THE DIGITAL REVOLUTION, OPEN SCIENCE AND INNOVATION FOR DEVELOPMENT IN SUB-SAHARAN AFRICA – POLICY BRIEF

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SCIENCE GRANTING COUNCILS INITIATIVE SGCI IOSRS INITIATIVE DES ORGANISMES SUBVENTIONNAIRES DE LA RECHERCHE SCIENTIFIQUE

AFRICAN TECHNOLOGY POLICY STUDIES NETWORK

TheScinnoventCentre
SCIENCE, INNOVATION AND ENTERPRISE

The Digital Revolution, Open Science and Innovation for Development in sub-Saharan Africa

African Technology Policy Studies Network (ATPS) Technopolicy Brief No. 52

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The African Technology Policy Studies Network (ATPS) is a transdisciplinary network of researchers, policymakers, private sector actors and the civil society promoting the generation, dissemination, use and mastery of Science, Technology and Innovations (STI) for African development, environmental sustainability and global inclusion. In collaboration with like-minded institutions, ATPS provides platforms for regional and international research and knowledge sharing in order to build Africa's capabilities in STI policy research, policymaking and implementation for sustainable development.

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About the Science Granting Councils Initiative

The Science Granting Councils Initiative in Sub-Saharan Africa (SGCI) seeks to strengthen capacities of Science Granting Councils (SGCs) in Eastern, Southern, Central and West Africa in order to support research and evidence-based policies that will contribute to economic and social development. It is jointly funded by the United Kingdom's Department for International Development (DFID), Canada's International Development Research Centre (IDRC), South Africa's National Research Foundation (NRF) and the Swedish International Development Cooperation Agency (Sida).

The objectives of 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 implementation of these objectives is achieved through regional training courses, individualised on-site training sessions, on-line training, webinars and, collaborative research. The SGCI works with 15 councils in Kenya, Rwanda, Uganda, Tanzania, Ethiopia, Cote d'Ivoire, Burkina Faso, Senegal, Ghana, Zambia, Mozambique, Botswana, Malawi, Namibia and Zimbabwe.

The SGCIs principle output include 1) more effective research management practices among Councils, 2) strengthened ability of Councils to design and monitor research programmes, and to formulate and implement policies based on the use of robust science technology and innovation indicators, 3) increased knowledge transfer to the private sector and 4) increasingly coordinated and networked Councils. More effective Councils are expected to strengthen national science systems, and ultimately lead to nationally-led research that contributes to development in participating African countries.

About the African Technology Policy Studies Network (ATPS)

The African Technology Policy Studies Network (ATPS) is a trans-disciplinary network of researchers, policymakers, private sector actors and the civil society promoting the generation, dissemination, use and mastery of Science, Technology and Innovations (STI) for African development, environmental sustainability and global inclusion. ATPS has over 1,300 members and 3000 stakeholders in over 51 countries in 5 continents with institutional partnerships worldwide. We implement our programs through members in national chapters established in 30 countries (27 in Africa and 3 Diaspora chapters in the Australia, United States of America, and United Kingdom). In collaboration with like-minded institutions, ATPS provides platforms for regional and international research and knowledge sharing in order to build Africa's capabilities in STI policy research, policymaking and implementation for sustainable development.

About Scinnovent Centre

The Scinnovent Centre is a science, technology and innovation (STI) policy think tank registered in Kenya as a not-for-profit company. Their preliminary concern is that despite advancements in science, technology and innovation (STI), poverty levels in Africa are increasing; environment degradation is worsening; the ecosystem has become more fragile; sustainability has been compromised and livelihoods threatened.

So they ask three big questions: Why have the developments in science, technology and innovation not made any significant difference in African development? Why have STI policies not translated into practical change on the ground? How come pockets of success piloted across countries have not scaled?

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Key Messages

- The last two decades have experienced the explosive global growth of powerful digital technologies that have invaded all parts of the human experience, with profound implications for citizens, societies, economies and for science.

- This digital revolution, and the scientific and technological capacities that generate its dynamic, form the bedrock on which the globally pervasive "4 industrial revolution" is built, disrupting pre-existing norms and unleashing an unprecedented new era of innovation.

- Science systems in Africa, as worldwide, must adapt their working practices to these challenges, create knowledge that can be drawn upon by public and private sectors, and develop individuals with the high-level skills and competencies to develop the entrepreneurial agents that all dynamic societies need.

- A major new practice has been development of an international "Open Science" movement, enabled by this new digital world, and well-adapted through an ethos of sharing, to maximising the potential for benefit and as a means of addressing the many pressing global challenges, including those of the SDGs.

- New "digital" practices are also onerous, including provision of IT infrastructure, policies, incentives, methods and standards for data sharing, security against malign interventions, policing of ethical standards, and systems and software needed by high-level analytic and AI procedures; such that no individual and few organizations or states in Africa could hope to provide them alone.

- A way forward for Africa lies in an approach that has proved efficient at institutional, disciplinary, national, or international levels, in scaling up the effort to develop well-managed, integrated digital services and open, sharing practices, through Open Science platforms or commons that serve a wide community through more or less seamless provision of support and processes for highly creative interactions.

- The Science Granting Councils occupy an intermediary position between governments and the science community, and could act as a powerful and persuasive collective force in developing an African open science area, with a platform or commons at its heart, and potential synergies with the African Continental Free Trade Area (AfCFTA).

- Such an initiative, if seized with boldness and determination, offers benefits of greater effectiveness in achievement and efficiencies in operation through the development of joint strategic planning, virtual critical masses, cost efficient procurement, shared infrastructure, shared curricula, and increasing international impact through a powerful common voice.

1. Introduction

The last two decades have experienced an explosive global growth of powerful digital technologies for communication, data acquisition, computation, artificial intelligence and unrestrained information broadcasting. Together they constitute a "digital revolution". It is a revolution of historic significance that has invaded all parts of the human experience, with profound implications for citizens, societies, economies and for science, and which no society can ignore. It is the basis of the so-called 4th industrial revolution. A new scientific paradigm, of Open Science, has been enabled by the digital revolution. This Open Science has the potential to efficiently and effectively exploit these revolutions to the benefit of societies and economies. The African Science Granting Councils Initiative has commissioned a report entitled *Open Science in Research and Innovation for Development in sub-Saharan Africa* to explore this potential for Africa. It sets out: the basis of this revolution and its impacts, why Africa has no alternative but to respond to its challenges, and how it could most productively do so through a major Open Science initiative.

2. Context: Knowledge, Innovation and Human Progress

New knowledge and its dissemination have always been powerful drivers of human material and social progress. Human history has seen a series of spectacular bursts of innovation with profound economic and social consequences as new knowledge has spread. The development of arable agriculture was able, for the first time, to create an agricultural surplus, thereby spurring population growth and enabling many social innovations. The invention of printing with moveable metallic type reduced the costs of producing text, leading to the spread of literacy and education, and deep efficiencies in trade and governance. The invention of electricity dramatically enhanced energy production and powered an unprecedented range of systems that form the technological bedrock for modern society.

2.1 A new knowledge revolution

We are now in the midst of a further revolution of world historic significance, potentially more powerful and pervasive than all the others because it concerns knowledge itself, not just knowledge of other technologies. The last thirty years has seen the rapid replacement of analogue by digital devices for acquiring, storing, transmitting and manipulating data in ways that dramatically reduce costs and increase flexibility. It has created the unprecedented phenomenon of "big data", the fuel that dramatically enhances the capacities of computers and that releases the potential of artificial intelligence technologies. Although the latter were largely created five decades ago, there were inadequate data to fuel them, so that they produced only trivial results. That has changed decisively.

2.2 The power of digital technologies

It may appear counter-intuitive, but science has hitherto been concerned with relatively simple phenomena, which have been assumed to have arbitrary boundaries that isolate them from other influences in so-called closed systems. This "reductionist" approach has been, and still is, a powerful one, responsible for many of the great discoveries of science. But the enormous and diverse fluxes of data that are now available to science, to business and to society, permit us to realise the vision of Stephen Hawking, the renowned cosmologist who, in the year 2000, argued that "the next century (the 21st) will be the century of complexity". Complex systems display what physicists call "emergent properties". It is not possible to predict the behaviour of such systems merely by understanding their individual constituents: the behaviour of the whole is different from the sum of the parts. The dawning science of complexity is the science of the real world, the Sustainable Development Goals (SDGs) and the real universe, of cities, bio-molecular medicine and black holes.

Almost all the major challenges that face humanity and individual states, from infectious disease, to the behaviour and functions of cities, to national and global economies, to global sustainability, are embedded in complex systems. Today's data deluge permits us to characterise and model such complexity using high performance computing and machine learning, a core technology of artificial intelligence.

Computers execute our commands, but learning machines learn like humans, from experience. Their "experiences" are derived from the powerful and diverse fluxes of data that stream through them at high rates, and their learning experience lies, as it does in humans, in the progressive identification of patterns in the data that pass through them. This 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. Is that really so profound? Yes, it is. Almost all the great discoveries of science have been based on initial recognition of patterns in reality, which have spurred the question “why” and the deeper investigations and the discoveries that have followed. Equally, the recognition of patterns in the complexity inherent in business and industrial processes, health systems, governance systems and public affairs are leading to profound increases in efficiency and reductions in cost through the use of machine learning algorithms. Patterns of disease in populations improve targeted provision; transport systems are optimally scheduled; goods are efficiently delivered to markets; energy systems are optimally run to minimise costs and reduce power outages; and government services can be most efficiently matched to human needs.

2.3 The 4th industrial revolution and its consequences

These digital knowledge technologies are the power underlying the so-called 4th industrial revolution, because of their applicability to most human, societal and economic purposes. They constitute a “general purpose” technology, one of only four in human history, that continually transforms itself, progressively penetrating new domains, boosting productivity across all sectors and industries because of its cost effectiveness (Fig.1). It is globally pervasive, disrupting pre-existing norms and unleashing an unprecedented new era of innovation that has profound implications, for science, for industry and economies, but also for society and for policy at all levels of governance. Machine learning is unlocking value across every industry. PricewaterhouseCoopers expect it to be responsible for $15.7 trillion of global GDP by 2030 – more than the current GDP output of China and India combined. By 2035, Accenture estimates that it will increase productivity and profitability by 40% and 38% respectively. Whether and how these technologies are embraced and how underlying capacities and skills are developed will determine which side of the disruption equation states and societies will lie.

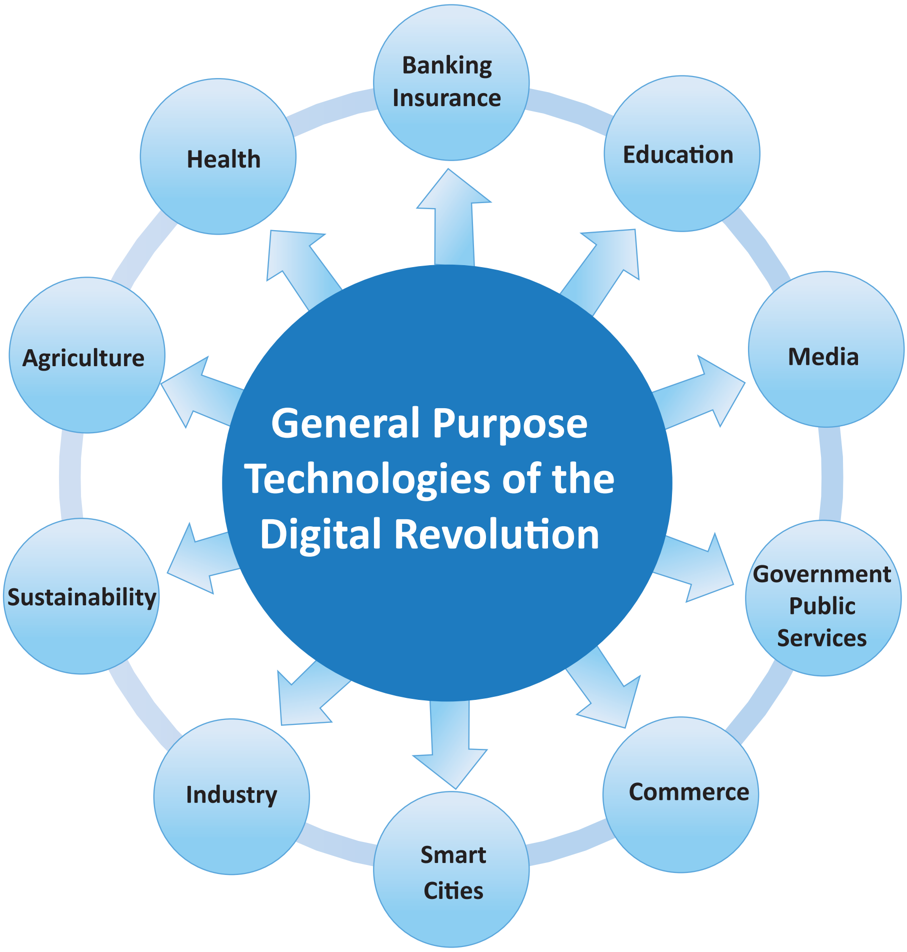

Fig. 1: Changing economies, societies and lives: the impacts of the digital revolution.

All new technologies generate not only new benefits but also new dangers. The invention of the aeroplane also, in effect, generated plane crashes, the invention of the ship, shipwrecks. The dark side of the digital revolution lies in cyber-fraud, a massively growing industry, cyber-warfare, including attacks on national infrastructure, cyber-espionage, including attacks on the integrity of databases, and cyber-lies that undermine civic consensus and electoral integrity. It is a responsibility of governments not only to stimulate the use and effectiveness of this new technology to create social and economic benefit, but also to mitigate its risks.

3. Key Report Findings: Challenges and Opportunities for Africa

Reaping the economic and social benefits and avoiding or mitigating the harms of the digital revolution depend fundamentally on the capacity of national science systems to promote research that exploits the cutting edge of fast-developing technologies and their applications. There is a two-fold purpose:

- to create knowledge that can be drawn upon by public and private sectors;
- and to develop individuals with the high-level skills and competencies required by these sectors to become the entrepreneurial agents that all dynamic societies need.

A country that fails to develop these capacities will inevitably become dependent upon skills bought in from elsewhere as a passive and ill-informed consumer of expensive digital services, lacking the creativity to thrive in a fast-changing world. Could such developments be left to the private sector? No. Such roles are invariably developed by the public sector in creating "public goods" that are available to any innovative individual or group to exploit in competitive enterprises. Private sector investment at this basic level encloses knowledge behind a pay-wall, deepens and entrenches monopoly power, and deprives society or government of the skills to act as an intelligent customer, to their great financial and social disadvantage.

3.1 What knowledge, infrastructures and skills does Africa need to develop?

To engage effectively with this revolution and to benefit from it depends on developing and adapting the infrastructures and competences of national science systems. Just as science systems worldwide are struggling to adapt to this new paradigm, so must Africa, but in its own way. The revolution offers great possibilities for Africa, which, if seized with boldness and imagination, have the potential to support scientific, economic and social dynamism that can help advance the energies and potentials of the continent. Africa should move on from a world in which maintaining exclusive access to data that individuals and groups have created has been a key to scientific discovery and its application, to one where data access is the priority. One can either hoard little or access a lot. The former is an island – the latter is an ocean.

The report for the African Science Granting Councils Initiative (SGCI), Open Science in Research and Innovation for Development in sub-Saharan Africa describes in detail the policies, approaches, infrastructures and capacities required to address the challenges now facing Africa as a whole. In summary they are:

a) to adopt common polices for access and use of data;
b) to create data repositories, as well as research data management and software services, to enable scientists and other stakeholders to utilise modern data resources in innovative and creative ways;
c) to improve the infrastructure and communication networks, together with high performance computing centres and cloud computing capacities that enable stakeholders to undertake state of the art data analyses;
d) to improve the circulation of scientific knowledge through open access publishing that serves Africa's needs, best done by working in collaboration with the international scientific community, for which the current dysfunctional model of scientific publishing is a major concern;
e) to create programmes of research on major issues of specific relevance for Africa that will drive the use of these infrastructures and stimulate scientists and other stakeholders to create economic and societal benefits;
f) to create state-of-the-art capacity in artificial intelligence,

particularly in machine learning, in ways that are able to inspire and support data-intensive science and innovation;

g) to develop the individual skills and competencies required to progress data-intensive science and to realise its potential for socio-economic benefit.

3.2 Open Science as an effective and efficient framework for development

The opportunities offered by the digital revolution for science and its application to economies and societies have stimulated a major international movement for “Open Science”, which the SGCI report characterises as “open data”, “open access publishing” and “open to society”. The value of such an open science for Africa is based on two fundamental premises:

- The efficiency of science in exploiting this new world of data depends upon the ability to move beyond a world in which scientists only have access to the data that they have created, to one of sharing in which they have access to the diverse data series needed to address complexity, and where access to scientific publication for both producers and users is affordable and easy.
- The openness of the World Wide Web and the development of the social media that it has enabled have created a new social dynamic that has undermined the authority of the traditional media that have been the “gatekeepers” of authorised wisdom, disrupted the prevailing pathways through which scientific knowledge permeates into society, and undermined trust in scientific institutions. In a world that needs science more than ever, an open science is needed that engages with society, with business, policymakers, governments, communities and citizens as knowledge partners in ways that increase both effectiveness and socio-political legitimacy.

Responding to these imperatives imposes considerable pressure for change on both scientists and national science systems. 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 the potential to absorb so much of scientists' efforts that they are either deterred from data-intensive science or unable to find time for research itself.

It has proved far more efficient at institutional, disciplinary, national, or international levels to scale up the effort and develop well-managed services in the form of open science platforms or commons that serve a wide community. These recognize that the individual functions described above are inter-related, all parts of a system of functions, rather than standing alone. Initiatives to create open science or open data platforms or commons are designed to provide a more or less seamless provision of support, from IT infrastructure to high-level analytic and AI procedures, and in many cases, support for data-intensive scientific programmes on specific thematic priorities. They free domain scientists to concentrate on their scientific priorities rather than acting as amateur data technologists. Such an approach has been developing in Africa in human heredity and health[1] and as a general approach across the sciences[2].

3.3 Building Africa's science capacity through an Open Science area

By international standards, sub-Saharan Africa's investment in science is low as a proportion of GDP (<1%), compounded by its low GDP in relation to a population of 1.216 billion. It is therefore not surprising that its contribution to global research output is less than 1%, although having 16.27% of global population. As a consequence, sub-Saharan countries consume research outputs from outside the continent and contribute very little from their own resources,

[1] *H3ABionet H3ABioNet is a "hub and nodes" platform that is developing and rolling out a coordinated bioinformatics research infrastructure, tightly coupled to sophisticated pan-African bioinformatics training.*
[2] *The African Open Science Platform (AOSP) has the mission of putting African scientists at the cutting edge of contemporary, data-intensive science, based on a federated infrastructure and on servicing scientists and other societal actors with modern data resources to maximise scientific, social and economic benefit.*

depending heavily on international funding, collaboration and visiting academics for their research output. The science effort is already in the unhealthy state referred to in section 3.

The African Union's 2017 report on Science Technology and Innovation 2024 (STISA2024)[3] identified a series of major priorities for research, but also drew attention to two major structural deficits within African science:

- the paucity of intra-African collaborations;
- the scarcity of critical masses of researchers in key areas of research.

As examples from mature, efficiently-functioning research systems show, these are crucial features, which undermine the capacity to address the priority research targets in STISA2024 and those of the SDGs.

Building on the growing open science movement in Africa could, if developed with boldness and imagination, begin to grapple with these fundamental problems and set Africa on a trajectory that would augur well for its development and long-term economic and social prosperity.

An open science commons or platform could be a powerful means of realising the potential of the digital revolution for Africa through the mechanisms described in 3.2. Rather than these being created at a national level, it would be more efficient by far to create, through collective action between member states, a federated African open science area with a platform or commons at its heart. Such a collective strategy is the one most likely to deliver individual national benefits and, in the near term, to mobilise the resources necessary to implement the operational policies, infrastructures and practices that are needed for a powerful open science capacity:

I. Access to state-of-the-art computation and communication systems, with major distributed nodes of capability to serve a growing network.

[3] *http://www.nepad.org/news/stisa-2024-guide-africa-exploit-its-opportunities*

II. Grand challenge, data-intensive, research programmes on major issues for Africa, to stimulate take-up of data intensive capacities, and to create virtual critical masses and enhanced intra-African collaboration.
III. Major database centres that serve the above objectives.
IV. An internationally competitive artificial intelligence/machine learning capacity to inspire and serve the open science community.
V. Up-to-date curricula and concerted programmes of capacity building to ensure an efficient pipeline of the skills needed in science, in the public and private sectors, in education and for citizens.

Not only could this deliver the priorities outlined in points 3.1a-g, but it could also resolve the structural weaknesses identified in STISA2024, whilst adding to the overall strength, dynamism and utility of the African science effort through:

a) joint strategic planning to achieve the priorities of 3.1a-g;
b) developing virtual critical masses;
c) enhancing intra-African collaboration through major programmes directed towards African priorities;
d) efficiencies in procurement;
e) efficiencies of scale through shared infrastructural provision and database services;
f) federating existing capacities as a basis for a powerful network;
g) strategic capacity building with shared curricula;
h) partner of choice in international consortia;
i) increasing international impact through a powerful common voice.

A question that should be considered is whether the launch in September 2019 of the African Continental Free Trade Area (AfCFTA) could be a springboard for an African open science area, possible based on the developing African Open Science Platform. Following hard on the heels of the AfCFTA, such a move would be a major statement of intent from Africa about a confident and creative scientific future. As the European experience has shown, free trade and the mobility of ideas and people it stimulates are precisely the qualities that science thrives on and contributes to. It is a duo that could be a powerful source of economic, social and cultural dynamism.

Multi-national open science platforms that are now operational demonstrate the productivity of a hub-and-nodes model that could efficiently serve African needs. The hub acts as a coordinating body to service overall management. The nodes are specialised centres, contributing in an agreed way to the delivery of platform competences and representing regional or national priorities in the overall strategy and functioning of the platform.

3.4 Delivering national benefits

National investments in science systems designed to derive benefits from the digital revolution, be they cultural, social or economic, depend on the effectiveness of the system and the efficient placing of the investment needed to deliver them. Effectiveness depends on the creativity of the system in producing new knowledge, and doing so in ways that bring benefit to society, including development of the human capacities and the dissemination of innovative knowledge into the public and private spheres. Efficiency relates to the productivity of national investment in realising those benefits at optimal opportunity cost. The combination of high effectiveness and high efficiency are persuasive reasons for a government to invest in digital capabilities through the open science route.

In seeking maximal exploitation of the digital revolution, well-funded national science systems tend to fund large numbers of diverse initiatives Ain the expectation that competition will be an important creative force, though with core state funding of expensive infrastructure. This is a model that depends upon high levels of investment that African states are generally unable to mobilise. For Africa, national effectiveness and efficiency are most likely to be delivered through cooperation, by creating a multi-national platform as described in section 3.3. Its potential national benefits are:

Effectiveness. A well-organised platform as the core of a major African initiative would permit the key structural issues in STISA2014 to be addressed through the creation of virtual critical masses (3.3b) and enhanced intra-African collaboration (3.3c). Shared IT and data-science infrastructure enable this, and major collaborative programmes of data intensive science for African priorities generate direction and power (3.3a). National benefits are created through involvement in a dynamic scientific community, whilst a stronger African voice creates the potential for greater global engagement as an equal partner (3.3g,h). Collaboration in such an environment enhances the potential to create and deliver cutting-edge, nationally focussed, learning curricula in vital public and private sector application domains. It enables the potential for deeper engagement with society and with citizens.

Efficiency. A collaborative initiative offers cost-efficient economies of scale to national science through joint procurement (3.3d), cost sharing for expensive infrastructure (3.3e), federation of existing capacities (3.3f - NRENS, HPC, Cloud facilities), shared database service provision (3.3e), and strategic approaches to international funders.

Such an effective and efficient system with developed pathways to societal stakeholders and the ability to respond to national and regional priorities is likely to be seen as an essential and productive investment in the future, thereby justifying higher levels of funding than currently allocated.

4. Recommendations to the Science Granting Councils and Governments

The Science Granting Councils have a unique, intermediary position in national science systems. They both represent and influence government policies for science, whilst also influencing and responding to the priorities of the scientific community. Because of their intermediary position they have a crucial role to play when confronting epochal challenges such as that of the digital revolution. The principle issue for them is how boldly they are able to act in confronting these challenges. Section 3.3 presents powerful arguments that the strength of the Councils' leverage and their capacity to generate benefits at national levels are based on their preparedness to act as a collective. We therefore base our recommendations on this premise.

Recommendation 1

The Councils should intensify the level, scope and ambition of collective action by building on the SGCI to play a strategic role in developing an African open science area, and seek the support and acquiescence of their respective governments in doing so.

Recommendation 2

The Councils, in consultation with their governments, should determine the level of collective ambition, considering whether they should act:

- to promote creation of an open science area based on platform or commons with the components and functionalities as set out in section 3.3 (I-V & a-i);

- to coordinate and complement existing open science activities in Africa;
- or to develop a more limited, but focused role for collective action designed to have major impact on two key areas: of enhancing IT infrastructures by federation and expansion of existing capacities; and creating major data-intensive programmes on intra-African priorities to stimulate creative use of IT capacities and to build intra-African virtual critical masses.

Recommendation 3

Granting Councils should work with governments to develop a concordat for the coordination of policy and action and the strategic use of collective resources. It should involve agreement on matters such as intellectual property, open data standards and rules of access for common infrastructure. An operational open science system will require convergence on these issues if it is to be efficient and effective.

Recommendation 4

Granting Councils should work to mobilise support, commitment and understanding for the above priorities from a wide range of stakeholders within their scientific communities. The development of a platform could be a forum for creating synergy between key players, maximising collective impact, and reducing unnecessary duplication. Its members should include national academies; researchers, motivated by scientific opportunity; universities, motivated by reputation, funding and attractiveness to staff and students; and private sector companies, motivated by innovative potential, the supply of innovative personnel and the creation of markets for their products.

Recommendation 5

Granting Councils could act collectively as an interface with international development bodies, other donors and strategic partners to make a collective and integrated case for African science priorities[4]. The Councils should collectively express continental priorities with greater coherence, encouraging other national, regional and international funders to act in coordinated ways in response to these priorities. They could also be a means of gaining support from the international science community as represented by the International Science Council (ISC) and its data bodies (the Committee on Data – CODATA - and the World Data System -WDS), and the Research Data Alliance (RDA).

Recommendation 6

The Science Granting Councils should commission and be involved in expert reviews of:

- The potential for convergence of national policies, regulations and standards for open science, and the possible role of the Councils in facilitating convergence.
- How African priorities for scientific publishing can be achieved, and to ensure that these concerns contribute to a global review being led by the International Science Council.
- The impact of metrics for research on the research process, and how they might be improved to satisfy African priorities. They should ensure that these concerns contribute to a global review being led by the International Science Council.
- Identifying cost-efficient means of federating current computational, cloud and communication capabilities (including the NRENS, and linking with SKA capabilities), and extending and efficiently managing them. This might also involve potential funders.

[4] For example Canada's International Development Research Centre (IDRC), Sweden's Sweden's International Development Cooperation Agency (SIDA), UK's Department for International Development (DFID), the World Bank, which has a major project on the digital economy for Africa, the European Union, the USA's National Institute of Health (NIH), the Wellcome Trust and many other international foundations.

5. Afterword

"The basic economic resource is no longer capital, nor land, nor labour. It is and will be – knowledge." The digital transformation is a massive leap in the production, communication and use of knowledge, with profound implications for all societies and economies. The train is leaving the station. Jump on board now, or be left behind. Unless Africa responds with urgency to develop vital capacities, it will inevitably become, yet again, dependent upon skills bought in from elsewhere as a passive and ill-informed consumer of expensive digital services, lacking the creativity to thrive in a fast-changing world. It has the opportunity to avoid this fate, by bold and timely action, possibly building on the creation of the AfCFTA, in order finally to achieve continental development goals, with science, technology and innovation as primary drivers. This is not simply a vision for a future of conventional, carbon energy-driven growth, but one that is entirely consistent with the ethos and the priorities of global sustainability and the SDGs.

Appendices

About the Authors

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