Global Citizen Science perspectives on Open Science

Written input by the CSGP Citizen Science & Open Science Community of Practice to the UNESCO Recommendation on Open Science

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Authors: Uta Wehn[1], Claudia Göbel[2], Anne Bowser[3], Libby Hepburn[4], Muki Haklay[5]

The contributors to this paper included Jens Bemme, Michela Bertero, Marit Bogert, Egle Butkeviciene, Cobi Calyx, Darlene Cavalier, Luigi Ceccaroni, Ted Cheeseman, Antony Cooper, Theresa Crimmins, Melissa Demetrikopoulos, Daniel Dörler, Shannon Dosemagen, Mohammad Gharesifard, Margaret Gold, Bastian Greshake Tzovaras, Gerid Hager, Rick Hall, Florian Heigl, Pen-Yuan Hsing, Turgay Kerem Koramaz, Sonia Liñán, Jonathan Long, Seán Lynch, Metis Meloche, Andjelka Mihajlov, Alice Motion, Maina Muniafu, Tony Murphy, Ricardo Mutuberria, Michelle Neil, Eva Novakova, Marta Oliveira, Jessica L Oliver, Emu-Felicitas Ostermann-Miyashita, Lucile Ottolini, Thomas Palfinger, Jim Salmons, Sven Schade, Lea Shanley, Laura Smith, Karen Soacha-Godoy, Angela Tavone, Marta Teperek, Laure Turcati, Jordi,Vallverdú, Katerina Zourou, Raul Zurita-Milla.

Abstract

Both Citizen Science and Open Science are emerging movements, becoming more significant and layered with more sophisticated understanding of the themes, dynamics and shared characteristics. Now, there is an important window of opportunity for laying the foundations of future, mutually beneficial development - but this needs to happen on the basis of careful analysis and through participation of the respective practitioner communities.

This short paper answers a call for input representing perspectives of Citizen Science communities from around the world to the elaboration of the UNESCO Recommendation on Open Science. In response to the call, a Community of Practice on Open Science and Citizen Science (CS & OS CoP) was founded under the Citizen Science Global Partnership (CSGP) and launched a global survey-based consultation through CSGP networks. We received 63 responses to our survey from 24 countries in 7 days.

Based on careful analysis of current understanding, tensions and trends in the Citizen Science perspective on Open Science, this paper makes two recommendations for the UNESCO Recommendation on Open Science:

1. Opening up access to data, publications, and other research products is necessary but not sufficient to transition science fully towards Open Science. Citizen Science presents the means for open, holistic and participatory processes of knowledge generation, *therefore Citizen Science should be acknowledged as an important pillar of Open Science to enable it to add this significant value.*
2. The Citizen Science contribution to Open Science should be maximised by *i) drawing on the vast practical experience within its communities, of the implementation of Citizen Science via the careful assessment of opportunities and challenges, and application of lessons learned, ii) fostering greater and enhanced cooperation, synergies and cross-pollinisation of practitioners among and between Citizen Science and Open Science communities, and iii) ensuring global access to supporting infrastructures, including technical infrastructures and community networks*.

[1] IHE Delft Institute for Water Education, Delft, The Netherlands
[2] HoF Halle-Wittenberg
[3] Woodrow Wilson International Center for Scholars
[4] SDG Maximisation Working Group
[5] University College London, United Kingdom

1 Topic and Approach

Citizen Science is a growing global movement fostering the participation of volunteers without formal scientific training in scientific research. Examples range from volunteer flood monitoring to participatory digital humanities to Do-it-Yourself biology research or participatory health research. **Across these, Citizen Science is notable for enabling participation throughout various stages in research and innovation processes that are possible in virtually all scientific disciplines**. As such, Citizen Science is an essential building block for advancing science, society, and policy (Hecker et al., 2018). This short paper provides a basic understanding of Citizen Science along with reflections and examples on its potential and challenges for Open Science.

Just as lessons learned from Citizen Science can inform and strengthen Open Science, the UNESCO Recommendation on Open Science can support and help shape the growth and proliferation of Citizen Science. There is not one global Citizen Science community, nor one view to represent, nor one representative body; however, with the Citizen Science Global Partnership (CSGP), there is a dedicated forum emerging at the global level. The CSGP seeks to provide a structure to foster exchange among and between Citizen Science communities, act as a coordinated point of entry for stakeholders such as the United Nations, and explore significant and cross-cutting areas within Citizen Science, including data and metadata standards and the contributions of Citizen Science to the Sustainable development Goals (SDGs). The establishment of Citizen Science as an essential element of a global perspective of Open Science is a topic of equal weight and represents a key occasion for international exchange and cooperation. To seize this opportunity, the primary authors of this short paper, practitioners and researchers of Citizen Science that have worked with Citizen Science associations globally on various aspects of Open Science, co-founded an Open Science and Citizen Science Community of Practice (CS & OS CoP) under the CSGP.

This CS & OS CoP became the springboard for a global call for inputs launched through a questionnaire distributed through CSGP networks. We received 63 responses from 24 countries in 7 days (in May 2020). The results of this survey, along with community knowledge codified in published white papers, peer reviewed articles, and our shared reflections, have informed this short paper[6]. The CS & OS CoP's will continue to support and contribute to UNESCO Recommendation on Open Science as the process unfolds.

While we were able to collect inputs from across world regions, a majority of responses came from Australia, Europe (inclusive of the UK), and the United States. This likely reflects the longer presence of supporting practitioner networks and organisations institutions, Citizen Science Associations (CSAs), based in these regions.

Figure 1: Countries of survey respondents

[6] The full list of >120 recommended peer-reviewed articles, policy briefs, blogs etc. is included in Annex 1.

2. Concepts, Actors and Principles

This paper aims at outlining the cornerstones for establishing Citizen Science more firmly among other elements of Open Science. It is important to note that both Citizen Science and Open Science are emerging movements. As they develop, they are both becoming more significant and layered with more sophisticated understanding of the themes, dynamics and shared characteristics. At this point in time, there is an important window of opportunity for laying the foundations of future, mutually beneficial development. However, this needs to happen on the basis of careful analysis and under participation of the respective practitioner communities. Only in such a way can we avoid the severe risks of restricting the potential of Citizen Science for innovation and inclusion that lie in a limited interpretation and reduction of the concept to crowdsourcing of data and volunteer work. To set the scene, we provide core definitions of both terms, highlight important actors and introduce key principles for implementation.

2.1 Definitions of Citizen Science and Open Science

Citizen Science has long – arguably always - been practiced, essentially consisting of **public participation in scientific knowledge production (Eitzel et. al., 2017).** Over time and across disciplines, different aspects of Citizen Science have been stressed: the collaborative nature of knowledge generation among professional scientists and the public (Irwin, 1995); a means to promote the public understanding of science (Bonney, 1996); and different degrees of public participation in scientific research. For example, citizen scientists can "contribute" to research solely through crowdsourced data collection, but can alternately "co-create" Citizen Science projects by participating in all aspects of research design (Shirk et al., 2012).

In practice, there are currently many forms of Citizen Science. In order to capture the current shared understanding among practitioners of what Citizen Science is, a recent effort led by a dedicated ECSA working group (ECSA, 2020) gathered inputs from more than 300 Citizen Science practitioners. The generated insights into the (European) interpretation of Citizen Science emphasize that **Citizen Science:**

- Works across all areas of research and knowledge production, including monitoring of environmental or health conditions;
- Is applicable across all scientific disciplines, alongside a variety of disciplinary traditions and research methods;
- Involves participants in one or more steps of the scientific research process;
- Follows protocols and principles of the discipline within which the research is framed; and,
- Varies in terms of the roles, responsibilities, and leadership opportunities for citizens, scientists and other stakeholders.

Open Science is an umbrella term that includes various dimensions of openness [Fecher & Friesike]. In the context of the European Union, the definition of the Open Science Policy Platform has become central: "*Open Science is scholarly research that is collaborative, transparent and reproducible and whose outputs are publicly available*." [EC, 2018, p.6] Within this framework, Citizen Science is considered alongside Open Code, Altmetrics, Open Resources, Open Data and so on. Many of the most important aspects to citizen science will be discussed in the next section.

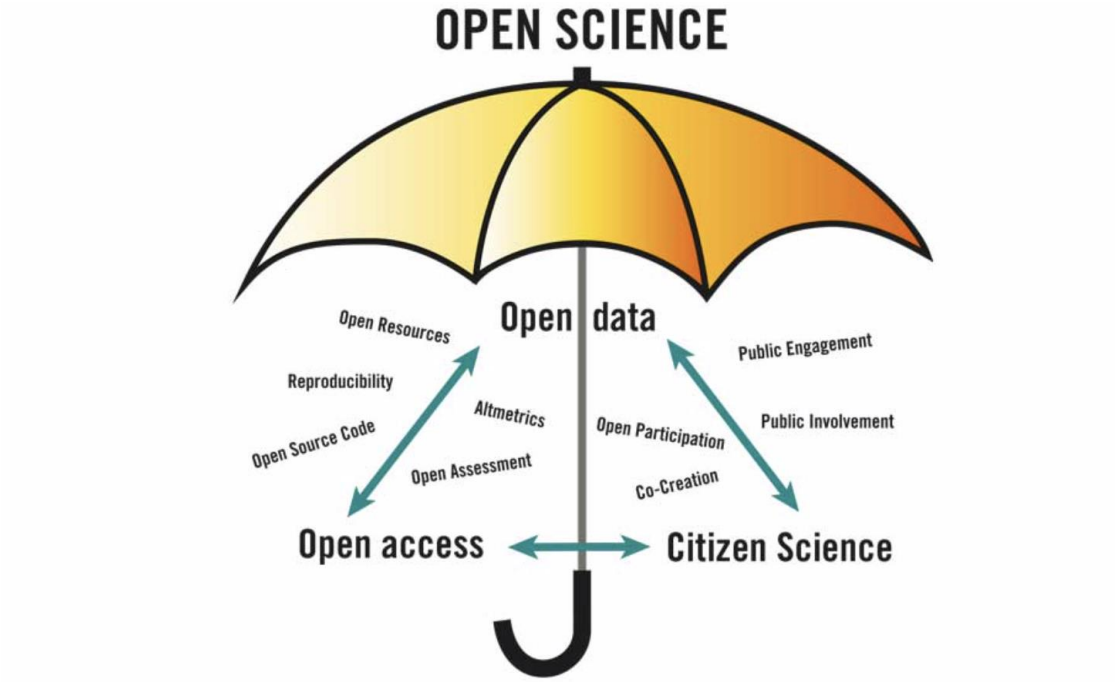


Figure 2: Open Science as an umbrella concept

2.2 Elements of Open Science and their relations to Citizen Science

"While Open Science opens the door of academia to the world, Citizen Science invites the world in (to experience science). The interaction between citizens and scientists reduces the gap between the two. In this way, experts and non-experts solve problems of common interest together, according to the rigor of the scientific method." (respondent)

To start with, and based on the perceptions expressed by respondents to our survey, it should be highlighted that Citizen Science and Open Science are two paradigms that not only describe how research **can be** done but also encapsulate normative views on how science **should be** done. Within different environments, they sometimes develop independently and sometimes interdependently. Depending on the interpretation, they may share core values for the advancement of science and society, which is why it is worth examining their (actual and potential) relations. Since UNESCO has chosen to posit Open Science as the overarching concept, we propose to understand Citizen Science as a linked and essential element of the former.

Open Science is usually defined by a range of key concepts that refer to accessibility of research results and processes, increasingly also research infrastructures. Citizen Science, in turn, is generally proposing to enlarge the understanding of openness by including participation of non-professional researchers (Figure 2).

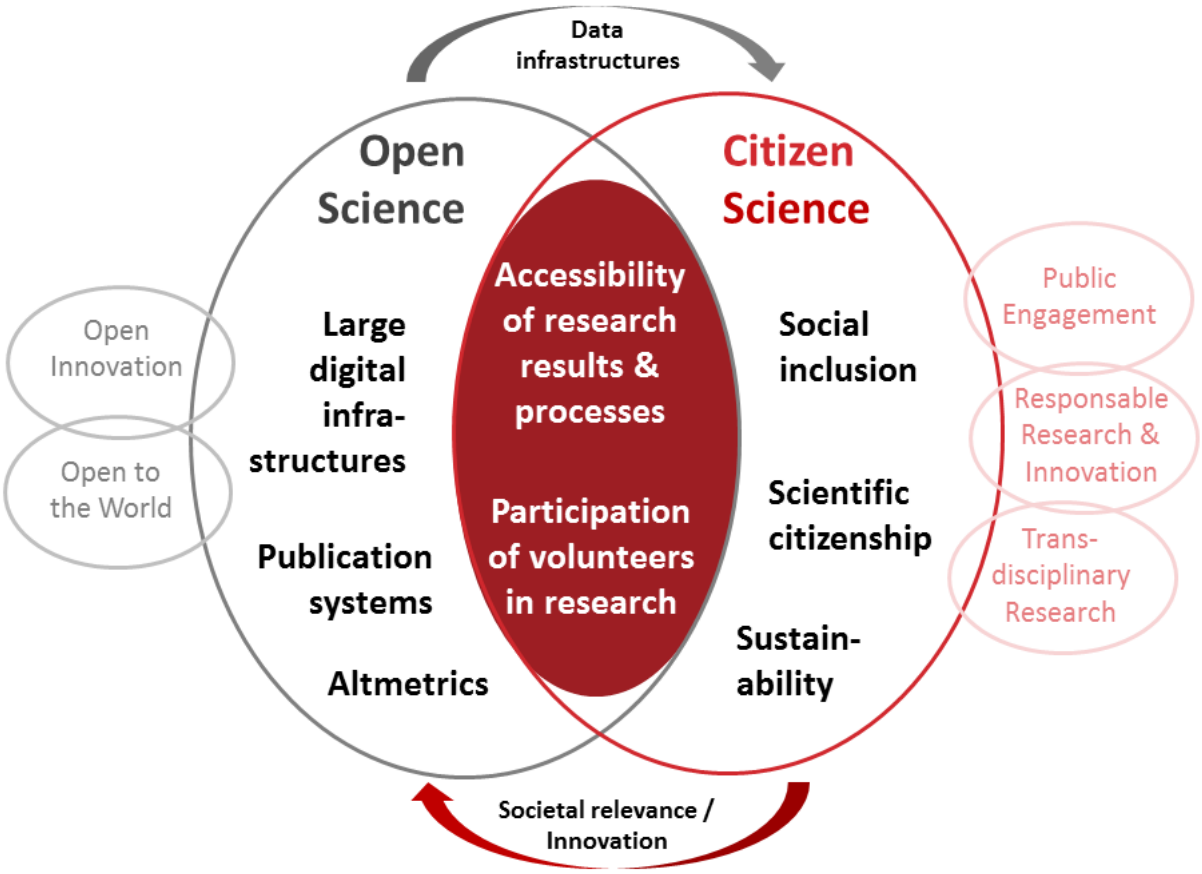


Figure 3: Citizen Science and Open Science Core Concepts and Areas of Synergy (Vohland and Göbel, 2017)

"Opening up data and access to scientific papers is necessary, but not sufficient to transition towards Open Science - the production of knowledge also needs to become more open for deeper participation!" (respondent)

Citizen Science can be understood as providing meaning to Open Science in a process dimension, by constituting the means for open, holistic and participatory processes of knowledge generation. In order to consider how Citizen Science can benefit or is hindered by a more open academic science and to discuss how open Citizen Science is, we focus on the key elements of Open Access, Open Educational Resources, Open Data, and Open Software and Hardware.

Open Access is a core element of Open Science. It is usually framed as science communication – allowing other researchers, and sometimes the general public, to access a publication regardless of institutional funding, ability to reuse text in machine interpretation, and the business of academic publishing. As such, the establishment of Open Access as standard in academic research would also significantly accelerate Citizen Science research, especially for initiatives driven by civil society.

Regarding the outputs of Citizen Science, the issue of Open Access is seen as an ethical and moral issue of making sure that the outcomes of research are shared with those who contributed, as well as society at large – e.g., as codified in the European Citizen Science Association (ECSA)'s 10 principles of Citizen Science (see section in guiding principles below), in the recommendations of the League of European Research Universities (LERU) or the rationale of the digital archive for African research **AfricArxiv**. However, beyond academic scholarship, the forms of Citizen Science publication are diverse and tailored to the many different stakeholder groups involved (see section on actors below).

Discussions of Open Access in connection to Citizen Science raise the question of authorship and what amounts to a "contribution". Often, the activities carried out by Citizen Scientists are considered at a level of technicians or hired helpers who are rarely if even acknowledged. However, the volunteering and time investment associated with Citizen Scientists means that opportunities for co-authorship can push the scientific practice towards more egalitarian practice of appreciating contributions and using advances in Information and Communication Technology (ICT)s for exploring new forms of acknowledgements.

Open Educational Resources (OER) are teaching, learning, and research materials developed for use within Citizen Science projects that are then shared through open distribution. Because of the need to train volunteers, Citizen Science projects often create their own educational resources, aspects of which can be re-used beyond a specific project or community. OER are made available in a range of forms, such as explainer videos or taxonomic species guides, and a range of digital formats, ideally marked with an open license or copyright waiver. These are developed from, and promote learning within, formal and informal science, education and life-long learning settings. In addition to training materials, many Citizen Science projects publish, or give access to, their research results in formats like whitepapers or quarterly reports.

Because a key component of the scientific research process is understanding an existing knowledge base, OER, like Open Access, facilitates Citizen Science by broadening the base of who may meaningfully participate. In the context of Citizen Science, OER complements academic open access publications by presenting knowledge in formats that appeal to specific volunteer populations or a general public (e.g., not everyone wants to read an academic paper to learn about bees). This is a major contribution that Citizen Science can make to Open Science.

Open Data – Often, the general discussion in Open Science is about reusability, accelerated innovation, and exploitation of more openly accessible research data for a range of purposes, including government and commercial use. As with publications, open research (and government) data represent an important asset for Citizen Science initiatives to use and expand upon in their work. Regarding data generated by Citizen Science projects, Open Data is a two-edged sword. On the one hand, it appears desirable that research results are openly available to the public for others to use as freely as possible. However on the other hand, Citizen Science brings to the fore discussions about the ethics of data, including around privacy concerns.

Open Software and Hardware - Published software code that enshrines the freedom to use, study, modify, and share is an under-explored and under-appreciated avenue for citizen participation in science. Some believe that the entire infrastructure supporting Citizen Science projects should be published under Open licenses. Notably, the well-known Zooniverse Citizen Science crowdsourcing website publishes the code behind their platform for others to study and build on. There is also a need to better involve civil society in this aspect of Open Science (see Box 1). Open hardware is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware devices. Open source software (OSS) and open source hardware (OSHW) can enable volunteers to participate in

Box 1: Examples of Open Software and Hardware in Citizen Science

Grassroots Citizen Science has demonstrated the ability to efficiently organise citizens in research formulation, data collection, and acting on the results. For example, Safecast was founded after the Fukushima disaster in Japan in 2013 where concerned citizens collected data on the spread of harmful radiation in the region. Since then, Safecast has grown into a global citizen science network across 100 countries collecting more than 60,000 daily measurements of environmental data (not just radiation) and most recently data related to COVID-19. In addition to data, Safecast also exemplifies citizen-initiatives to design and fabricate scientific hardware and release them as open source hardware. The Safecast bGeigieNano is a professional-grade geiger counter where the hardware design files/schematics are published for others to learn from and remix. Just One Giant Lab was recently featured by the Creative Commons as an experimental, grassroots organisation to bring people together to do science. Open Science Hardware represents a key area of activity of Do-it-Yourself science communities, such as those that have grown around the Gathering of Open Science Hardware (see section on collaborations and networks below).

data collection activities, facilitate data analysis, or even open the opportunity to co-create the tools that underpin scientific research processes.

Based on this rough sketch of relations between Citizen Science and other core elements of Open Science, the following sections explore implications of casting a Citizen Science perspective on Open Science.

2.3 Actors of citizen science

Key actors in Citizen Science are "scientists" such as professional academic researchers and (typically) unpaid "Citizen Scientists," or volunteers. Both draw on a range of knowledge sources and levels of expertise. Towards one end of the spectrum, experts are often (but not exclusively) professional, academic, and/or traditionally credentialed researchers who are opening their research activities to the public. Towards the other end lay researchers are often members of the general public who participate in or otherwise contribute to scientific activities without having gone through formal training in the particular discipline drawn upon in the Citizen Science activities.

The expertise that Citizen Scientists bring to the table is often of a different nature than the expertise of professional researchers, for instance contributing local knowledge or access to private data. They often move from lay to expert perspectives throughout the course of their engagement in science. For example, a researcher who begins by *participating in* a Citizen Science project could wind up serving in a more authoritative role over time, for example by validating data contributed by other participants or co-authoring a publication. In addition, researchers who have been trained in a specific discipline, often gain expertise in different epistemological approaches through Citizen Science activities. In fact one of the values of Citizen Science is to promote learning and develop greater understandings through engagement. In the Citizen Science context, scientists are individuals who may work within institutions (e.g. universities, research organisations, public authorities as well as museums), or independently.

Beyond the knowledge-based perspective of the individuals participating in Citizen Science, various other actors, organizations and institutions play a role by determining legal and policy conditions for Citizen Science, providing or directing funding sources, and determining how and by whom the results of Citizen Science research are applied. For any given Citizen Science project, the ecosystem of actors can be quite complex, especially when direct links to local policy are involved (see Box 2); it is therefore important to carefully map this in order to navigate the roles, relationships and agendas of different actors.

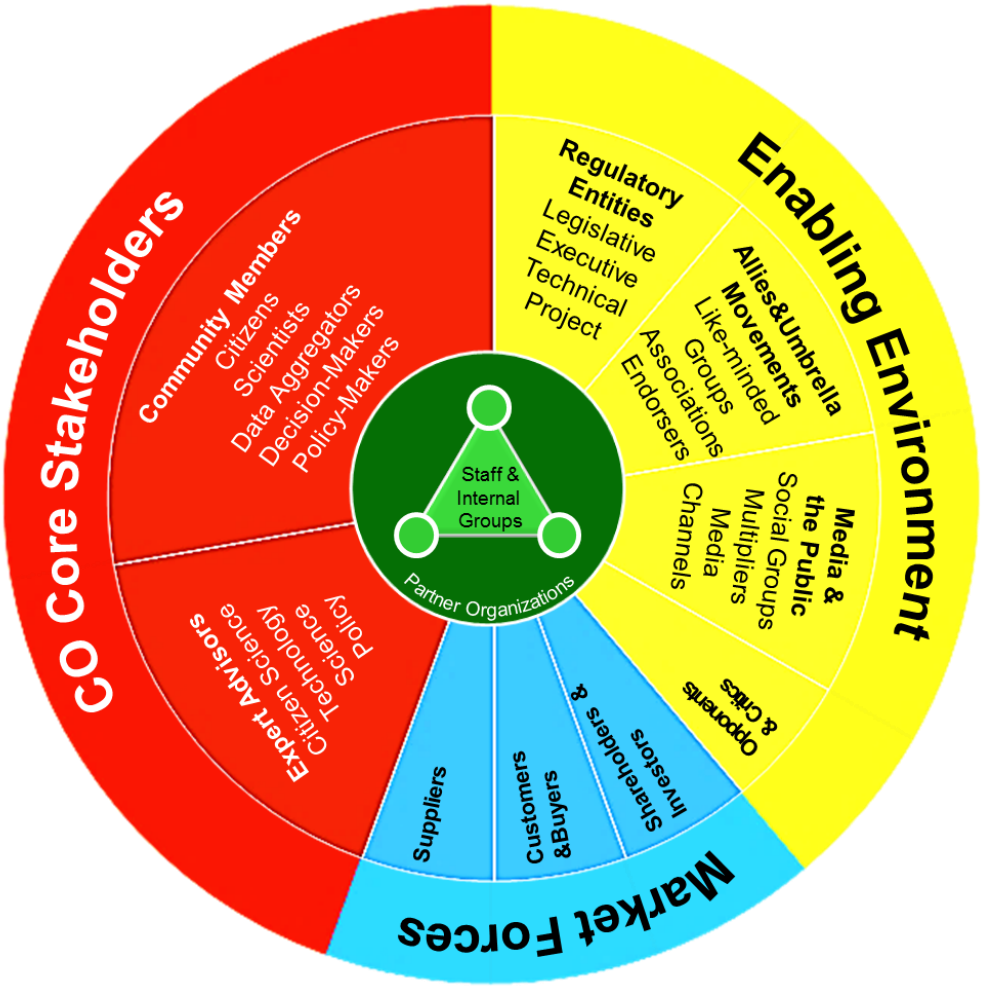
The landscape of Citizen Science at large is supported by robust organizations and institutions in the civil society and NGO sector, including professional associations of Citizen Science practitioners (Storksdieck et al. 2018). Over the past few years they have been created in countries and regions across the world (see section on networks below for examples and discussions).

Other actors outside and at the margins are NGOs like the Creative Commons who provide tools like licenses that bridge Citizen Science and Open Science perspectives. Policy bodies, like UNEP and UNESCO at international level or national agencies, are influential actors for Citizen Science, at multinational, national, sub-national, and local scales.

Within the Open Science paradigm, additional actors are influential for Citizen Science, namely publishers, funders (public agencies, private foundations or companies) and providers of data repositories/research infrastructures, all of whom have strong influence on the drive of Citizen Science practitioners to comply with Open Data and Open Access (see section 3 Opportunities, challenges and incentives).

Box 2: Example of stakeholders in Citizen Science projects

The Ground Truth 2.0 project developed a generic stakeholder analysis for citizen observatories that it applied in six countries (four in Europe, two in Africa). Citizen observatories are a particular form of Citizen Science initiative with a close link to (local) environmental policy. This identified ten main stakeholder categories, with stakeholders deliberately listed with more than one role (i.e. in several categories), indicating potential role conflicts, or the need to engage the same stakeholder via for multiple reasons. Core stakeholders in the observatory are citizens, scientists, (commercial) data aggregators, decision- and policy-makers. The enabling environment consists of stakeholders who either have a legal mandate or live in the project area and who influence how the activities of the citizen observatory are received, hence enabling or limiting the impacts that the observatory can achieve. In contrast to the core stakeholders, the enabling environment can be influenced but not chosen by the citizen observatory. Market forces consist of those stakeholder groups that engage in direct economic (financial) transactions with the observatory. Internal stakeholders are important functional entities in the project or organization. Typically, internal stakeholders are employees and managers of organizations, not all of whom are necessarily in favor of the observatory. This approach is applicable in various geographical contexts, social settings and related to different issues.



Source: Pfeiffer et al., 2016

2.4 Guiding principles for Open Science implementation

Regarding the implementation of Open Science, our paper is mainly concerned with implementing "good" Citizen Science. To determine what may count as such on a project level, the "Ten principles of Citizen Science" advanced by ECSA have been widely distributed within the global Citizen Science community (Box 3). There are other principles for other elements of open science related to open science, for example open hardware.

Box 3: Two sets of principles of good Citizen Science

ECSA 10 Principles of Citizen Science (Robinson et al., 2018)
Principle 1: Citizen science projects involve citizens in **scientific endeavour that generates knowledge**.
Principle 2: Citizen science projects have a **genuine science outcome**.
Principle 3: Both the professional scientists and the citizen scientists **benefit from taking part**.
Principle 4: Citizen scientists may, if they wish, participate in **multiple stages of the scientific process**.
Principle 5: Citizen scientists receive **feedback** from the project.
Principle 6: Citizen science is...a **research approach** like any other, with limitations and biases.
Principle 7: Citizen science **data and meta-data are made publicly available** and where possible, results are published in an open access format.
Principle 8: Citizen scientists are **acknowledged** in project results and publications.
Principle 9: Citizen science programmes are **evaluated** for their scientific output, data quality, participant experience, and wider societal or policy impact.
Principle 10: The leaders of citizen science projects take into consideration **legal and ethical issues**.

Principles by OCSDNet for of Open and Collaborative Science
Principle 1: Enables a **knowledge commons** where every individual has the means to decide how their knowledge is governed and managed to address their needs.
Principle 2: It recognizes **cognitive justice**, the need for diverse understandings of knowledge making to co-exist in scientific production.
Principle 3: It practices **situated openness** by addressing the ways in which context, power and inequality condition scientific research.
Principle 4: It advocates for every individual's **right to research** and enables different forms of participation at all stages of the research process.
Principle 5: It fosters **equitable collaboration** between scientists and social actors and cultivates co-creation and social innovation in society
Principle 6: It incentivizes **inclusive infrastructures** that empower people of all abilities to make, and use accessible open-source technologies.
And finally, open and collaborative science:
Principle 7: strives to use knowledge as a pathway to **sustainable development**, equipping every individual to improve the well-being of our society and planet.

However, an important factor for how well a Citizen Science and Open Science ecosystem can develop within countries and regions across the world, are inequalities in resources and power. In order to take this systemic level into account, remove barriers, and strengthen diversity and equity, the 7 principles of Open and Collaborative Science by OCSDnet provide an additional compass for reflection and setting aspirations for where to go.

As the differences between these two sets of principles show, multiple objectives and values are pushing towards Open Science (and Citizen Science) from different directions, which make simple definitions impossible. As a substantial discussion of these orientations is beyond the scope here, it is important to highlight at least three starting points for the deeper reflections necessary to guide the further implementation of Open Science. First, it is useful to compare two contrasting views on Open Science. While Nielson (2020) considers it a vision of a better science that is contributing well to society, a competing view from Mirowski (2018) regards it as part of further market-driven approaches to the production of knowledge. Citizen Science actually serves to realise both. Second, a more egalitarian perspective of the theory and practice of Citizen Science calls into question more hierarchical conceptions of expertise (Collins, 2014). According to this view, scientific expertise is no longer regarded per se as superior to other forms of expertise; instead, pluralities of knowledge frameworks, integration of values into decisions about science, and a "deep" democratisation of the production and use of knowledge are brought to the fore. Third, Open Science and Citizen Science

need to be considered in their global dimensions, since scientific and political systems, and increasingly also civil society, are densely networked internationally. From this point of view, it is noteworthy that perspectives from the Global South (e.g. Chan et al., 2019) are often underrepresented, if not entirely absent, from the discourse; however, they are essential if we want to use Citizen Science as part of Open Science for sustainable development. The CSGP recognises that a key function of its work is to partner with, nurture, and elevate Citizen Science Associations, networks and all their work, globally.

Considering these starting points, from a Citizen Science perspective the questions that need to be asked are: Open Science for whom, and to what end? Who benefits, and to what degree? Who stands to lose and how and who is excluded? With this paper, we aim to chart this terrain in a first, indicative way in order that this can serve as a basis for future discussions of these and other questions in a CS&OS Community of Practice.

3. Opportunities, challenges & incentives for Open Science from a Citizen Science perspective

In this section, we explore the opportunities of Open Science as well as the challenges and incentives for Open Science, from a Citizen Science perspective.

3.1 Opportunities of Open Science

Opportunities created by sound implementation of Open Science are perceived to abound and are closely related to and increasingly experienced within Citizen Science. These range from i) improvements to process itself, e.g. the mass production of global open data of a 'scientific renaissance' owing to a new and more democratic research community; ii) the creation of economic opportunities, e.g. via required infrastructure investments, (new) jobs, and business models built on public data, and significant reduction in public expenditure; and iii) outcomes resulting from this form of knowledge creation, application and change such as improved empowerment of communities and community resilience, enhanced governance and social cohesion; disaster risk reduction and mitigation of permanent global pollution. More specifically, evidence is emerging of Open Science being achieved through Citizen Science around the world, including via data sharing with involved communities and uptake of results by managing agencies.

Open Data, with scientific datasets released under the appropriate licenses, can allow professional scientists as well as citizen scientists to 'explore and tinker' while providing novel information that professional scientists may use to augment targeted studies or analyze through meta reviews. This is especially important in fields such as climate change and global ecological change where there usually is not any one dataset that can encompass the whole world, hence needing to combine "local" information from different sources into a cohesive whole (e.g. Gerstner et al. 2017, Wallace et al. 2017). In addition, Open Data from Citizen Science can also provide key inputs to issues that can be practically addressed (primarily on local levels) see Box 4).

Box 4. Examples of areas of application / issues that can be addressed with open Citizen Science data

Where to put bins, ashtrays. How to evaluate introduction of public services and understand shifts in problematic consumer behaviour (eg. night time drinking, broken glass, public injecting, dog shit, accessibility for wheelchair users, walkability, safety, mental health, etc). How to enforce polluters pays principles. Whether to develop new indicators for the deprivation index and improve the allocation of resources across society. How to set fines and taxes for plastic / litter diminishing shared natural resources. See also https://www.publicsectordigest.com/article/embracing-open-data-plastic-pollution

All of these questions are opportunities for local policy communities to intervene and mitigate the spread and impact of plastic pollution. By involving citizens in data collection, there is an opportunity to collect more information for better evidence-based decision making. In addition, widening the network of stakeholders who are responsible can mean that citizens can better hold themselves and policymakers accountable for driving change.

In these cases, data collected for one purpose (like scientific research) can also inform different types of decision-making, at the policy and individual level.

Open Access to results ensures that papers, including those based on Citizen Science contributions, are not only accessed more easily but also can also be read, used and cited more frequently, hence increasing their impact.

In terms of knowledge generation and understanding, participation in Citizen Science provides the opportunity to grow and expand participants' knowledge. Moreover, Citizen Science enhances the scientific process within an Open Science paradigm by helping to understand the limitations of the process and - depending on the level of participation of a given Citizen Science initiative - it serves to produce 'relevant science with real output and significance'.

At this point in time, Citizen Science presents a unique opportunity for Open Science given its potential to address the need for understanding at a global scale: with open data and mechanisms to enable interoperability, data that were previously in silos can be combined and cross-referenced. This can be particularly valuable in sharing data that can be used to monitor progress towards the SDGs from a local to national and global scales. For example, the United Nations Environment Program recognizes the value of data re-use in global assessments, and are looking towards Citizen Science marine litter initiatives to help measure progress against SDG 14.1.1 (health of our oceans).

This case also serves to exemplify that by engaging a wider range of stakeholders in monitoring plastics pollution, Citizen Science not only produces more open data for assessment, but also engages and empowers participants to understand the problem and make better decisions in their daily lives. While not all Citizen Science projects set out (and actually manage) to democratize science or lead to specific societal outcomes, the process and results of Citizen Science strengthen open society by making (more) facts available. It can also provide opportunities for experiential learning, leaning to topical knowledge gains as well as enhanced knowledge of the process of research. That can help people to better understand their environment, as well as develop the critical thinking skills required to evaluate and ultimately counter fake news as well as fake science.

3.2 Challenges for Open Science and how to overcome them

Open Science expectations of opening up the ability to shape research projects in a way that matches societal interests (making science more responsive) is also challenged in Citizen Science. Participation in Citizen Science projects falls on a spectrum, with involvement sometimes limited to data collection, and sometimes encompassing all aspects of the scientific research process (Haklay, 2013; Shirk et al., 2012). In more collaborative ("co-created") forms of Citizen Science, the expectation of giving up power by professional scientists to include other people in shaping the project and its methodologies can be challenging (Golumbic et al., 2017). The promotion and incentive structures of many scientists, as well as a false ethos of rewards to individuals (e.g. "becoming a PI or lab head") are such that without addressing this cultural issue, it will be difficult to open up science. Moreover, it also explains why the "contributory" mode is a common model for Citizen Science, as it more closely aligns with traditional research practices and keeps the hierarchy in place.

The challenges for Open Science are multi-fold and commonplace, concerning both the process of Open Science as well as its outputs in terms of Open Data and Open Access to results. Open Science still suffers from misunderstanding by the public. There is a general lack of awareness of Open Science that should be addressed by proactive outreach. Soranno et al. (2015) provides a good reflection and critique of this problem in the environmental sciences, while also noting that some progress is being made.

The attitudes of academics towards Open Science are mixed; some authors argue that industrial

actors are more receptive to Open Science than academics. Others refer to a general institutional resistance by the traditional science community, the politics of making journals open access, the cost of publishing in Open Access journals and the difficulty of finding volunteer reviewers for open access Citizen Science journal papers. Even when sound policy is in place, researchers may need support to adhere to it in practice (Cruz et al., 2019). Moreover, funding for financing Open Science practices are currently very limited and Open Access fees provide a key challenge particularly for researchers in developing countries or at less established institutions.

"It is necessary to re-evaluate the evaluation model of scientists in order to promote collaborative work with society in the construction of scientific knowledge via Citizen Science". (respondent)

The dominant research evaluation system (both institutional and individual) does not foster the implementation of Open Science, and the current evaluation model for scientists often does not encourage their use of Citizen Science. The performance of scientists, their status and recognition are all primarily linked to the quantity and "quality" of the publications. Consequently, data is treated as a valuable commodity, which many researchers keep confidential until publication. Practicing Open Science by developing a Citizen Science project implies additional effort and dedication by researchers, including time spent on incentivized practices like scholarly communication, which translates into less time to publish. At the same time, in their evaluation, time invested in collaborative work with society is not sufficiently regarded or rewarded.

"The challenges for opening up to the public are problematic in terms of cultural change of what scientists and research institutions do" (respondent)

There are 'pockets of privilege and protective status' in academia that regards Citizen Science and the involvement of non-specialists in any form beyond data gathering (or other steps of the scientific method) as a different and less important category of research. And within Citizen Science there are 'pockets of apprehension' about the involvement of lay, local, ethnic and non-Western systems of knowledge in the design and practice of research. Yet it is precisely the needs of underserved communities that we have to work to address (Soleri et al., 2016).

Opening up the scientific process to various stakeholders, particularly citizens is often easier said than done. Stakeholder engagement and volunteer management - particularly for sustained involvement over time in one or more steps of the scientific method - require time, resources and dedicated approaches, strategies and skills. Overall, this demands a balancing act and compromises in order to accommodate the interests of citizens (and other stakeholders) while living up to scientific standards. The Citizen Science community has advanced the understanding of the boundaries of participation, including who can participate and how. Nevertheless, much more work is needed to improve the inclusiveness and equity of Citizen Science, which demonstrates the variable access to education, resources and technologies, gender, socio-economic, national, and other differences (Haklay, 2018). To stimulate exchange and debates on these topics, ECSA has a Working Group dedicated to Empowerment, Inclusiveness and Equity together with the Living Knowledge Network of science shops. The WeObserve Community of Practice on Co-design & Citizen Engagement is producing guidance in the form of a 'landscape' of co-design practices in Citizen Science. Taking such approaches into account, Citizen Science demonstrates the need to actively reach out to underrepresented parts of society, and to not consider Open Science as a passive act in which, once open, there is no need to pay attention to how the outputs are used and by whom. Competition in Citizen Science in some regions is experienced as quite fierce due to lack of funding, career ambitions, and culture. Infrastructure is expensive and often only funded for development over short periods, without long-term revenue streams that would make an Open Science initiative truly sustainable. Limited funding perpetuates among people who are often re-inventing the wheel creating "new" projects in grant applications to last the short-term funding cycle etc. While this is a systemic issue in science more generally, it seems to be even more severe in Citizen Science since its data is still often mistrusted – and short term projects limit the ability to increase data reliability over time. Ideally, a stream of income would provide some independence from competition for funding.

"[There is] pressure to make everything open and valid, and reasons why it is not always appropriate to be open." (respondent)

In Citizen Science, it seems ethically reasonable to, whenever possible, provide full access to publicly collected data and metadata as well as to the analytical tools and results of data analysis. In addition to realizing the ideals of Open Data and Open Access, such as new and accelerated research, this would help satisfy ethical requirements specific to "giving back" to volunteers. In practice, "*contrary to what many people assume, data sets from volunteers are among the most restrictive in how they can be used.*" (Groom et al., 2017, p.612). In some instances, Citizen Science data is not open in order to avoid misuse of the data (e.g. revealing the location of observed endangered species). In others, data policy is difficult to agree on due to the dynamics among involved stakeholders, e.g. when open Citizen Science data may trigger shifts in governance structures and changes in the responsibilities and accountability of public authorities in terms of the continuity and responsiveness of their interactions with the public (Wehn et al., 2015). De facto, specific stakeholders may end up as gatekeepers, whose control of Citizen Science data and processes can discourage or even prevent participation in Citizen Science. Finally, a lack of common nascent data and metadata standards, and limitations to data management including licensing remain, alongside a lack of awareness, capacity or access to infrastructure. Guidance and process support for arriving at agreed data policy in multi-stakeholder Citizen Science settings (incl. clarity on rules for use, appropriate 'levels of openness') could provide ways to foster open Citizen Science data.

Challenges for Open Data also relate to a lack of willingness to share data because of competition on different levels: among countries (innovation index), among research institutions (research evaluation system), and among individual researchers (individual KPIs, attestation, job opportunities). But once a researcher decides to share their data, ethical challenges remain, including around privacy. Because the vast majority of Citizen Science data involves the collection of location, information about where an 'observed property' (such as the presence of biodiversity) may be found is also information about the location of the observer, in this case a Citizen Science volunteer. Potential privacy threats are exacerbated when data are made available in real time, and when repeated participation can illustrate information into personal routines (Bowser et al., 2017).

To promote data sharing and interoperability, some standards and advances are now widely adopted across scientific disciplines, for example by The Open Science Framework, the Findable, Accessible, Interoperable, and Reusable (FAIR) framework, Research Ideas and Outcomes, or the Zenodo platform.

"There are strategies that emphasise Open Science, however when it comes to implementation level, the philosophy changes." (respondent)

For example, Citizen Science data often lacks clear and standardized meta-data, and detailed descriptions of the research process including quality control metrics. Further, while many groups informally describe their data as open, in practice they are often challenging to access (e.g., through ideal practices like machine-readable Application Programming Interfaces, or APIs) or otherwise download the data. Further, copyright labelling can be ambiguous, and standardized licenses are not yet the norm. This means that while users might be technically able to download the data, they may not be able to evaluate its fitness for (re)use in other research and policy contexts, nor legally reuse it. This is a significant issue that prevents many Open Science ideals, including replication and meaningful transparency, from being realized.

Similarly, data policies such as terms of use that form contractual agreements between professional researchers and Citizen Science volunteers often prevent either or both parties from reusing data outside an initial context without permission.

More and clearer technical guidelines, and supporting infrastructures, are needed. Many Citizen

Science projects, especially those conducted outside of traditional academic institutions, lack easy and obvious access to platforms for data sharing and management. Elevating ongoing work on standards, as described below, as well as refining and updating Citizen Science data management guides (e.g., Wiggins et al 2013), would be an improvement to issues of transparency and access.

In themselves, the challenges to realise the large ambition of the concept of Open Science can bear the risk for it to be captured by different interests. *"The modern political frame of discourse presents a central challenge to Open Science where hysterical tribalism seeks to shout down opponents"* (respondent). In principle, sound Open Science is (supposed to be) apolitical, but the humility to simply present evidence and interpretation in a compelling but unbiased manner, is not easy to maintain.

3.3 Incentives for Open Science

The elaboration above of the opportunities and challenges for Open Science demonstrates that there is a good understanding already of both. In general, incentives should leverage opportunities and help address challenges. Therefore, it may be useful to question current practices and consider how a stable system of cooperation can be established without enforcing it. This requires careful understanding of drivers of individual as well as organisational behaviour.

From a rational perspective and where professional researchers are concerned, a key incentive for Open Science is that by making research more widely available to the general public and other researchers, the greater likelihood that the research will be used in practice (and hence have societal impact) and cited by other researchers (and hence have scientific impact). A main driver behind Citizen Science initiatives can be the existence of an urgent information gap, especially in emergency situations, such as the Safecast project in Japan to measure radiation levels following the Fukushima disaster, which provided citizens with the information necessary to make decisions on their own safety.

Within Citizen Science projects, the motivations of Citizen Scientists differ, ranging from a general interest in specific species, being involved in a community with similar interests, learning new skills and understanding, contributing meaningfully towards evidence-based decision making and contributing to environmental activism (Wehn and Almomani, 2019). While citizens are key actors in Citizen Science, they are also not the only ones. The composition of citizens, scientists, authorities, etc. as well as the cultural setting and resource availability, determine which actual incentives are at play in any given situation, either fostering or inhibiting Citizen Science in particular and Open Science more generally. Moreover, there is evidence that voluntary data collection does not automatically imply the participants' willingness to share such data; recognition of contributions needs to align with their particular incentives while data policies need to be open and explicit (Groom et al., 2017).

For professional researchers and Citizen Scientists alike, incentive systems need to be shifted to encourage them to open up their data and make it FAIR. As is evident from the current COVID-19 pandemic, faster sharing of disease outbreak data enables faster diagnosis (see Box 5). Publishers have a key role in enforcing that applicants conduct Open Science, publish their work accordingly and that data is open even before publication, but such openness criteria or financial incentives may need to go hand in hand with considerations for the practical support and skills required to open up data (e.g. EC, 2017). While these and other practices may work and these incentives even be formalised in grants/policy and other structures of research, individuals may comply because they have to, not because they believe in the value of such practices. In the long run, with resources and funding requirements still in place, it would be better to change salient beliefs of key Open Science actors, e.g. via demonstration of tangible impacts of Open Science practices.

Box 5: Examples of existing and new Citizens Science initiatives to track the COVID 19 virus, behaviours and mental health

Existing initiatives updated to cover the COVID19 virus

The citizen science app 'CoronaReport' for social science, led by the University of Edinburgh, will be ready soon. Get your app invite now at coronareport.global.

FluTracking is a surveillance system to detect and monitor the spread of influenza in Australia and New Zealand. By taking part, you'll not only be contributing to scientific research, you will be helping to track influenza in your local community and nationwide.

Flu Near You has launched a new initiative called CovidNearYou to help track corona symptoms in the US and Canada. **https://covidnearyou.org**

Flusurvey has now been adapted to monitor community prevalence and trend of symptoms related of the novel coronavirus. The system will capture additional information about possible community acquired covid-19 using self reported respiratory symptoms reported on the platform.

Influmeter, the Danish part of Influenzanet, is based on voluntary efforts by citizens who, regardless of whether they have sought medical attention or received treatment, report weekly on whether they have had symptoms and thus contribute to knowledge about dissemination in the community. Everyone who lives in Denmark can join the Influmeter.

New initiatives for tracking COVID19, behaviours and mental health

Operation COVID19 is a project to track, mobilise and prevent the spread of coronavirus-19 to save lives and improve global public health systems, and also has a Facebook Group.

The NHS in the UK has a symptoms checker with advice, that might also be tracking that data https://111.nhs.uk/covid-19

TraceTogether is an app launched by the Singapore government that uses a community-driven approach to identify close contacts of users.

TrackTogether in the UK is a not-for-profit survey on contact tracking.

A new Israeli initiative to track and monitor Coronavirus outbreak "hotspaces" using citizen science has been set up in Israel.

CoronAPP is a questionnaire in Danish on physical and mental health and well-being in relation to the coronavirus situation.

Corona-land (in English and Danish) provides a 'before and after' survey for the effects of using an interactive coronavirus simulator. The simulator can also be used as an educational tool on its own, with tutorials on social distancing, hospital capacity and what people can do to help.

The COVID Symptom Tracker has been launched in the UK by King's College London and their Healthcare spin-off **Zoe.** It rushed to launch so still has some hiccups, such as excessive phone-access permissions, but is backed by scientists who are collaborating with the NHS as well.

How is coronavirus affecting your life? Survey from international collaboration including researchers from 31 countries worldwide to understand behaviour and psychological effects of the corona epidemic.

Source: This extract is from a list that was initiated by the CSA and includes inputs from ACSA, CitizenScience.Asia, ECSA and RICAP and is being continuously updated.

4. Implementation and support for Citizen Science as part of Open Science

This section examines three key factors of the implementation and support necessary to anchor Citizen Science practice more thoroughly in Open Science: infrastructure and capacity, collaborations and networking, and funding.

Baseline argumentation can be drawn from two reference publications that stem from substantial discussion processes: a policy brief from the EU-funded project DITOs (DITOs consortium, 2017) examining synergies between Citizen Science and Open Science work in Europe and beyond, and

the Roadmap of the Gathering for Open Science Hardware (Murillo et al., 2017). By those communities, it is generally acknowledged that there is an urgent need to build dedicated technical and institutional research infrastructures for community-based approaches, including Citizen Science, and support the integration of these approaches into those of Open Science. This is important, because Citizen Science and Open Science can be understood as providing socio-technical infrastructures for open and participatory research in their own right. Opportunities for collaboration and networking - among practitioners as well as with other stakeholders - are considered central to foster a rich and prospering Citizen Science ecosystem. The latter is essential to increase quality, mutual learning and credibility. There is also consensus that funding opportunities for Citizen Science need to significantly expand in scale and scope as well as to be better adapted to the particular needs of practitioner communities. These include, for instance, recognizing civil society organisations and individuals as grant holders, introducing scoping phases for co-design of research agendas, offering long term support for community projects or funding prototyping and open hardware distribution. Both publications, and in particular the GOSH road map, also emphasize empowerment, inclusiveness, and equity across broad stakeholder groups.

The very dynamic development in both the fields of Citizen Science and Open Science over the last few years has brought about a wealth of exciting new initiatives, actors, challenges and ideas that need to be considered. Those are discussed below.

4.1 Infrastructure and capacity

Citizen Science depends on many kinds of infrastructures to flourish, especially in an Open Science context: (digital) repositories for data and information, ways of data and sample deliveries, research labs and scientific institutions in a broader sense, engaged people, communities and NGOs, events, festivals and scientific culture as well as cooperation networks. Infrastructures are important because they

- enable access to data and information that constitute both inputs and outputs of joint research processes,
- enable doing Citizen Science both for practitioners and researcher, and
- provide an overview on the field, supporting exchange and learning.

Infrastructure for supporting Citizen Science needs to be built with the flexibility and diversity of project types in mind but also have some overall guiding principles. Looking at data and information, there is a need for new models of governing privacy, personal data and data repositories. Integrations between Citizen Science and Open Science infrastructures, for instance with the EU Open Science Cloud , are important and will need to be created for the panorama of research areas. For working with data infrastructure, e.g. to catalog and interpret data as it becomes available, capacity building is necessary. However, numerous physical and geographical barriers exist for the Global South and those from outside stereotypically-"developed" countries to engage in Open Science and Citizen Science, such as lack of internet access or the ability to easily travel internationally to collaborate. Infrastructures should address these problems head-on to enable equitable access to technology, information and practitioner communities. Solutions to these problems should also be based on the principles of Free Culture, where the often-invasive tendencies of multinational proprietary technology conglomerates will not dominate.

4.2 Collaborations and networking

Since Citizen Science is constituted in collaborations between actors from within and outside academia, cooperation is at the heart of this approach. Intermediary organisations and brokers as well as IT-platforms are key for establishing and maintaining exchange and communication. Beyond Citizen Science projects, numerous practitioners networks and associations have been created over

the past decade (Storksdieck et al. 2018). They comprise geographical networks that by now exist on almost every continent as well as thematic ones (see box 6)[7].
Practitioner associations and networks stimulate and do learning and exchange, research as well as advocacy activities. They also entertain platforms, capacity building projects and working groups, which undertake communication and co-creation work, and provide services like the Open Access Journal Citizen Science: Theory and Practice. Finally, Citizen Science-related networks also exist within organisations of professional science, such as the Association of European Research Libraries, as well as among policy makers, like the US Federal Community of Practice on Crowdsourcing and Citizen Science.

Box 6: Examples of high level Citizen Science practitioner networks

Africa Open Science and Hardware community and summit
Alliance Sciences et Sociétés France
Australian Citizen Science Association
CitizenScience.Asia
Citizen Science Association United States
European Citizen Science Association and Eu-citizen.science-platform
GLOBE
Gathering of Open Science Hardware community and conference
Hackteria Network
Les Petits Débrouillards France and global network
Living Knowledge - The international Science Shop Network
Local Indicators of Climate Change Impacts Citizen Science Platform
Open and Collaborative Science in Development network
Open Source Hardware Association
Public Lab
Red Iberoamericana de Ciencia Participativa
Safecast network
Sensor.Community

Inclusiveness and equity are cornerstones of networking in Citizen Science communities and still need to be improved significantly. For instance, current Citizen Science conferences are significantly restricted to professional academics for their scheduling, registration fees and often travel requirements with little to no online components. This creates high barriers to entry for Citizen Scientists and leaders from civil society initiatives to participate in the discourse and for two-way collaboration. Along these lines, numerous survey respondents suggested that more support is needed to support peer-to-peer learning among non academic Citizen Science practitioners. What is more, the Public Lab example also shows that "ordinary" citizens have very limited access to scientific discourse such as scientific journals, databases, or even a way to communicate with professional scientists. These opportunities should be encouraged more and come with financial support that individuals without formal credentials (such as an advanced degree) can be eligible for.

4.3 Financial considerations

In order to support citizen participation and more openness, research funding needs to be adapted. Central aspects collated from major policy papers of Citizen Science communities that have been derived from deliberative processes include (see Box 7):

Additional suggestions that have been made in the knowledge gathering for this input paper include:

- Working on other models for Open Science e.g. not-for-profit research that can perpetually fund Open Science research through ethical commercialisation of results;
- 'Negative taxation' for scientific work;
- Predictable and sustainable funding for volunteer organisations conducting Citizen Science at the local level; and,

[7] See also https://en.wikipedia.org/wiki/Citizen_science.

- A "no doc" fellowship program to bring promising #CitizenScientists into intimate involvement (both in persona and remotely) with leading research universities where a "win-win" of such collaboration is possible.

Citizen Science demonstrates the challenge of research funders to open up in terms of whom they are funding. In the case of Open Access, or Open Source software, etc. the funding continues to go to actors within the scientific ecosystem. While there are winners and losers internally (e.g. more money to people who develop Open Source software, less to people who rely on proprietary tools) money is still typically invested within the academic community. This is also true when important work around understanding the outcomes of participation, including in formal and informal education settings, is also supported solely through grants designed primarily to create academic knowledge of these practices. In Citizen Science, the growing expectation is that money that will be invested in science will concurrently benefit the wider society. This means that funder investments in public engagement in general, and Citizen Science in particular, is relatively underfunded within the Open Science area (Bernstein et al., 2017). This has a detrimental effect on the ability of the field to grow and strengthen. It also hurts individual Citizen Science projects, though some gaps are filled through crowdfunding or in kind support.*"Public policy should fully recognise the enormous value from Citizen Science and Open Science, and demonstrate that by providing financial support" (respondent)*

Box 7: Funding recommendations from reference policy papers

DITOs Policy Brief on Citizen Science and Open Science [DITOS Consortium, 2017]

- Increase and diversify the opportunities for small seed funding for project prototyping and experimentation in Citizen Science and Open Science.
- Offer mechanisms for funding that address the different project characteristics of Citizen Science and Open Science initiatives, such as scoping phases for co-design of research agendas, flexibility in accepting changes to project execution, and recognition of civil society organisations as well as citizens as applicants and grant holders.
- Fund positions and horizontal measures for community management.
- Treat increased transparency and public participation in research projects as an opportunity to reduce bureaucracy around such projects.

GOSH Roadmap [Murillo et al., 2017]

- Address the lack of funder awareness about OScH, which prevents projects from securing seed funding, by creating an advocacy toolkit for funders as well as engaging directly with investment partners and funders.

ALLISS White Paper "Taking Knowledge Society Seriously" and other work [ALLISS, 2017]

Proposes innovative financial dispositives to make more research funding available and accessible for the third sector of research that comprises civil society organisation and initiatives, such as the creation of a dedicated foundation as well as a mutual fund.

In some cases, limited support for non-academic practitioner networks and challenges related to funding intersect: "*Open Science facilitates collaboration and networking, though it can be very difficult for those who are not in the core (the top universities and research organisations in developed countries) to get into the networks. No one comes looking for us, except as 'cheap labour' to provide data. Infrastructure, capacity and funding are obviously major constraints for many researchers. Policy becomes irrelevant when there simply is no funding." (respondent)*

In many cases, the implementation of Open Data policies is not supported financially and business models for coordinating structures of Citizen Science initiatives are still unclear. Infrastructure is expensive and often only funded for development over short periods, without long-term revenue streams that would make an Open Science initiative truly sustainable. Limited funding perpetuates people often re-inventing the wheel creating "new" projects in grant applications to last over the short-term funding cycle etc. This challenge is actually an opportunity for innovation, as the demand for open data and reusable infrastructure could help create business opportunities and new markets that would generate economic value while benefiting the field.

Discussions that extend beyond traditional ideas of patents and IP are also necessary to promote Open Science practices within institutions reliant on commercialisation and traditional ideas of

'ownership' rather than credit or attribution. Moreover, the value of both professional scientists and Citizen Scientists are not appreciated and captured. The major problem is that Citizen Science is very often mistaken as a purely voluntary activity with no expectation or need for financial support. In the US and globally, public institutions are in heavy retreat from supporting science in general, a sorry state that does not foster the robustness of society that strong Open Science can deliver.

5. Learnings and recommendations

5.1 Best practices

As with Open Science, here is no common, agreed-upon list of best practices for Citizen Science, and our consultation may provide insight into why. The Citizen Science practitioners who contributed to our consultation often characterized their knowledge as contextual, whether relating to a domain, like water quality or marine debris; a stakeholder group, such as school children; or, a specific aspect of project design, like understanding the motivations of Citizen Science volunteers. Many hesitated to generalize beyond their immediate knowledge and experience. There were, however, a few cross-cutting themes. Many effective Citizen Science projects:

- *Invest in stakeholder engagement and co-design to ensure impact*. Depending on specific goals, relevant stakeholders might include audiences who receive and act on research results (e.g., the policy community), or volunteer contributors who benefit from joining the research process.
- *Practice critical reflection or formal evaluation.* Self-aware assessments help researchers improve the process of Citizen Science, though formal evaluations are often neglected or simply not possible for capacity or resource reasons.
- *Cultivate and share knowledge of key aspects of Open Science.* In particular, Open Access and Open Data are aspects that unfold differently in Citizen Science than in other areas of Open Science, as discussed above.

Across these themes, the importance of sharing rich, contextual knowledge was highlighted by responses that emphasized the value of opportunities for peer-to-peer learning, such as journals and collaborative networks. Ultimately, beyond generalizable best practices, the Citizen Science community more commonly shares knowledge through contextual lessons learned.

5.2 Lessons learned

Invest in stakeholder engagement and co-design to ensure impact. Public volunteers are key actors in Citizen Science. Evidence is clear that when the sweet spot of community interest and well-designed Citizen Science projects based on Open Science principles is found, take-up, long term engagement and significant robust scientific data are possible with increased understanding in the community and policy influence inevitable.

Recently, the science of Citizen Science has advanced its understanding of the incentives, barriers and drivers for Citizen Science by taking a behavioural perspective, examining the motivations and incentives of various key actors, and providing the basis for modelling and explaining stakeholder dynamics (and clashes) at play (e.g. Wehn and Almomani, 2019). *“Our greatest realization for our program was that we aren't going to appeal to everyone” (respondent).* Citizen Scientists are not a homogenous group: it is clear that there is no ‘one size fits all’ approach to incentivise participation in Citizen Science, not least due to the variety in Citizen Science ‘shapes and sizes.’ Many Citizen Science initiatives in fact appeal to ‘a pretty narrow slice’ of the population. Characterizing that segment and figuring out the best ways to reach them via quite targeted and sophisticated communication, is key for success.

Open Science initiatives and Citizen Science approaches require working with research, policy, community, and other stakeholder networks to ensure that the impacts of a project are achieved. The co-design of projects with relevant (local) stakeholders and beneficiaries (e.g. communities, authorities, industry) is becoming an increasingly pervasive practice in demand-driven and collaborative Citizen Science. This serves to ensure that impacts are considered from the start rather than as an afterthought; it is also particularly important in order to include underprivileged and disadvantaged peoples to understand their needs. There is not 'one size fits all'; rather, distinct co-design methodologies and practices are appropriate, depending on the time, resources and expertise available to a given Citizen Science initiative.
For each Citizen Science initiative, it is important to create a network of organizations with common or overlapping objectives, which is never an easy job. To broker the trust needed to meet this challenge, Memorandum of Understandings (MoUs) amongst shareholders are often recommended. MoUs are particularly powerful when no financial resources are exchanging hands, and in-kind support and partnership is required for a project to achieve its goals.

Practice critical reflection or formal evaluation. In many cases, reflection begins with an ongoing dialogue between professional researchers and Citizen Scientists. These informal evaluations enable communication and knowledge exchange, and help projects understand how the parameters of participation may change (and invest resources accordingly) in response to events like COVID-19. Many respondents shared stories of working with their volunteers to improve data collection protocols, or even fundamentally alter research questions, as the partnership continued over time.

Many Citizen Science projects, particularly those with educational goals, also embark on formal evaluations. Some research projects, beginning with the 2010 flagship project on Developing, Validating, and Implementing Situated Evaluation Instruments (DEVISE), seek to provide evaluation resources that many projects can use. Most recently, projects such as Measuring Impact of Citizen Science (MICS) and Streamlining Embedded Assessments (SEA) are bolstering knowledge on evaluation through detailed impact assessments, and assessments embedded in core research tasks.

Cultivate and share knowledge of key aspects of Open Science. The networks described earlier provide critical scaffolding for mutual learning and sharing expertise. Some of these networks nurture explicit links to Open Science topics and communities, such as the Citizen Science Network Austria providing trainings for Open Science tools. Networks such as the Gathering for Open Science Hardware (GOSH) can also support knowledge exchange within open source communities. Key values, principles, codes of conduct, and other norms of the open hardware community are shared as best practices through the GOSH Manifesto.

Regarding open data, some best practices for data sharing are emerging. On the interoperability front, groups like the Open Geospatial Consortium (OGC), CSA Data and Metadata Working Group and the WeObserve Community of Practice on Interoperability are collaborating on data and metadata standards for science projects across domains. On the data side, versions of OGC's Sensor Web Enabled for Citizen Science (swe4cs) are being iteratively implemented by groups in the EU and US. Metadata standards are emerging through the CSA's Public Participation in Scientific Research (PPSR) Core. These standards will greatly enable open Citizen Science data, thus bringing open data and Citizen Science into even closer alignment.

In regard to the ethics around open data, privacy concerns can be addressed by reducing the precision of the location data so that a precise location is not shared. Beyond location, "sensitive" data, such as climate data or air pollution data in certain geopolitical environments, also needs to be treated with diligent stewardship. A working group on open Citizen Science biodiversity databases has identified a list of questions project leaders should consider before publishing data in an open format. The data processing requirements under the new EU data protection (GDPR) addresses tensions between Open Data and data protection, including in health research (e.g. disclosure of sensitive personal data such as ethnic grouping or control of data processing and data

transfer) and more generally (Suman & Pierce, 2018). Generally, instead of “openness by default”, an approach of “situated openness” that balances benefits, risks and costs of openness for the specific context of a given initiative seems more suitable to participatory research. Finally, the integration of community data, indigenous knowledge, and alternative forms of knowledge, challenges what counts as data, how open knowledge should be, and under what conditions.
Regarding Open Access, a critical challenge is acknowledging volunteers through co-authorship. One potential solution is for publications to include a link to a list of contributors involved in each aspect of the project. This requires the development of consensus concerning the definition of roles in scientific research in order to generate a consistent way to identify various contributions. Ultimately, it may also necessitate an increase in the number of levels of attribution beyond author and acknowledgement, with the potential development of intermediary categories. This approach may begin at the individual project level, and eventually develop into norms shared across projects. Ultimately, once used consistently it could also serve as a model to other areas of science.

Beyond open access publications, open educational resources add value to Open Science and Citizen Science by enabling more informed, and therefore meaningful, participation. Most projects develop materials for training their volunteers, including through digital tutorials, webinars, or in-person training with worksheets. Citizen science projects as well as educational institutions compile lesson plans and other resources for bringing Citizen Science into different educational environments. Lastly, and suiting the public nature of research, information on Open Science and Citizen Science projects (as well as research results) are often shared through popular media including radio or podcasts. In addition to sharing information in ways that engage and educate a wider public audience, these resources may have the added value of recruiting new volunteers.

Moving forward: “Preach what you practice” - The shared value and principles of Open Science and Citizen Science to open up the scientific process is met by concerns - from professional scientists as well as decision makers - about such data generated outside the traditional scientific paradigm. Often, data generated by citizen scientists and communities is still not considered as a valid source of knowledge; this is hampering its uptake and thus the ultimate purpose of scientific knowledge as evidence in decision making processes. The above-mentioned efforts (see section 3) jointly serve to start turning the tide by countering these concerns with transparency about the steps taken in the scientific process in Citizen Science projects, the implementation of data management principles and data quality assurance measures, among others. A key aspect in this regard is not only to implement these practices, but to communicate clearly and widely that this is done, in order to change the perceptions of key stakeholders: a bottom-up, as well as a top-down, approach is needed.

5.3 Policy recommendations

Citizen Science is relevant to, and can inform, policy at local, national, supranational, and global levels (Shanley et al., 2019). It is key for addressing acute, urgent challenges such as the COVID-19 pandemic as well as medium and long-term challenges posed by the combination of climate change impacts, environmental degradation and population growth, by contributing to monitoring of the Sustainable Development Goals (Fritz et al., 2019) and by triggering the transitions required to achieve them (Sauerman et al., 2020).

At national level, many countries do not have a strategy on how to foster Citizen Science, so ‘*Citizen Science is hidden, invisible and unrecognised’ (respondent).* Yet acknowledgement and promotion of Citizen Science and Open Science at policy level, strengthened by bottom up evidence, is essential. Fortunately, efforts are emerging to develop such strategies and to share and learn at national levels, with early examples emerging in Europe and the United States (Nascimento et al., 2019). Capacity building for decision makers is necessary to strengthen education, advocacy and promotion of Open Science initiatives across national governments and associations.

Elevated attention at the international level, such as through the UNESCO Recommendations work on Open Science, will help further establish and elevate the value of Citizen Science, clarify the link between Citizen Science and complementary Open Science paradigms, and provide permission, support, and/or guidance for national action. UNESCO's promotion of the outcomes of Citizen Science and Open Science as important and highly relevant sources of evidence will foster their inclusion in decision making processes and can serve to make strides towards enhanced participatory governance.

Overall, we would like to highlight that the Citizen Science practitioners responding to our call for inputs to this paper reflected extensive experience, understanding, expertise and good practices regarding infrastructure, networking and financial considerations. Therefore, the Citizen Science and Open Science CoP can offer the UNESCO Recommendations process valuable discourse, exchange and cooperation in these areas. We also found that in addition to well-established actors, such as Citizen Science umbrella associations in each world region, a rich landscape of initiatives and people active in promoting innovative approaches exists in and outside these networks. This calls for diversifying occasions and structures for cross-pollination and synergies. However, there is still not much overlap with the broader Open Science landscape. Consequently, in order to open up Open Science infrastructures, networks and financial models for Citizen Science both in depth and breadth, lots of work remains to be done. Facing such rich opportunities, however, it is important to take inequalities in resources and power in global science and science policy into account. In the same way that, when properly aligned, infrastructure, networks and funding may bring to fruition a new approach, their interlinkages can also reinforce or intensify barriers and exclusion, if measures are not chosen cautiously based on equity.

Based on careful analysis of current understanding, tensions and trends in the Citizen Science perspective on Open Science discussed in the previous sections, this paper concludes with two recommendations for the Advisory Group for the UNESCO Recommendation on Open Science to consider:

1. Opening up access to data, publications, and other research products is necessary but not sufficient to transition science fully towards Open Science. Citizen Science presents the means for open, holistic and participatory processes of knowledge generation, *therefore Citizen Science should be acknowledged as an important pillar of Open Science to enable it to add this significant value to it.*

2. The Citizen Science contribution to Open Science should be maximised by *i) drawing on the vast practical experience our communities have with the implementation of Citizen Science, via the careful assessment of opportunities and challenges, and application of lessons learned, ii) fostering greater and enhanced cooperation, synergies and cross-pollinisation of practitioners among and between Citizen Science and Open Science communities, and iii) ensuring global access to supporting infrastructures, including technical infrastructures and community networks*.

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