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RESEARCH PAPER

Developing Open Science in Africa: Barriers, Solutions and Opportunities

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The paper argues for the development of open science in Africa as a means of energising national science systems and their roles in supporting public and private sectors and the general public. It focuses on the complexity of the social and economic challenges created by climate change and the demographic explosion and the difficulty of confronting them in the absence of an adequate digital infrastructure. Although a well-coordinated, federated multi-state open science system would be a means of overcoming this barrier, African science systems largely operate independently of each other, creating siloes of incompatible policies, practices and data sets that are not mutually consistent or inter-operable. Africa's linguistic chasms of English, French, Portuguese, Spanish and indigenous languages create further barriers. As international science moves towards greater openness and data sharing to address the complexity inherent in major global challenges, Africa's stance needs radical overhaul. The paper draws on the questionnaire data from 15 African Science Granting Councils and the state-of-the-art Report to them on "Open Science in Research and Innovation for Development in Africa". It concludes that a well-developed Open Science system for Africa, would develop and enhance collaborations and partnerships among Africans to tackle the challenges that they face and accelerate innovation and development.

Keywords: Open science; collaborations; open data; science systems; innovation; development

1 Introduction

The digital revolution presents opportunities for Africa to systematically address many of the challenges that it faces, such as drought, poverty, and youth unemployment that result from the combination of a population explosion and weak economic growth. It has been argued that the capacity to exploit these opportunities would be greatly enhanced by a strong, multi-state open science system that could drive innovation and development on the continent (Boulton et al, 2020a). Africa is currently poorly equipped to confront and benefit from the so-called 4th Industrial Revolution (4th IR) because of generally weak scientific systems that operate in isolation and, with some notable exceptions, fail to create the collaborations that could create economies of scale and generate impact in communities across Africa. Deep African engagement with the open science movement could be a powerful means of providing evidence-based solutions to put Africa on a path to sustainable development as espoused in the United Nations Sustainable Development Goals (UNSDGs 2015) and the African Union's Agenda 2063 (AU, 2015).

Open science is a powerful concept that is crucial to the global capacity to address many of the fundamental issues that human society will continue to face. In this, we adopt the International Science Council (ISC)'s definition of open science as:

> *Science that is open to scrutiny and challenge, and to the knowledge needs and interests of wider publics. Open science makes the record of science, its evolving stock of knowledge, ideas and possibilities accessible and free to all, irrespective of geography, gender, ethnicity or socio-economic circumstance. It makes the data and evidence of science accessible and re-usable by all, subject to constraints of safety, security and privacy. It is open to engagement with other societal actors in the common pursuit of new knowledge, and to support humanity in achieving sustainable and equitable life on planet Earth.* (ISC, 2020)

Studies of Africa's open science landscape reveal a paucity of adequate data management capacities (ASSAF, 2019; Lehohla, 2008) that threatens and frustrates efforts aimed at providing evidence-based policy solutions and implementable actions for development in African countries. The low level of intra-African collaboration in the exchange and sharing of data and in scientific collaboration is well documented (Trust Africa, 2015; UNESCO Science Report, 2015). In trade, Africa currently has the lowest percentage of intra-regional trade in the world at 18%, compared with 70% in Europe, 55% in North America, 45% in Asia and 35% in Latin America (Pityana, 2019). African countries collaborate more with other countries on other continents than they do with each other. In a century that is defined by the digital edge, Africa needs to exploit digital technology for the continent to be a meaningful economic partner in the 4IR (Ndung'u and Signè, 2020). This paper argues for the development of open science in Africa and highlights the potentials it holds for continental aspirations while acknowledging the numerous barriers that Africa has to overcome to operationalise open science.

1.1 Contextual background

Despite Africa's surging interest in the Internet and other digital computational technologies (Kende, 2017), its participation in the creation of scientific knowledge is negligible in comparison to the global north. As an example, a landscape survey by the Academy of Science South Africa (ASSAf) on Open Science/Open Data initiatives in Africa (ASSAF, 2019) reported "0.74% of global scientific knowledge" as Africa's contribution. An earlier study (Fonn, etal., 2018) on repositioning Africa in global knowledge production established Africa's share of less than 1%. Amongst other things, African scientific research outputs are not adequately visible on the internet as they are poorly represented in indexing systems such as Scopus (2020) and the Web of Science (2020), and open access online journals have only begun to make an impact. The African Journal Online (AJOL, 2019 n.d), laments that "mainly due to difficulties of accessing them, African-published research papers have been under-utilised, under-valued and under-cited in the international and African research arenas". The internet offers ways of changing this, but many hundreds of worthy, peer-reviewed scholarly journals publishing from Africa cannot host their content online in isolation because of resource limitations and the digital divide. That said, there is a wide divergence of capability and digital infrastructures among African countries. South Africa, Egypt, Ethiopia and Kenya for example have well-developed ICT capabilities compared with other states.

2 Open science initiatives in Africa

African states are generally weakly engaged with the global open science movement (UNESCO Science Report, 2015). Operational open science enterprises tend to be at an early stage of development, though they signal potential for the establishment of a multi-state collaborative system that could be focused on key African agendas whilst also promoting economies of scales. **Figure 1**, shows examples of open science initiatives in Africa, and **Figure 2** shows Africa's standing in the Global Open Data Barometer.

We summarise below some notable open science initiatives in Africa in three categories: (i) open science initiatives of international significance; (ii) active, sectoral initiatives with the potential to contribute to major developments and (iii) projects in development with major potential.

i) *Operational open science projects of international significance*:
   - the H3ABionet project (H3ABioNet, 2019) that we describe in 9.2 below.
   - the South African National Biodiversity Institute (SANBI), a major node of the Global Biodiversity Information Facility (GBIF, 2001). It hosts biodiversity information to make it freely available on the internet so that policy makers, managers and researchers can make well-informed decisions that contribute to sustainable development.
   - Data First – the only African database that has the CoreTrustSeal of the International Science Council's World Data System (Data First, 2020). It provides a trusted repository service for SA and other African users, with training and research on the quality and usability of data.

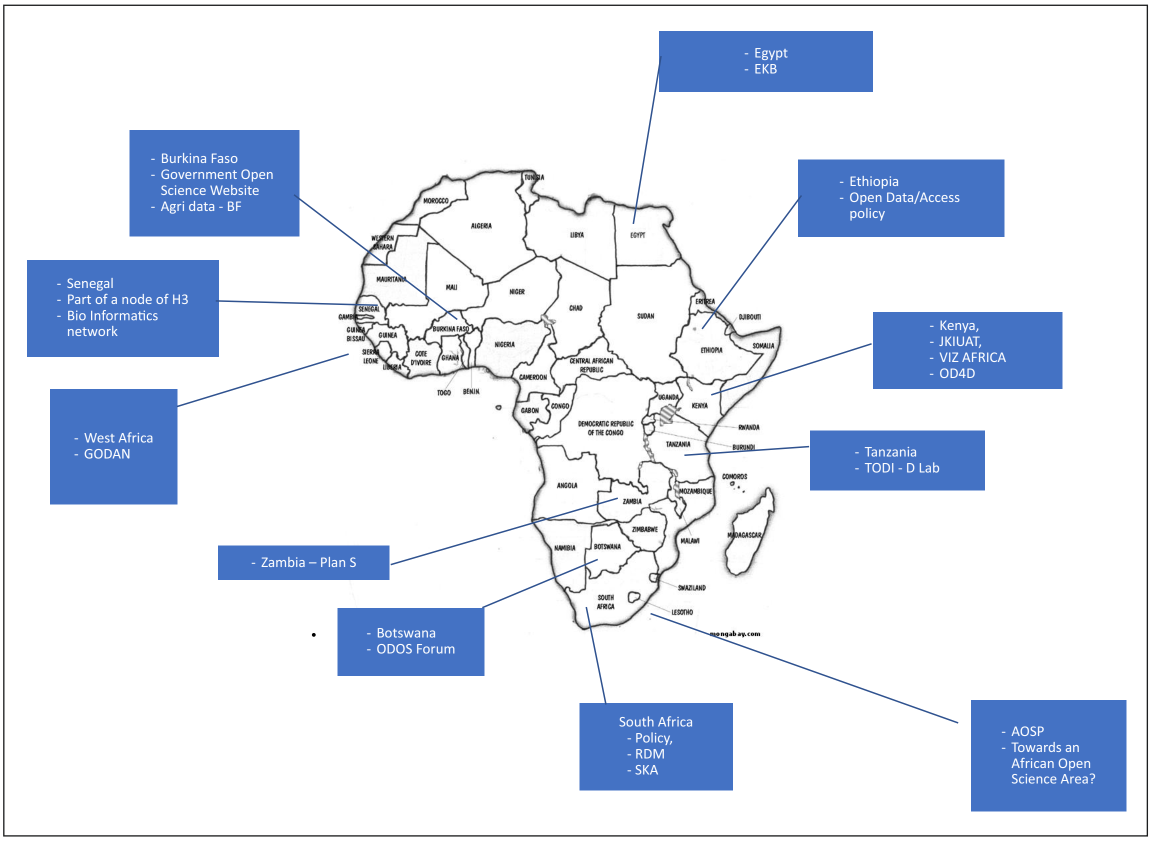

Figure 1: Examples of Open Science Initiatives in Africa.
Adapted from https://adagebiopower.com/world-map-with-countries-labeled-printable/.

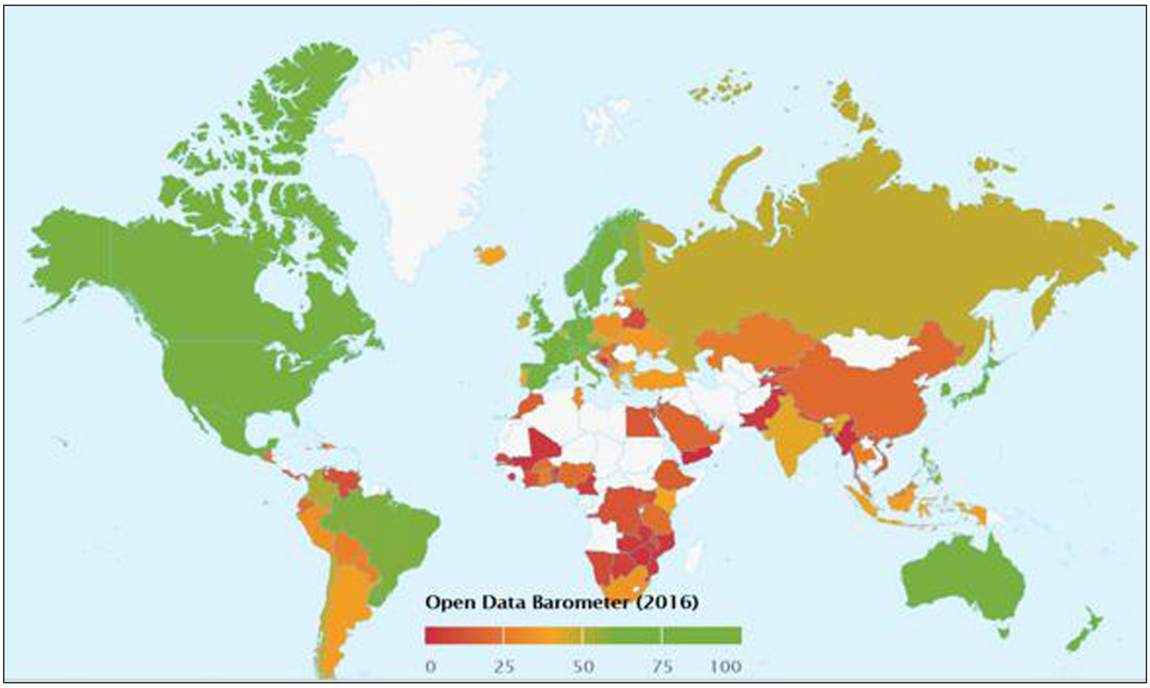

Figure 2: The Global Open Data Barometer 2016. Though a little dated, illustrates the extent to which open science policies and practices have been adopted, country by country. Source: World Wide Web Foundation (2016).

- African Academy of Sciences (AAS) Open Research (AAS, 2019) – a platform for rapid publication and open peer review for researchers. It enables researchers to publish any research they wish to share in support of reproducibility, transparency and impact. It uses an open research publishing model, including all supporting data, reanalyses, replication and reuse. All types of research can be published rapidly, See (AAS, 2019).

ii) Active, sectoral initiatives with the potential to contribute to a major development:

- ICT development: NRENS, SADC cyber-infrastructure roadmap, high-performance computing facilities in 10 countries.
- Data science courses in 15 higher education institutions, of which 6 are in SA.
- Open Access/Data declarations or agreements endorsed by 12 governments.
- 63 Research data repositories, of which 24 registered with re3data.org.
- Open data awards in 2 countries.

iii) Projects in development with major potential:

- The African component of the Square Kilometre Array (SKA) is based in South Africa and involves 8 African national partners (South Africa, Botswana, Ghana, Kenya, Madagascar, Mozambique, Namibia, Zambia) (SKA, 2019). It is developing an African Data Intensive Research Cloud and the associated skills needed to cope with the vast big data streams to be produced by the astronomical programme.
- The Indigenous Knowledge and Climate Change Adaptation Research Project among the Griqua and Nama peoples in South Africa (OCSD, 2020). It includes participatory action research ("PAR") design and methods with the aim of promoting open science by reducing the power relations within and between researchers/researched. PAR takes a "bottom-up" approach by developing partnerships with communities to identify key issues of importance and find means of conducting research, interpreting results, and acting on the findings (Kahn and Mann, 2010).
- The African Open Science Platform (AOSP) has a mission to put African scientists at the cutting edge of contemporary, data-intensive science. It is developing an integrated approach involving a federated hardware, communications and software infrastructure, including policies and enabling practices to support open science in the digital era, and a network of excellence in open science that supports scientists and other societal actors in accumulating and using modern data resources to maximise scientific, social and economic benefit. It plans for an operational launch in 2020.
- The World Bank project, The Digital Economy for Africa (World Bank, 2019) is a continent-wide initiative which covers five pillars, including Digital Infrastructure, Digital Skills, Digital Platforms, Digital Finance and Digital Entrepreneurship. The World Bank has committed to lend $25 billion up to 2030 to contribute to the overall goal of making every African individual, business and government "digitally enabled".

These are important projects with considerable potential, but they are islands of activity in a sea of relatively weak infrastructural provision. Could a federated, intra-African open science area correct this, and be a basis for exploitation of the digital revolution in ways that energise African science? Could common strategies be developed that would remove national boundaries as siloes for scientific policy and practice and stimulate intra-African collaboration as a means of creating virtual critical masses of researchers on important common problems? It was precisely such collective approaches that enhanced the creativity of Europe to become a scientific super-power.

3 Skills and capacity building

Skills and educational programmes in data science and engineering and data management in the broadest sense are fundamental to the effective exploitation of the digital revolution. Such is the volume and diversity of digital data streaming into storage systems from a large variety of sensors and sources that rigorous control and management of these data have become a fundamental issue for modern science and for the public and private enterprises for which such data is crucial to success.

Although the lack of data science (including data curation) and software engineering skills are problems worldwide, they are particularly acute in Africa, which has not been able to train and produce enough data analysts, data scientists and other support staff required to effectively acquire and process large data sets, to identify patterns, establish relationships and solve problems (Mwelwa, 2019). The gap between Africa and much of the rest of the world is widening. The use of resources is not optimised, training institutions function in isolated silos, and African students are only exposed to data science during tertiary level education (Mwelwa, Smith and Molutsi, 2018). Rationalised and coordinated training schemes and common, perennially up-dated curricula are essential.

There is a particular need from research, governmental and private sectors for:

Data stewards who handle and manage data and whose responsibilities include planning, implementing and managing research data input, storage, search, and presentation for the whole data management lifecycle.[1]
Data scientists who have expertise in the overlapping regimes of business needs, domain knowledge, analytical skills, programming and systems engineering, and managing end-to-end scientific processes through each stage of the data lifecycle, up to the delivery of scientific and business value to science or industry.[2]

Primary factors that hinder the development of these skills are:

- lack of political/managerial leadership and awareness of the need for investment;
- lack of training opportunities and acknowledgement of courses by national accreditation agencies;
- inadequate infrastructure, including slow and unstable connectivity, unreliable power supply, obsolete computing infrastructure from medium-scale server infrastructures to small numbers of workstations, and lack of centralized and secure data storage.

Overcoming these barriers would benefit from:

- Developing a federated pan-African strategy and actions.
- Developing agreements with a consortium of funders for a decadal support programme.
- Enhancing and coordinating supportive international collaboration.
- Having funders make provision for capacity building as a part of grant allocation.
- Having institutions make provision for capacity building as part of institutional budgets.
- Including data science training as part of Continuing Professional Development (CPD).

4 Data analytics and machine learning

Re-invigoration of skills in statistical analysis is vital for handling large and complex data volumes where the pitfalls are serious for the unskilled. Training and degree offerings must ensure that they are embedded in relevant programmes. A further major priority derives from the impact that machine learning in particular is having on cutting edge scientific research, on governmental and business processes, and in providing efficient and cost-effective solutions for a wide variety of complex problems across the whole breadth of human concern. Such is its ubiquitous applicability, that scientists and researchers from almost all fields need to understand, at least in schematic form, how learning algorithms work, and be able to use them. A crucial issue for Africa is and will be, how to create, manage and apply high level skills in machine learning for a wide and diverse community, whilst also maintaining a cutting-edge presence in this rapidly developing field. It is possibly that the African Institute for Mathematical Sciences (AIMS, 2020) which has a distributed presence in Africa, could fulfil this latter role. Deployment of state-of-the-art service, training and educational functions for excellent scientists in their field, whether it be biology, philology, economics or chemistry, should also include support in ways that do not require such scientists to become AI experts in order to use AI technologies with rigour.

5 The Open science movement

The above discussions (See **Figure 2**) illustrate a trend in science in Europe, Australia, the United States, Canada and South America where the hegemony of disciplinary science, with its strong sense of an internal hierarchy between the disciplines and driven by the autonomy of scientists and their host institutions, the universities, are being superseded, although not replaced, by a new paradigm of knowledge production

[1] The working definition of data steward adopted in this paper is the Edison definition for a data steward on p. 21 of the Data Science Framework document presented at the Malta workshop June 8–9 2017.
[2] The working definition of data scientist adopted in this paper is the Edison definition of a data scientist on p. 9 of the Data Science Framework document presented at the Malta workshop June 8–9 2017.

which is socially distributed, application-oriented, trans-disciplinary and subject to multiple accountabilities (Gibbons et al., 1995; Nowotny, Scott and Gibbons, 2003). These developments have been enabled by the digital revolution and its delivery of ubiquitous communication. Moreover, the openness and interdisciplinary interactions that it has stimulated also favour sharing data that is a necessary pre-condition for exploring the complexity inherent in many global challenges, and which necessarily require the integration of data from a diverse range of disciplines.

The digital revolution has also brought learning algorithms from artificial intelligence into their own. Such algorithms were developed decades ago, but limitations in the amount of data that they could be fed with failed to yield other than trivial results. That has now changed radically. Vast and complex data fluxes can now feed the voracious appetites of learning machines such that a new paradigm of data-led science has been added to the classical approach of hypothesis-led science. In the former, machines learn, as do humans, from experience, represented by the enormous fluxes of data that pass through them, and are thereby able progressively to identify deeper and deeper patterns. It enables them to identify patterns that have hitherto beyond our capacities to recognise, which is the basis of their value to science and to society. The latter is the classical scientific paradigms of observation, experiment and theory.

These perspectives have arisen from and been driven by the science community and are the background to and conceptual drivers of open science with its potential to deliver opportunities to communities nationally and internationally. In Africa, scientists and scientific organisations tend to work in isolation (Bezuidenhout, et al., 2017) due to a number of factors and barriers (IBID, 2017). As a result, Africa's science systems have not been as effective and efficient (STISA 24) and have not been able to create the critical masses needed to address the many complex problems on the continent. There is however the possibility that developments such as the recent ratification of the Africa Continental Free Trade Area Agreement among 50 of the 51 member countries of the African Union and the challenge of the United Nations Sustainable Development Goals (UNSDGS, 2015), could provide the stimulus for development of a strong and inclusive open science initiative in Africa.

6 Methods

To capture the multidimensional data for the paper, the study adopted a four- iterative multi-stage method consisting of a *systematic literature review* that entailed collecting and assembling documentation on Open Science. Available and accessible peer-reviewed and grey literature was analysed with a view to gaining insights and determining the status of OS in Africa. This enabled the research team to identify empirical evidence on OS in and out of Africa and facilitated an environmental scan for challenges and opportunities for OS in Africa and to generate baseline data that informed the line of argument in the introduction of this paper. The next stage involved *analyzing the broad scope of the research questions* that were part of the brief to generate data for the report on Open science. This entailed thinning the questions to design two questionnaires for the 4 SGCs and the 15 SGCIs' member countries and external stakeholders. The questionnaires were used in the survey outlined in the next stage.

We then conducted a survey of the African Science Granting Councils that are part of the Science Granting Councils' Initiative (SGCI)[3] to determine their attitudes to Open Science and its relevance to development and to the 4th industrial revolution. The survey contributed to the preparation of a report (Boulton et al., 2020a), produced as a background document for the annual meeting of the Granting Councils, for which the topic was *Open Science in Research and Innovation for Development in sub-Saharan Africa.* It has also informed a policy brief (Boulton et al., 2020b) and a further published paper (Boulton, et al., 2020c). The SGCI initiative seeks to strengthen capacities of Science Granting Councils in the region to support research and evidence-based policies that will contribute to economic and social development.[4] 15 Science Granting Council member countries were targeted in the survey. See (questionnaire in appendix 1). 13 returned the questionnaire which sought respondents' affirmation or disapproval of the following hypotheses:

[3] Participants in the SGCI are: Kenya, Rwanda, Uganda, Tanzania, Ethiopia, Cote d' Ivoire, Burkina Faso, Senegal, Ghana, Zambia, Mozambique, Botswana, Malawi, Namibia and Zimbabwe.

[4] The SGCI is jointly funded by the United Kingdom's Department for International Development (DFID), Canada's International Development Research Centre (IDRC), and South Africa's National Research Foundation (NRF). The objectives of the SGCI are to strengthen the ability of participating SGCs to 1) manage research; 2) design and monitor research programmes, and to formulate and implement policies based on the use of robust science, technology and innovation (STI) indicators; 3) support knowledge transfer to the private sector; and; 4) establish partnerships with one another, and with other science system actors.

The fourth industrial revolution is powered by the tools of the digital revolution.
A collaborative "Open Science" area would be an efficient response to this challenge.

The first hypothesis concerns the roles of digital technologies in revolutionising economies, societies and lives while the second one postulates that an open science area created through collaboration between African states would be an efficient response to the challenges posed by digital technologies. These were followed by a series of questions about support for or resistance to open science, national experiences of open science, and key priorities.

The last stage required *data collation, anonymization, analysis and aggregation*- Data was analysed using thematic analysis (Braun and Clarke, 2006). The above process informed the subsequent discussions, conclusions and recommendations of the paper.

6.1 Results and discussions
All the SGCIs' respondents to the survey agreed with the hypotheses a) and b) above. This provides strong support for the desirability of rooting open science in Africa as a critical agent of economic development, and for the need to mainstream it in national and institutional research. It comes from representatives of bodies with the foremost responsibilities for the guidance and funding of national science systems. It implies that Science Granting Councils see open science as a means of enhancing intra-African collaboration (cf: STISA 2024) to harness the technologies of digital technologies to invigorate and release the potentials of African science, stimulate innovation and creativity for economic and social development.

6.2 National experience of open science
Forty percent (40%) of respondents acknowledged having experienced open science at institutional and/or national level. It was observed that Zambia has been practicing open science and making available to the public free of charge all results of publicly funded research as a public good. It was not clear how long this has been going on. Most other countries are at the formative stage of considering an open science approach. The governments of Burkina Faso, Malawi and Tanzania are in the process of establishing websites and repositories for sharing research data. Kenya was the only country that reported to be working on policy and legal reforms so as to accommodate open science.

6.3 Barriers to open science
a) African states were at different levels of development in open science, and in general, there is a lack of political commitment in government, suggesting that this new paradigm is yet to be fully understood.
b) Most researchers and innovators have little trust in the open science approach, particularly with regard to the ownership of results, the intellectual property that might arise from technological developments and the importance of publications and prime authorship, issues that are regarded as important for career progression. See **Figure 3** below.
c) There is a lack of adequate human and infrastructural capacity in ICT to handle the complexity of open science and the institutionalisation of open science.
d) There is a lack of research data bases and journals dedicated to open science.
e) There is a general lack of policies at national and institutional levels to set a legal and regulatory framework for open science and for the coordination of relevant research efforts.
f) The demand by funders, universities and research institutions for researchers to publish their results in "high impact journals", which are rarely open-access journals, compounds the problem of open science in Africa, where access to published scientific works, let alone access to the internet, are inhibited by prohibitive costs.

6.4 Ranking of priority interventions
If, as respondents agree, open science is a powerful mechanism for realising the potential of the digital revolution for science and the benefits of the 4th industrial revolution for society, it is important to identify priority interventions that would set African science on a trajectory to do so. A series of possible priorities were suggested in the questionnaire, which were then ranked by respondents, as shown in **Figure 4**. Ten issues were rated as major contributors to collaborative open science. The emerging view from the data is that:

Figure 3: Issues in barriers to open science.

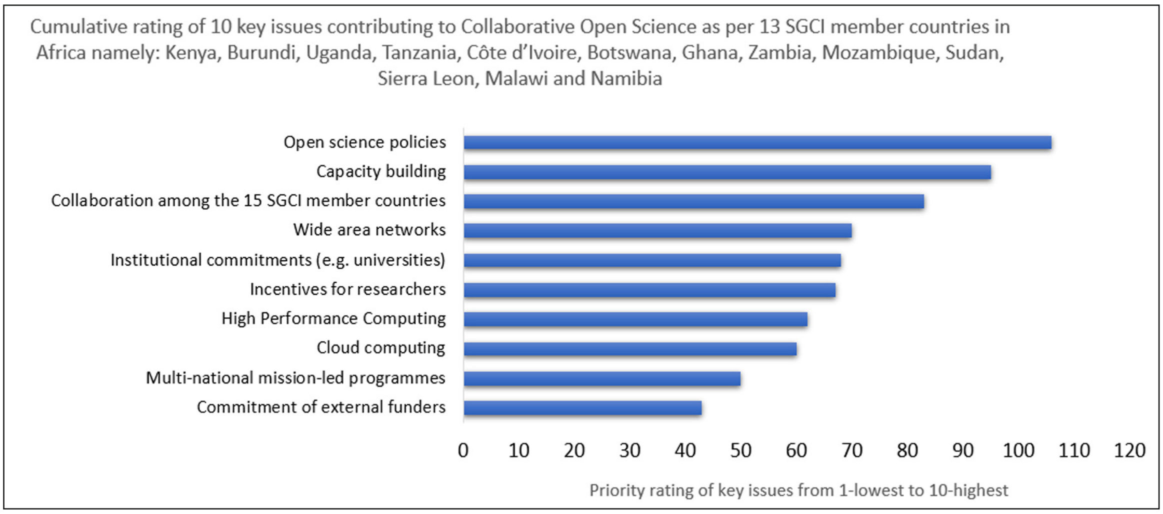

Figure 4: Priority rating of key issues on operationalising open science in Africa.

a) The 13 participating countries were unanimous in ranking open science policies first.
b) This was followed by a group of three priorities: collaborations among member countries; institutional commitment; and capacity building.
c) High Performance Computing, incentives for researchers and wide area networks were of lesser priority.

It is important to note that all the issues in **Figure 4** were regarded as important, but that some things come first. By affirming the primacy of open science policies, the SGCs confirmed the need to inform policy makers about data and the 4^{th} industrial revolution. Having collaboration and institutional commitment ranking third and fifth reflects a view that resolving "soft" issues are a precondition for effective use of "hard" infrastructures such as High-Performance Computing (HPC) and Wide Area Networks.

7 Enablers, inhibitors and opportunities

We now discuss key enablers and inhibitors that need to be exploited and overcome respectively if a successful open science enterprise is to be created in Africa. Technology is a key enabler of open science, whilst some pre-existing policies, processes and habits that were more or less well adapted as enablers in earlier circumstances have become inhibitors of innovation, and need to change. They include national policy frameworks, some incentives and norms of scientific behaviour, technical skills and outmoded cultural assumptions.

7.1 National policy frameworks

A framework of policy, regulation or legislation on data sharing, access and use is necessary in enabling sharing of scientific data and knowledge. For research undertaken in universities, the normal process (Wafula, 2019) has been for national funding bodies to require, by regulation, data acquired in research that they have funded to be made open, with a prescribed deadline for submission to a trusted data repository and in a format prescribed by regulation or negotiation. In addition, many governments have adopted an open government charter (Nordling, 2015) that requires them to open some of their data holdings, such that many national statistical offices now collaborate internationally in developing open data practices (Open data charter, 2020). The principles underlying such developments should ideally be "openness as a default position" or "as open as possible, as closed as necessary", although the latter formulation begs the question, who decides? The extent to which the private sector monopolizes data, much of which is publicly sourced, is a matter of increasing international concern, and under review by the International Science Council (International Science Council, 2019). An African contribution to this discussion is essential.

Policies are also required for research data management, funding, intellectual property, and copyright. It is particularly important that IP protection is well balanced between protecting the rights of originators and not stifling innovation. A number of African organisations already implement open access policies though this also needs to be done at national and intra-national levels rather than piecemeal through decisions by individual institutions. Relevant policy statements that have been advocated for Africa comprise (roarmap, 2020):

- Adopt **F**indable, **A**ccessible, **I**nteroperable and **R**eusable as a (FAIR) Data Principle.
- Observe Data Justice when distributing data, selecting procedures for distributing data and finally using data (Open data charter, 2020).
- Establish open access to publications through repositories and journals.
- Support submission of data to a repository before submitting the respective manuscript describing that use of the relevant data.
- Develop shared and interoperable data infrastructures.
- Encourage use of recognized waiver or license appropriate to data.
- Public and private funders should adopt obligatory green, gold or a hybrid of green and gold open access policies (Rubow, Shen, Schofield and Law, 2015) with their respective implementation measures.
- Offer incentives to acknowledge open practices in publications.
- Encourage open peer-review models.

7.2 Resistance to openness and sharing

Although many scientists support the OS agenda in principle, they are often resistant in practice. It is important to distinguish between three related issues:

(i) *The data supporting a published truth claim.* The reproducibility crisis of recent years (Dewald, Thursby, and Anderson, 1986; Pienta, 2006; Wilkinson, et al, 2016) reflects in part a widespread failure to make the data and metadata underlying a published truth claim openly available. This subverts a process that is at the heart of the scientific enterprise. The motivation for such failure is frequently that authors wish to mine the same data for further publication. Nevertheless, it is malpractice and should be non-negotiable. Funders, scientific bodies and particularly science publishers should work to ensure essential compliance with what is a fundamental scientific norm.

(ii) *Data from publicly-funded research.* The attitude implicit in the behaviour of most publicly-funded researchers is that that they "own" the data they have collected or have caused to be collected. In contrast, the international accord on open data (Science International, 2016) endorsed by over 120 major scientific bodies world-wide, enunciates the principle that – "Publicly funded scientists have a responsibility to contribute to the public good through the creation and communication of new knowledge, of which associated data are intrinsic parts. They should make such data openly available to others as soon as possible after their production in ways that permit them to be re-used and re-purposed." (This implies that publicly funded researchers should not assume that they "own" the data that they have collected. They are data custodians on behalf of taxpayers who have funded the research, and their responsibility is to ensure that the maximum benefit is derived from these data, whether by them or others). It is our view that this ethos is growing, but most strongly in those areas of science where collaborative, sharing enterprises have shown the power of openness in creating new scientific understanding (e.g. crystallography, bioinformatics, linguistics, Earth science etc). Africa should take note of this in promoting joint programmes of Africa-relevant open science.

(iii) *Asymmetric benefits of N-S collaboration.* There is concern that one of the consequences of adopting an OS agenda in Africa would be to enhance a process that has been experienced in recent decades whereby collaborative research between African and Northern Scientists has led to data migration from Africa and the loss of intellectual property, including from indigenous sources. It has been referred to as 'helicopter science', where collaboration with global north partners, funded by northern agencies, are frequently dominated by northern scientists, who fly in, collect data from their African partners, then fly out. Collaborations have proliferated in recent decades as international agencies have stepped up funding for research in Africa, particularly in the field of health. Yet many African scientists have often been little more than data-collectors and laboratory technicians, with no realistic path to develop as research leaders. However, overseas funders are increasingly prepared for African agencies to influence the agenda (FORUS, 2019). African representative bodies should consider an intervention with the purpose of agreeing a concordat with overseas funders to ensure that collaborations support the career development of African scientists.

7.3 Incentives and motivations

7.3.1 The challenge of change

It is important to recognise the impacts on well-established personal and institutional habits created by the technologies of the digital revolution and the open science transition. Many of those habits, such as those surrounding scientific publication, represent adaptations to modes of communication and working that are well-suited to paper-based and pre-digital technologies that have become almost obsolete, rather than matters of unavoidable scientific necessity, and can create a barrier to open science innovation. However, changing embedded habits is not easy. It is vital to reconsider the incentives for change, and how those incentives can draw upon deep motivations that are shared by many or most scientists.

OS fundamentally threatens the comfort zone of researchers, institutions, governments and international funders who have long-held habits of conducting science and how to handle and treat data from the scientific process. Systems of accountability cut out the public, being considered as a matter a between the researchers, publishers and universities alone. The dominant mode of work until recently has been that of researchers working in isolation or in small, closed groups sharing lab notes, with results being published in pay-walled journals, inaccessible to the average citizen. However, the edifice of open science is built on sharing scientific activities, knowledge and data beyond the nexus of the researcher/research group/pay-walled journals (JISC, 2015). From the perspective of the traditional researcher/university/government, OS threatens a loss of power and control over information, data and management of the research process. The change in mind-set and of practice expected of participants in the new open science paradigm is radical in destabilising the status quo (Ali-Khan et al, 2017). We acknowledge the philosophical arguments for the development of local knowledge and priorities (Nkoudou, 2016) and agree that open science, left to the dictates of the north may threaten Africa's ability to identify research problems and deploy methodological and epistemological choices that would best serve the needs of the African societies (Piron et al, 2017). It is understandable therefore that some in the African scientific community, like their counterparts in other continents, should be lukewarm or even trenchantly resistant to OS. In this setting it is crucial to understand not only where established patterns of incentive are barriers to change and where they need to change, but also how open scientific approaches can speak to the fundamental motivations of scientists and their institutions to discover and disseminate robust new knowledge.

7.3.2 Incentivising change

In recent decades, for good or for ill, research has become perceived by universities, which contain the majority of public sector researchers, and their academic staffs, as the predominant determinant of reputation. Reputations of both scientists and their institutions have been predicated on the basis of metrics of research income, numbers of citations, publication in so-called "high-impact" journals, prizes and the academic league tables that purport to reflect university excellence.

Journal impact factors have proved to be a powerful incentive to academic researchers, although they have been heavily criticized as a perverse index of scientific excellence. The 2013 San Francisco Declaration on Research Assessment (DORA) (sfdora, 2012), now endorsed by 1,954 organizations and 15,943 individuals worldwide, issues the general injunction: *Do not use journal-based metrics, such as Journal Impact Factors, as a surrogate measure of the quality of individual research articles, to assess an individual scientist's contributions, or in hiring, promotion, or funding decisions.* Nonetheless it continues to be used, to the general disadvantage of African scientists. DORA stresses the need to improve research by using more robust means of assessment that focus on primary values of insight, impact, reliability and re-usability, rather than on questionable proxies. It is the quality of scientific outputs that need to be recognised, not a flawed proxy of journal status. The latter serves to reinforce the brand name, and thus the market power of the major commecial publishers, rather than the real value of published research (Brembs, Button, and Munafò, 2013).

All of the largest commercial publishers are now based in Europe or North America. These publishers own the most frequently used indexes of science publications such as the Web of Science (Web of Science) and Scopus (Scopus) have, in essence, the power to define scholarship and to abuse that power for commercial gain. They tend to favour their own journals and are extremely reluctant to add new publishers or publishing processes to their indexes – so inhibiting innovation and competition. The research outputs of developing regions are very poorly represented in these indexes, which also focus on English language journals that are mainly published in Europe and North America. The response in Africa has been to create African Journals Online (AJOL), an open access publishing infrastructure and index that give visibility and access to the content of their high-quality journals (Vessuri, Guédon, and Cetto, 2013). This is mirrored by Journals Online collections in several countries (Dunning, de Smaele, and Böhmer, 2017) and Scientific Electronic Library Online (SciELO, 2002) in Latin America. Much would be gained if these systems could be federated to create a more representative and inclusive view of the international scientific effort.

Such metrics have become barriers to change by concentrating at the level of researchers, on the performance of the individual rather than the team, and, at the level of the university, of the performance of the university team rather than the wider scientific group of which the university team or individual may be a member. They both militate against the intra-African collaboration which we argue could be a powerfully positive impact of OS.

It is imperative that incentives are developed that are appropriate to the evolution of science (Reports – MLE Open Science, 2018) systems and not to so-called altmetrics. These incentives should permit recognition and visibility in the scientific community whilst encouraging collaboration with other researchers and regaining authorial rights to their work and data stored online. The International Science Council is shortly to announce major projects on metrics and science publishing that will address these issues (International Science Council, 2019). It would be appropriate to ensure African engagement with this project to ensure that the distinctive concerns and voice of Africa, and indeed of the global south, are heard.

7.3.3 Motivating change

A fundamental lesson in the management of scientists and science systems is that scientists are enthusiasts. They are profoundly motivated by the opportunity for discovery in their chosen fields. Incentives are the stick, but self-motivation is the carrot, and much more nutritious. It is one of the clear lessons to be drawn from the examples of open science systems discussed below.

8 Operational models for open science

Open science is relatively easy to enunciate as a principle: open data, open access publishing and open to society; much more difficult to realise in practice. Managing, curating and using large and diverse data volumes, developing the incentives, methods and standards for data sharing, maintaining security against malign interventions, ensuring the preservation of ethical standards, developing the systems and software to undertake all these tasks and keeping abreast of the rapidly evolving state of the art in data science has proven to be an onerous task. It is one that would introduce profound inefficiencies into science systems if individual scientists or groups were expected to develop and operate their own systems in order to satisfy FAIR requirements. Standard models for the data management process have been introduced (Sci Data, 2016) but even then, the management effort remains significant.

These demands have spawned a trend towards the development of open science or open data commons or platforms, at institutional, disciplinary, national, or international levels, to provide well-managed services that support the relevant community. They provide such things as access to IT infrastructure, to management of the data curation life cycle, to high-level analytic and AI procedures, and, in some cases, support for data-intensive scientific programmes on specific thematic priorities. They offer important efficiencies of scale and free researchers to concentrate on their research whilst being assured of effective data management, but they also have the advantage of stimulating growth of open science communities.

We offer three examples. Two are mono-disciplinary and international, in the field of bioinformatics, where relatively standardized techniques are used to generate large data volumes. The other is multi-disciplinary and international, with the purpose of providing a service for a much broader, more heterogeneous range of data producers. They also vary in their range of concerns. The first two focus largely on open data for disciplinary communities. The third is broader in its scope. Not only is it multi-disciplinary, but it also includes a regulation that requires its users to commit to open access publication and involves a certain openness to society through its citizen science programme.

8.1 ELIXIR

Is an intergovernmental organisation that brings together life science resources from across Europe (ELIXIR, 2020). These resources include databases, software tools, training materials, cloud storage and supercomputing access. The goal of ELIXIR is to coordinate these resources so that they form a single infrastructure. This infrastructure makes it easier for scientists to find and share data, exchange expertise, and agree on best practices. Its long-term purpose is to help scientists gain new insights into how living organisms work. For organisational structure and operational model, see (ELIXIR, 2020).

8.2 Pan African Bioinformatics Network for the Human Heredity and Health in Africa – H3ABioNet

It is particularly helpful to contrast the preceding European effort to create a major open science bioinformatics enterprise with an analogous effort in Africa. H3ABioNet (2013), was established to develop bioinformatics capacity in Africa and specifically to support genomics data analysis by H3Africa researchers across the continent. It develops human capacity through training and support for data analysis, facilitates access to informatics infrastructure by developing or providing access to pipelines and tools for human, microbiome and pathogen genomic data analysis. Its mandate is to develop and roll out a coordinated bioinformatics research infrastructure that is tightly coupled to a sophisticated pan-African bioinformatics training programme (H3ABioNet, 2013).

The consortium is based on a system of collaborating nodes. The network, which is run from a central node at the University of Cape Town, consists of more than 30 nodes across 15 African countries (Ghouila, et al., 2018) with one partner in the United States and one in the United Kingdom. The institutions range in their current capacity from full nodes with a track record in bioinformatics research, training, and support; through associate nodes with some bioinformatics activities; to developmental nodes with little or no bioinformatics capacity. Major objective of H3ABioNet therefore are to develop human resources through the training of bioinformaticians and researchers in computational techniques and to develop a robust, continent-wide research infrastructure that provides access to bioinformatics tools, computing resources, and technical and data management expertise.

The consortium faces a number of high priority challenges that need to be overcome to enable genomics research and competitiveness on the continent. These include, poor internet connectivity, data access, transfer and remote computing; lack of significant computing infrastructure for data storage and processing; lack of bioinformatics skills in clinical genetics and genomics teams performing genomics research; and disparate pockets of bioinformatics expertise across the continent. There is an important contrast here with the ELIXIR programme. Although both are designed to work on analogous issues for which the approaches of open science are essential, ELIXIR can depend on high levels of computational, networking and cloud capacities that are provided by European states and the European Union as a matter of course for their science systems, whereas H3ABioNet has to confront these issues itself and throughout its network, and to perennially make the case for their development. With ELIXIR, the case is already accepted at national and European Union levels such that their requests for development are accepted as parts of ongoing science system planning processes.

8.3 European Open Science Strategy

The European Union strategy recognises an ongoing major transition in how research is performed and how knowledge is shared. In response it has adopted an ambitious strategy that seeks to make open science a reality across all its member states. It contrasts with the two previous examples in being a top-down policy-driven initiative in contrast to being science-driven, although scientific researchers are involved in advising on its policies. The other contrast lies in its being designed to address the interests of a wide range of varying needs from the whole science community such that no single science agenda that is able to attract enthusiasms of a well-defined disciplinary group is particularly targeted.

The strategy's component parts are:

> ***The Open Science Policy Platform*** with the role to advise the Commission and act as a consulting body for all European open science policies and the development of a Science Policy Agenda to radically improve the quality and impact of European science across member states and internationally.
> **The European Open Science Cloud** is designed to provide a public data repository which conforms to open science values. It is projected to become a reality by 2020. It aspires to be Europe's virtual environment for all researchers to store, manage, analyse and re-use data for research, innovation and educational purposes. It is also intended that data submitted to the system should progressively conform to FAIR data principles.
> **Open Access Publication** policies that require all projects receiving Horizon 2020 funding to make sure that any peer-reviewed journal article that they publish is openly accessible, free of charge.
> **The EU Citizen Science Platform** is designed to support the activities of individuals and groups wishing to undertake citizen science projects. It will be interesting to observe how the projects undertaken on this platform evolve.

The examples of European open science initiatives should not be construed as a prescription for Africa. They are offered as examples of infrastructural design and implementation that could be adapted to African realities within the framework of an African open science strategy designed to serve the needs of the African science community and citizens.

9 Conclusion

There is a consensus amongst the national members of the African Science Granting Councils' Initiative (SGCI) that a major collaborative open science development in Africa would greatly enhance the strength of their science systems and their ability to contribute to national and pan-African socio-economic priorities. It is most powerfully expressed in the unanimous agreement of questionnaire respondents to the statement that: *the fourth industrial revolution is powered by the tools of the digital revolution and that a collaborative 'Open Science' area would be an efficient response to this challenge."* This statement, speaks directly to the aspirations of the Science, Technology and Innovation Strategy for Africa 2024, and implies an imperative for action. Such actions should involve rooting in Africa, a distinctive open science that is adapted to and mainstreamed in African national and institutional research systems. This open science should accommodate indigenous knowledge systems expressed in multilingual formats to expand and assure access to millions of Africans who are likely to exploit the potential scientific knowledge for creativity and innovation for development. We have suggested elsewhere (Boulton, et al., 2020a) that this might be done through the agency of the African Science Granting Councils, possibly in association with the newly agreed African Continental Free Trade Area (CFTA, 2019), and operationally managed by the African Open Science Platform (AOSP, 2016) which is planned to become effective in 2020. Our survey clearly revealed the perspectives of the SGCIs about the potential of a federated open science initiative for Africa and to guide its operationalisation, we recommend in Table 1, Appendix 2, the indicators and corresponding actions towards realization and sustenance of open science in Africa.

Additional Files

The additional files for this article can be found as follows:

- **Appendix 1.** The Questionnaire to Science Granting Councils. DOI: https://doi.org/10.5334/dsj-2020-031.s1
- **Appendix 2.** Table 1: Indicators and Recommended SGCs Actions. DOI: https://doi.org/10.5334/dsj-2020-031.s2

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The authors have no competing interests to declare.

Author Contributions

Joseph Mwelwa was responsible for conceptualisation of the paper, developed the paper structure and coordinated authors. He also developed and contextualised the bulk of the content and managed the finalisation of the paper until submission. Geoffrey Boulton was responsible for developing the bulk of the content of the paper, quality control for accuracy and technical editing. Joseph Muliaro Wafula was responsible for data analysis, interpretation and write up of the Method and conclusion sections. Cheikh Loucoubar was responsible for data analysis, interpretation and visualisation of data.

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