73%) of these mandates were developed in Western Europe and North America.

With the proliferation of open science policies, mandates and policy instruments, one of the **key challenges is the alignment of open science policies, strategies and actions from individual institutions to national and international levels, while respecting the diversity of open science approaches and national contexts.** Another challenge is to **ensure broad consultation and engagement of the wide range of actors involved in open science in the development of relevant policies and in the monitoring of their impacts on science and society.** In addition, it is important that **all the pillars of open science receive the policy coverage they deserve, and that the development of open science policies takes into consideration all the other key factors enabling the cultural shift to open science.**

Co-creation of a shared open science framework for Finland

In Finland, open science is promoted through a national coordination model, in which the whole research community participates in developing national targets, co-creating policies and recommendations and coordinating policy implementation.

The National Open Science and Research Coordination (https://avointiede.fi/en) consists of over 380 active experts. The network is organised along four areas, each of which has an expert panel: culture of open scholarship, open data and methods, open access to scholarly publications, and open education and educational resources. The work is led by the National Steering Group for Open Science and Research, to which all the key organisations in the Finnish research community have nominated representatives. The Coordination is supported by a secretariat (four employees), whose mission is to support research organisations by promoting the development of policies, supporting implementation of these policies and monitoring international open science developments.

These efforts operate within the Finnish policy framework for open science and research, consisting of three levels. The highest level, the Declaration of Open Science and Research for the Finnish research community, contains the vision and mission for Finnish open science and research and defines goals for each of the four areas. Organisations and individuals can also sign the Declaration and thus show their commitment. The second level consists of four policies, which define in more detail what the Finnish research community should do to achieve the goals of the four areas. The third level consists of recommendations for good practices that help to achieve the objectives of the policies at an organisational as well as an individual level.

The framework documents for each level have been created through a collective effort by working groups with open participation, subjected to a public commenting round and accepted by a steering group representing the key organisations of the Finnish research community. A biennial monitoring process ensures implementation of the policy objectives and actions. Individual documents of the policy framework will be updated regularly. The policy framework provides a clear structure for the promotion of open science, while its collective creation process ensures that all the key actors are committed to it.

For more information, please contact the Secretariat for the National Open Science and Research Coordination, Finland

Development of an open science policy for South Africa

Placeholder of 300 words

The Netherlands uses policy to open science to society

In the Netherlands, an overarching national open science policy direction has been in development together with key players across the scientific landscape, starting with the National Plan for Open Science in 2017 and evolving into the National Programme for Open Science (NPOS) in 2019. NPOS has received annual funding for open science coordination from both the Ministry for Education, Culture and Science and from the Association of Research Universities.

Citizen science practitioners formed a Working Group in 2020 in a bottom-up initiative to embed citizen science within NPOS as one of the key pillars alongside FAIR Data and Open Access, resulting in citizen science becoming a third Programme Line within NPOS in 2021 and the launch of the first national network for citizen science in 2022.

A more ambitious perspective towards open science took shape over the course of 2021 in response to the UNESCO Recommendation on Open Science, with key contributions from the wider research community from an early stage. The NPOS strategic goals and ambitions towards 2030 (to which 78 institutions, networks, communities and individuals submitted feedback via an open consultation process) have been aligned with the Recommendation, the first goal being: "Close collaboration between knowledge institutions, government, industry, and citizens to strengthen the international position of Dutch science and optimise the processes of creating, sharing, and communicating knowledge for the benefit of society".

Via this open consultative process, NPOS has developed a Rolling Agenda to achieve the NPOS Ambition 2030, including the Action Line 'Towards Societal Engagement and Citizen Science'. Together, these NPOS outputs will inform investment in open science in the Netherlands.

In June 2022, the Minister of Education, Culture and Science announced that 20 million euros will be allocated for opening up science each year from 2023 to 2031, with explicit support for multi-stakeholder participation in the knowledge chain, bottom-up research practices that tackle societal issues and participatory collaborations between scientific and societal actors.

The Dutch Research Council has been given the responsibility of overseeing the investment of this impulse funding towards open science, via an internal governance body 'Open Science NL', based on the NPOS Ambition Document and Rolling Agenda.

For more information, please contact Margaret Gold (Leiden University) or Frederike Schmitz (Dutch Research Council)

CERN recognizes open science as one of its guiding principles

The core values of the European Council for Nuclear Research (in French *Conseil Européen pour la Recherche Nucléaire*, CERN) include making research open and accessible for everyone. In September 2022, CERN approved a new policy for open science at the Organization, with immediate effect. The policy aims to make all CERN research fully accessible, inclusive, democratic and transparent, for both other researchers and wider society.

Published alongside the policy document is a dedicated website (https://openscience.cern/) explaining all the open science initiatives at CERN. It is planned to update the policy every two years.

The CERN Open Science Policy (2022) covers all elements of open science relevant to CERN. This includes, in particular, open access to research publications, data, software and hardware, as well as research integrity, infrastructure, education and outreach activities supporting or enabling open science practices.

The policy was developed by the Open Science Strategy Working Group (OSWG), which includes members from every CERN department. Drawing on existing bottom-up initiatives, the working group designed comprehensive guidelines for the CERN community on sharing its research within a new framework for open science. The OSWG now serves as the principal body to oversee open science in the organization, following the Implementation Plan (CERN 2023), and is charged with creating a biennial report.

For more information, please contact Kamran Naim (CERN)

Monitoring impacts, including unintended consequences of open science practices

While open science has numerous benefits, there are also potential unintended consequences associated with its adoption. It is essential to be aware of these challenges and address them proactively to ensure the responsible implementation of open science practices.

Some of the most common unintended consequences of open science include:

- the shift of costs from readers to authors through open access publishing using article processing charges (APCs);
- an increase in predatory behaviours which bill themselves as open science solutions; and
- confusion over ownership and intellectual property management in an open science context, including potential misuse, such as unintentional misuse or unpermitted commercial use of open scientific knowledge.

If not addressed proactively, these unintended consequences can lead to exacerbated inequities in access to scientific knowledge and the benefits of science, increase in the gaps in science technology and innovation between and within countries, greater vulnerability and further marginalization of those already disadvantaged and marginalized within and outside the conventional scientific community.

There is a growing number of collective actions and collaborative efforts to address the unintended consequences of open science practices.

Scientist-led publishing using community-based infrastructures

To cover the costs of publishing services without charging readers, many publishers introduced article processing charges (APC). At least 30% of all open access (OA) scholarly articles were published upon payment of an APC (see

Figure 2.8). The average cost per OA article was about USD $1,203 in 2020, up from USD $180 in 2019 (Crawford 2021), with some journals now charging thousands of dollars for a single OA publication.

By contrast, collaborative investments in shared publishing architectures can be used to produce OA publications without charging fees to either authors or readers; the so-called Diamond OA model has been operationalized in several countries (Bosman et al. 2021). Several key international stakeholders are proposing Diamond OA as the dominant mechanism for global scholarly publishing, removing some of the barriers to open research.

In Latin America, scholarly publishing is traditionally in the hands of the academic sector, not commercial publishers. Universities are leaders in providing publishing services, embracing the digital transition and publishing free of charge to authors and readers. In some cases, distributed investment, including from national and international actors, is being harnessed to extend the benefits. Actors include Latindex, Redalyc, Scielo and La Referencia. Since its creation in 1996, Latindex has been a pioneer in open access, while Redalyc is committed to supporting only non-commercial open access.

Present publishing and reporting systems do not facilitate monitoring of APCs or other fees associated with the range of access options, inhibiting an understanding of the ramifications. To combat this, the OpenAPC initiative releases data sets on fees paid for open access journal articles by universities and research institutions under an Open Database License. In 2020, over €38 million was spent to publish 21,410 articles by the 360 indexed institutions representing Europe (354), North America (7) and Western Asia (1). Individual analyses provide additional insights: In Colombia, USD 740,000 was spent on APCs in 2019, about twenty times more than what was spent in 2009 with a 208% increase in the average fee per article (Pallares et al. 2022). Over USD $31 million was spent on commercial APCs from 2013 to 2020 for publications (co-)authored by Argentinian researchers (Vélez Cuartas et al. 2022).

Under 'closed' models, institutions are already spending money on scientific publications. Transitioning those funds, such as subscription fees, to support open access publication mechanisms could fully support a global shift to open access publishing, with the potential for cost savings (Schimmer et al. 2015).

Prepared with guidance from Ana María Cetto (National Autonomous University of Mexico) and Laura Rovelli (CLACSO)

Protecting researchers from predatory behaviours

As the concept and practice of open science continue to evolve, the research sector is becoming increasingly vulnerable to overt commercial predation driven by profit and self-interest. This predation risks polluting the global research enterprise, with serious implications for research quality and integrity, wasting research funding, derailing research careers and compromising evidence-based policy decisions.

Monetization and commercialization of academic research output is one of the three key drivers of predatory behaviours, which exist on a spectrum from outright fraud to questionable practices. All types of publishing and conferencing outlets, from reputable and established traditional publishers to the newly emerging and open access ones, can potentially engage in predatory unethical practices, anywhere in the world.

All actors and stakeholders have a responsibility to promote an open, inclusive and global discussion on how to transition to more sustainable, less profit-motivated academic models, including devising alternatives to author-pays or pay-to-publish/pay-to-present models to cover the costs associated with academic publishing and conferences.

Building awareness and capacity also mitigates risks. Forewarned is forearmed for individual researchers. Institutional and international action to reform research assessment also helps to protect researchers and communities from the pressures that increase their vulnerability to predatory publishers.

Based on "Identifying predatory academic journals and conferences", *part of the UNESCO Open Science Toolkit prepared in collaboration with an InterAcademy Partnership (IAP) study on predatory academic journals and conferences, accessible at* www.interacademies.org/publication/predatory-practices-report-english

Adequate investment

Science requires investment to thrive. Countries have committed to strengthening investment in their science systems as part of the Sustainable Development Goals (SDGs), tracking their progress with indicator SDG9.5.1 on research and development expenditure as a proportion of gross domestic product. The 2021 UNESCO Recommendation on Open Science also encourages Member States to make an effort to contribute at least 1% of national gross domestic product (GDP) dedicated to research and development expenditure.

The costs of engaging in open science are different among actors and uneven around the world, as are the costs of conducting science of any kind. Initial attempts to track the status and trends of investment in open science showed the opacity of existing financial flows through scientific systems. Measuring these costs is difficult and there are few indicator systems in use. Comparable, public reporting demonstrating financial flows through open science systems is limited, particularly for open science practices other than open access to publications or open research data sharing.

Despite the limited data on required or enacted investments in open science, there is sufficient information to understand that open science practices do involve costs, even as those costs may be lower than the short- or long-term costs of conventional science.

However, not all the costs related to the operationalization of open science require additional funding. A range of open science practices can be implemented by reallocation of funds within the existing funding frameworks, by for example enhancing collaborations and promoting the use of open resources and shared open infrastructures.

Estimates based on efficiencies and enablement suggest open science can provide cost savings or economic benefits of millions of monetary units per year (Fell 2019). For example, the European Commission (2018b) found that lack of FAIR[9] research data costs the European economy at least €10.2 billion every year, and open data could provide €11.7 to €22.1 billion per year in economic benefits to Europe. An assessment for the Australian research sector estimated 38,000 person days and AUD $84 million per year could be saved by adopting persistent identifiers (Brown et al. 2022). Open science hardware can provide economic savings of up to 87% compared to proprietary tools (Pearce 2020).

Open science practices also expand the possibilities for financing science that meets priority needs of a given community. Crowdfunding is emerging as a resource for researchers, with particular importance for those scientists operating outside of institutions, such as retired researchers or citizen science communities.

Key challenges regarding adequate funding for open science include resource limitations, awareness and capacity among funders to shape agreements and practices that enable open science, funding mechanisms that perpetuate existing power structures and inadequate monitoring mechanisms to track investments.

Evolving funding practices to boost open science: Open Research Funders Group

Research funders can intervene to make both the processes of grantmaking and the resulting research outputs more open, transparent and inclusive.

[9] FAIR data principles are intended to improve the **F**indability, **A**ccessibility, **I**nteroperability, and **R**e-use of digital assets. See: https://www.go-fair.org/fair-principles/

The Open Research Funders Group (ORFG, https://www.orfg.org) is a partnership of more than two dozen philanthropic organizations committed to the open sharing of research outputs. The ORFG acts as a community of practice to help private funders develop, implement, oversee and advance strategies that accelerate access to funded research, including papers and data. Additionally, ORFG members collaborate to explore the ways in which open science intersects with and amplifies efforts to improve both philanthropy and society, including civic engagement with science, equity and inclusion and evidence-based policymaking.

Resources and programs created by the ORFG include:

- Policy Clause Bank (http://dx.doi.org/10.17605/OSF.IO/7SH6K), including field-tested language for policies covering a range of different scholarly outputs and sharing practices, and Policy Generator (https://forms.gle/tbGctHc1sL1Q4eur9), an interactive resource for drafting tailored open science policy language
- Data sharing (McKiernan & Tananbaum 2023) and software sharing (McKiernan et al. 2023) policy guidance for funders
- Grantmaking interventions (https://www.openandequitable.org/resources) for building more equitable, inclusive, and transparent funding programs

ORFG is also taking a leading role in other initiatives such as the Alliance for Open Scholarship (All4OS) and the Higher Education Leadership Initiative for Open Scholarship (HELIOS).

For more information, please contact Eunice Mercado-Lara and Erin McKiernan (ORFG)

Integrating open science in all research funded by the European Commission

The European Commission is strongly committed to promote open science as the modus operandi for all researchers in Europe.

In 2014, the European Commission made open access to scientific publications mandatory for all research and innovation projects funded under Horizon 2020, the European Union's research and innovation funding programme for the period 2014–2020 (budget of nearly €80 billion). Moreover, specific Horizon 2020 calls for proposals were directly addressed the challenges of responsible open science and research data sharing, including open access, ethics and integrity perspectives, citizen science, science communication and the development of the European Open Science Cloud (EOSC).

For the period 2021–2027, the European Commission has developed a comprehensive Open Science policy and extended the range of measures supporting the uptake of open science practices through the Horizon Europe programme (budget of nearly €100 billion). Open science is embedded into the Horizon Europe evaluation system in both the criteria for "Excellence" (quality of open science practices and data management) and the "Quality and efficiency of implementation" criteria. Distinction is made between mandatory and recommended practices, thus ensuring minimum compliance while encouraging beneficiaries to incorporate additional good practices. Legal provisions in the grant agreements are also used to strengthen open access rights and responsibilities. Several Horizon Europe calls for proposals continue to advance knowledge on and uptake of open science policies and practices, tools and guidelines as well as supporting infrastructures and services.

Open science infrastructures funded by the European Commission notably include:

- The European Open Science Cloud (EOSC, https://eosc-portal.eu/), prototyped since 2018 as a federated environment of existing research infrastructures in Europe. This environment, which is progressively built as a public good, aims to support the full data life cycle for scientific research intended to support the full cycle of workflows for scientific research from 2023. by providing seamless access to Findable, Accessible, Interoperable and Reusable (FAIR) data and services for science.

- Open Research Europe (ORE), an open access and open peer-reviewed publication platform. The use of ORE is not obligatory for EU-funded research projects but enables automatic compliance with the open access requirements of Horizon Europe as well as the open peer-review and early sharing recommended practices, with no author fees.

For more information, please contact Dejan Dvorsek (European Commission) and Natalia Manola (OpenAIRE)

Characterizing open science infrastructures for priority funding

Many who develop innovative solutions become inadvertent maintainers, investing their own time and resources. The costs of providing and maintaining infrastructure services often mount as usership increases. Short-term project-based funding is central to the current operation of open science infrastructures but is not the most sustainable, stable long-term solution.

Equitable division of responsibility for financing essential open science infrastructures is in line with the values and principles of open science. Some groups are already collating information needed by policymakers and potential investors, such as the Global Sustainability Coalition for Open Science Services (SCOSS, formed in 2017, https://scoss.org/) and Invest in Open Infrastructure (IOI, formed in 2018, https://investinopen.org/).

SCOSS provides a co-ordinated cost-sharing framework that will enable the open science community to support the non-commercial services on which it depends, allowing stakeholder institutions to participate in direct and immediate funding of essential infrastructure. To date, 11 infrastructures have been funded, with over USD $6 million in pledged funds from over 335 institutions as of June 2023. Each year, the coalition invites non-commercial open science services to apply, following defined assessment criteria.

IOI works to increase the investment in and adoption of open infrastructure to further equitable access to and participation in research and to provide targeted, evidence-based guidance and support to institutions and funders of open infrastructure. IOI created a Catalog of Open Infrastructure Services as a means of standardizing information about core open infrastructure services, aiming to expand it to 70 services by December 2023. The Open Infrastructure Fund began in 2022 with a participatory funding summit to determine priority themes for allocation, with 60% of the funds reserved for projects in low- and middle-income economies. The IOI Fund, launching in 2024, will focus on furthering the adoption of open infrastructure through community-driven funding.

For more information, please contact Vanessa Proudman (SPARC Europe) and Sarah Lang (Invest in Open)

Chapter 4: Conclusion and next steps

Summary

The practice of open science is growing globally but unevenly. Progress varies across disciplines, actors and countries. The findings in this Open Science Outlook illustrate the need for global action and collective assessment in line with the values and principles of open science, enacted with mutual respect and collaboration.

Among other benefits, open science can enhance trust in science by promoting justice and inclusion, engaging society and diversifying contributors. However, obstacles persist, including limited access to infrastructure, conflicting incentives and resistance to the necessary cultural transformation.

International collaboration is essential to generate an environment supportive of open science, spanning low- and high-resource contexts. The seven areas for action set out in the UNESCO Recommendation on Open Science provide a structural framework for transforming science. These actions include promoting the culture of open science, creating an enabling policy environment, investing in human and financial resources, investing in infrastructures, building individual and institutional capacity, promoting innovation across the research cycle and promoting international collaborations in open science.

Open science must continue to adapt to evolving technologies, societal needs and scientific advancements. Only with shared values and principles as guides will the transformation to open science lead to a more inclusive, collaborative and impactful research landscape, fostering scientific breakthroughs while ensuring the responsible use and dissemination of knowledge for the benefit of all.

Chapter 4: Conclusion and next steps

The practice of open science is growing in various contexts around the world. These efforts are most effective when grounded in mutual respect and a commitment to a culture of openness, collaboration and dialogue based on shared values and principles. Due consideration of who is involved in setting the norms and practices is essential to avoid perpetuating inequities in today's scientific systems even as progress is made towards openness.

Trust in science is foundational for science to play its full role in modern society. Open science practices are associated with better trust in science (Rosman et al. 2022). Trust can be built through strengthened justice and inclusion, central factors in global, equitable open science (Sulik 2022). Engaging society in open science and building dialogue across knowledge systems can enhance trust in science and foster a sense of ownership and confidence in research outcomes. Involving actors outside of the conventional scientific community in open science initiatives may improve the diversity and quality of scientific outcomes. At the same time, there is a need to address ethical considerations related to open science, regarding for example data privacy and security and appropriate ways to partner with Indigenous Peoples and local communities.

Despite the remarkable strides made in promoting open science, several barriers impede its widespread implementation. These include issues related to lack of proper infrastructure and resources, incentives for researchers and other open science actors and cultural resistance to change. Policymakers and stakeholders must collaborate to address these obstacles and create an enabling environment for open science to thrive.

Creating an enabling environment requires coordination among different stakeholders, including policymakers, researchers and other knowledge holders, as well as civil society organizations (see Figure 1.4), to identify the different needs and priorities and to work collaboratively in developing policies and regulations that support open science.

Given the rapid growth in open science initiatives, international collaboration and exchange of knowledge among scientists and other knowledge holders, across sectors and among countries is fundamental for meaningful and equitable open science initiatives. Collaborations that facilitate knowledge sharing and international research partnerships, including partnerships to co-design research and co-create knowledge, can boost the sharing of research findings across borders to accelerate scientific progress and address global challenges collectively. International and multistakeholder collaboration can be a key driver in enabling open science, in both low- and high-resource contexts.

To achieve the objectives of the 2021 UNESCO Recommendation on Open Science, Member States are recommended to take concurrent action in seven areas, in accordance with international law and taking into account their individual political, administrative and legal frameworks. The seven areas include promoting the culture of open science, creating an enabling policy environment, investing in human and financial resources, investing in infrastructures, building individual and institutional capacity, promoting innovation across the research cycle and promoting international collaborations in open science.

As demonstrated in the examples presented in this Open Science Outlook, actions in all seven of the priority areas are ongoing in all geographic regions, involving and initiated by a range of open science actors. However, the pace, effectiveness and impacts of these actions vary considerably and the overall progress in the implementation of open science practices is uneven across disciplines and countries.

Governments and funding agencies are starting to develop policy and regulatory frameworks for open science. To be as effective as possible, these policies should outline the benefits and expectations for all actors involved in open science practices, individuals and institutions, across all of the pillars of open science, from open access to scientific knowledge and shared infrastructures to engagement of societal actors and dialogue with other knowledge holders. The 2021 Recommendation on Open Science serves as an enabling structure for collective action.

By increasing awareness about the benefits and practices of open science, we can nurture a new generation of researchers who value openness and collaboration as well as a society which expects—and facilitates—the same. A growing number of coalitions and communities centred around open science are emerging, building shared understanding and community-driven vocabularies or approaches. A common understanding of open science, its characteristics and purposes is foundational for much of the collaborative effort that is required to transform the global system of science. With growing awareness of open science (Box 4.1), the pace and scale of transformation may increase. Knowledge sharing and exchange of best practices can be facilitated among countries and regions to learn from successful open science initiatives and avoid potential pitfalls.

Building capacity remains a priority across regions, disciplines and communities. Coordinated investments in developing and maintaining robust infrastructures and services to support open science practices are essential to ensure that adequate resources and technical support are available, including to address inequities in access.

Box 4.1: The growing conversation about open science

Open science is gathering momentum around the world, building upon decades of action in some regions. Given the varied manifestations of open science according to local priorities, coordinated and global action was supported by the establishment of a shared definition, created as part of the negotiated text of the 2021 UNESCO Recommendation on Open Science.

Characterizations of the different elements of open science are still evolving. Shared, community-led glossaries of open science terms and concepts have been developed, such as those from the Framework for Open and Reproducible Research Training (https://forrt.org/glossary/; Parsons et al. 2022) and the Institut de l'information scientifique et technique (French Institute for Scientific and Technical Information, https://skosmos.loterre.fr/TSO).

Tens of thousands of scientific articles taking open science as their subject have been published each year for much of the past decade, well past the human 'cognition threshold' for individual scientists to keep up with the latest developments (Wang 2019). The 2021 UNESCO Recommendation on Open Science has itself been cited in over 200 indexed articles. As the conceptualization and surrounding vocabularies of open science grow, the science of open science must also grow in response.

Adopting a shared framework for assessment, for individual researchers through to institutions and national levels, is of urgent importance for a rapid, just transition to open science. Innovative and practical ways to recognize and reward researchers and institutions that actively embrace open science are needed, to suit various local contexts. In particular, funding agencies and institutions should consider open science efforts in grant evaluations and career advancement.

The global community is working to develop and adopt ways to measure the impact of open science practices and to assess the progress and impact of open science implementation at both global and national levels. Evidence-based evaluations are needed to refine policies and strategies.

Open science is an evolving concept, and its implementation should adapt to emerging technologies, societal needs and scientific advancements. For the global community, there are benefits to remaining attentive and receptive to innovations that align with the core values of openness and transparency.

Box 4.2: UNESCO Working Groups on Open Science

To ensure a transparent, inclusive and accessible multistakeholder process to feed into a global dynamic open science framework in the context of the implementation of the 2021 Recommendation on Open Science, UNESCO has mobilized over 500 experts and stakeholders across the different regions which are currently engaging in the work of five Open Science Working Groups. These Groups regularly meet to discuss the five high impact areas that have been identified as critical for the operationalisation of open science worldwide, namely: policy development, capacity building, infrastructures, funding and incentives and monitoring of open science.

As a result of the work of the Open Science Working Groups and with inputs from many partners, guiding documents of the UNESCO Open Science Toolkit have been developed to assist the Member States in raising awareness of open science and addressing the challenges of capacity building, policy development, funding and infrastructures for open science. Working Group members are also supporting the preparation of a monitoring framework, identifying a core skills framework and sharing best practices and lessons gained in diverse contexts.

One of the great strengths of working openly is the speed at which is it possible to generate high-quality results built with diverse engagement. The same patterns that can boost research can also boost collaborative efforts to advance open science as a field. It is important to support the creation and maintenance of effective international and multi-stakeholder collaborative networks to exchange best practices and lessons learned from the design, development and implementation of open science policies, initiatives and practices (Box 4.2).

Building upon the preliminary quantitative and qualitative analysis of the status and trends of open science across the globe and the examples shared in this inaugural edition of the UNESCO Open Science Outlook, the global and national implementation of open science can be guided by the fundamental values of open science: quality and integrity, collective benefit, equity and fairness, and diversity and inclusiveness. Only with these values as guides will the transformation to open science lead to a more inclusive, collaborative and impactful research landscape, fostering scientific breakthroughs that address some of the world's most pressing challenges while ensuring the responsible use and dissemination of knowledge for the benefit of all.

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UNESCO Open Science Toolkit

The UNESCO Open Science Toolkit is designed to support implementation of the UNESCO Recommendation on Open Science. The Toolkit is a set of guides, policy briefs, factsheets and indexes. Each piece is a living resource updated to reflect new developments and the status of implementation of the Recommendation. The Toolkit is evolving, with the following elements prepared to date or under development:

Brochures

- Official text: UNESCO Recommendation on Open Science
- An introduction to the UNESCO Recommendation on Open Science

Guides

- Building capacity for open science
- Developing policies for open science
- Funding open science
- Bolstering open science infrastructures for all
- Engaging societal actors in open science
- Supporting open source hardware for open science

Checklists

- Checklist for universities on implementing the UNESCO Recommendation on Open Science
- Checklist for open access publishers on implementing the UNESCO Recommendation on Open Science

Factsheets

- Understanding open science
- Identifying predatory academic journals and conferences
- Intellectual property rights and open science

Public indexes to connect users with open science resources and services:

- UNESCO Open Science Capacity Building index
- UNESCO Index of Open Science Knowledge Sharing Platforms
- UNESCO Global Observatory of Science, Technology and Innovation Policy Instruments (GO-SPIN), Open science policies: https://gospin.unesco.org/

UNESCO

UNESCO Open science website: https://on.unesco.org/openscience
Contact: openscience@unesco.org