The African Observatory of Science, Technology and Innovation (AOSTI)

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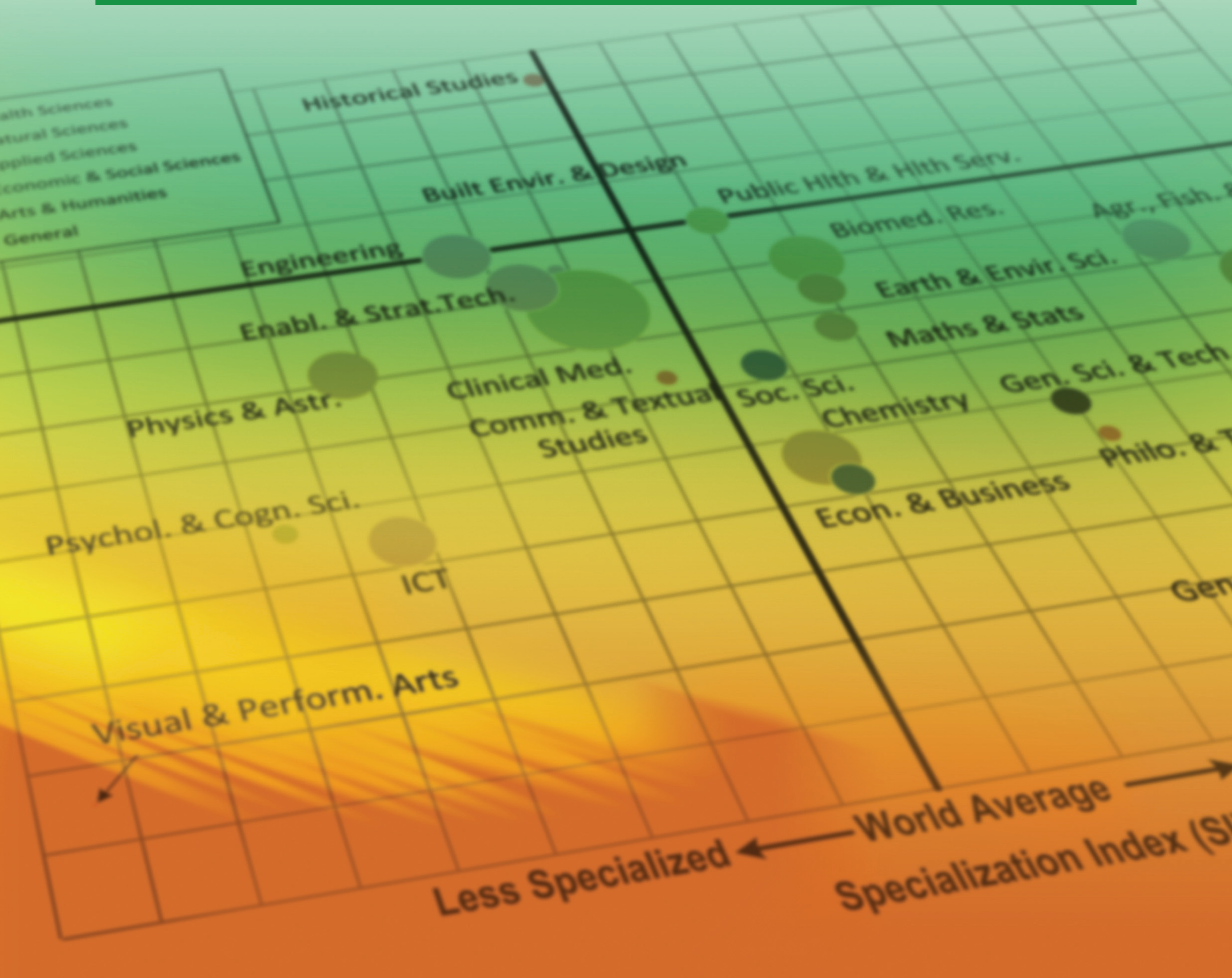
Assessment of Scientific Production in the African Union, 2005–2010



Assessment of Scientific Production in the African Union, 2005–2010

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Profound gratitude is expressed to the government of the Republic of Equatorial Guinea for providing a seed fund to the African Union Commission for the start-up activities of AOSTI and for hosting the AOSTI headquarters in Malabo.

The beginnings of this bibliometric project can be attributed to the intergovernmental meeting on AOSTI held in Malabo in May 2012. Country representatives noted the paucity and inconsistency of science, technology and innovation (STI)-related statistics in Africa and urged AOSTI to produce, among other indicators, those related to knowledge production as a building block in the production of the STI Outlook Series.

This project was contracted to Science-Metrix Inc. in Montreal, Canada. Dr Éric Archambault, the Chief Executive Officer of Science-Metrix, and his team deserve special mention, since they are responsible for most of the material included in this volume. Dr Watu Wamae, Analyst at the Department of Innovation and Technology Policy, RAND Europe, provided support in the early stages of this project.

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Dr Philippe Kuhutama Mawoko

Interim Director, AOSTI

Foreword

This report on scientific production in Africa comes at a time when the African Union (AU) celebrates and commemorates its 50th anniversary and charts its development trajectory for the next half-century, which is now known as the 'the African Union Agenda 2063'.

The findings of this report offer an opportunity for the AU Commission to take stock and reflect on the continent's capabilities to produce and use knowledge for its development.

The African Union is doing its utmost to achieve its vision of "an integrated prosperous and peaceful Africa, driven by its own citizens and taking its place in the global arena". While commendable efforts are being made towards achieving this vision, much more could be gained by seizing the scientific and technological (S&T) opportunities offered by the globalized knowledge economy.

However, understanding knowledge systems requires, among other things, using indicators to monitor, benchmark, evaluate and to support foresight exercises related to S&T undertakings. These are essential elements for an effective and relevant management system.

In assessing the performance of input–output systems, indicators can be used to facilitate the language of discourse for the contribution of science and technology to socio-economic development processes. A programme on science, technology and innovation (STI) indicators is therefore a business imperative for Africa.

This series on bibliometrics has gauged Africa's scientific flows and shown that overall scientific production is increasing. The study has also made visible the type of knowledge produced by African scholars, the fields in which they specialize and the collaboration between researchers, and has also critically highlighted grey areas that need further research.

These results strengthen the approach adopted in the AU Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024). The strategy starts by defining the African priorities for development, which are then transformed in flagship programmes. Research agendas generated out of these programmes call for multifaceted and networked efforts of collaboration among the African scientific community, the public and private sectors.

This report provides policy-makers, knowledge-workers and investors with additional information and equips them better to leverage these new insights into the African S&T system to strengthen relevant knowledge, skills and innovation capabilities to support the AU's vision.

This study responds to the persistent demands of the African Ministerial Conference on Science and Technology (AMCOST) and the Conference of Ministers of Education of the African Union (COMEDAF) for the production and use of relevant indicators in support of knowledge management.

I therefore encourage the STI community to make use of these findings to support and strengthen investments in research and establish practical mechanisms for optimal knowledge flows between research communities and industries.

Among many ways of using this report, countries could delve into areas in which their research excels and use the knowledge produced to underpin the creation of competitive goods and services. In this context, it would then become possible to consider a cycle of sustainable production, increased competition and commercialization. Such a situation would necessarily improve business processes whereby, furthermore, problems faced by industries could trigger research prospects that might be of interest and relevance to the research communities.

These interactions between government, industry, universities and civil society are necessary conditions in nurturing innovation for development.

I call on the African research community to ensure that the evaluation and diffusion of information is integrated in the scientific culture.

Profound gratitude is expressed to the government of the Republic of Equatorial Guinea for hosting and supporting the African Observatory of Science, Technology and Innovation (AOSTI).

I urge African governments to support AOSTI and its programmes to ensure relevant and elaborate studies for a shining Africa.

Dr Martial De-Paul Ikounga
Commissioner
Human Resources, Science and Technology
African Union Commission

Avant-propos

Ce rapport sur la production scientifique en Afrique arrive au moment où l'Union Africaine (UA) commémore son 50ème anniversaire et trace la trajectoire de développement de l'Afrique pour le prochain demi-siècle, communément appelée «Agenda 2063 de l›Union Africaine».

Les conclusions de ce rapport offrent l›occasion à la Commission de l›Union Africaine de faire le point, de lancer le débat et de réfléchir sur les capacités du continent à produire et utiliser les connaissances pour son développement.

L›Union Africaine est en train de tout mettre en œuvre pour réaliser sa vision d›une «Afrique intégrée, prospère et pacifique, dirigée par ses propres citoyens et occupant une place dynamique sur la scène mondiale». Bien que des efforts louables soient faits pour la matérialisation de cette vision, les résultats seraient plus rapides et plus visibles grâce à une meilleure exploitation des opportunités scientifiques et technologiques (S&T) offertes par l›économie du savoir et de l'innovation.

La compréhension des systèmes de connaissances exige, entre autres, l'utilisation d'indicateurs permettant de suivre, de répertorier, d'évaluer et de prévoir l'agenda de S&T, c'est-à-dire apporter les éléments nécessaires à un management efficace et pertinent.

En mesurant et en révélant les performances du système investissement-résultats, les indicateurs facilitent également le langage du discours sur la contribution de la science et la technologie au processus de développement socio-économique en Afrique. Dès lors, un programme sur les indicateurs de la Science, la Technologie et l'Innovation devient un impératif pour l'économie Africaine.

La présente série sur la bibliométrie mesure les flux de connaissances de l›Afrique et montre que la production scientifique globale des pays africains est en hausse continue. L›étude met également en évidence le type de connaissances produites par les chercheurs africains, les domaines dans lesquels ils se spécialisent et la collaboration entre les chercheurs. Elle montre aussi de façon critique les zones d'ombre qui nécessitent davantage d'investigations.

Elle vient donner raison à la démarche de la Stratégie Africaine pour la Science, la Technologie et l'Innovation (STISA-2024) qui après avoir défini les priorités pour l'Afrique, les transforme en programmes mobilisateurs qui eux-mêmes engendreront les programmes de recherche autour desquels la communauté scientifique africaine en étroite relation avec le secteur productif tant public que privé se mobilisera en de vastes réseaux de collaboration.

Ce rapport fournit aux décideurs, professionnels et investisseurs dans le domaine du savoir, des renseignements supplémentaires, et les prépare à mieux tirer profit de ces nouvelles connaissances dans le système S&T africain pour renforcer les acquis, les compétences et les capacités d›innovation afin de soutenir la vision de l›UA.

Cette étude constitue un premier maillon à la réponse aux demandes persistantes de la Conférence ministérielle africaine sur la science et la technologie (AMCOST) et de la Conférence des Ministres de l›Éducation de l›Union africaine (COMEDAF) pour la production et l›utilisation d›indicateurs pertinents en faveur de la gestion du savoir.

J'encourage vivement la communauté STI à faire usage de ses conclusions pour soutenir et renforcer les investissements dans la recherche et établir des mécanismes pratiques pour optimiser les flux de connaissances entre les communautés scientifiques et les industries.

Parmi les nombreuses façons d'exploiter le présent rapport, les pays membres pourraient s'intéresser de plus près aux domaines de recherche dans lesquels ils excellent, et utiliser les connaissances produites pour contribuer à la création de richesses à travers des biens et des services compétitifs. On peut ainsi plus facilement envisager d'entrer dans le cycle de la production soutenue, de la compétition accrue et de la commercialisation sans complexe. Une situation qui nécessairement améliore les processus dans le domaine des affaires en faisant que les problèmes rencontrés par les industries puissent stimuler des perspectives de recherche tout aussi intéressantes que concrètes pour les communautés scientifiques.

Ces interactions entre le gouvernement, l›industrie, les universités et la société civile sont des conditions nécessaires pour nourrir l›innovation pour le développement.

J'invite la communauté scientifique africaine à faire de l'évaluation et de la diffusion de l'information, une partie intégrante de leur culture scientifique.

J'exprime ma profonde gratitude au gouvernement de la République de Guinée équatoriale pour tout le soutien apporté à l›Observatoire Africain de la Science, la Technologie et l›Innovation (OASTI) dont elle est le pays hôte.

J›exhorte les gouvernements africains à soutenir l'OASTI et ses programmes pour nous donner l'assurance d'un travail plus élaboré et toujours utile au rayonnement de l'Afrique.

Dr Martial De-Paul Ikounga
Commissaire
Resources Humaines, Science et Technologie
Commission de l'Union Africaine

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List of acronyms

AIO	African Innovation Outlook
AMCOST	African Ministerial Conference on Science and Technology
AMU	Arab Maghreb Union
AOSTI	African Observatory for Science, Technology and Innovation
ARC	Average of Relative Citations
ARIF	Average of Relative Impact Factor
ASTII	African Science, Technology and Innovation Indicators
AU	African Union
AUC	African Union Commission
CAGR	Compound annual growth rate
CASTEP	China–Africa Science and Technology Partnership
CEN-SAD	Community of Sahel-Saharan States
CI	Collaboration Index
COMEDAF	Conference of Ministers of Education of the African Union
COMESA	Common Market for Eastern and Southern Africa
CPA	Africa's Science and Technology Consolidated Plan of Action
EAC	East African Community
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
EPO	European Patent Office
FTE	Full time equivalent
GBAORD	Government budgetary allocations or outlays to research and development
GDP	Gross domestic product
GERD	Gross domestic expenditure on research and development
GI	Growth index
GO→SPIN	UNESCO Global Observatory on Science, Technology and Innovation Policy Instruments
HRST	Human Resources, Science and Technology
ICT	Information and Communication Technology
IERI	Institute for Economic Research on Innovation
IGAD	Intergovernmental Authority on Development
IP	Intellectual property
MDG	Millennium Development Goal

NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organization
NSI	National System of Innovation
OAPI	African Organization for Intellectual Property (Organisation Africaine de la Propriété Intellectuelle)
OECD	Organization for Economic Cooperation and Development
PAIPO	Pan African Intellectual Property Organization
PATSAT	EPO Worldwide Patent Statistical Database
R&D	Research and experimental development
RC	Relative citation count
REC	Regional Economic Community
RIF	Relative impact factor
RLA	Revealed Literature Advantage
S&T	Science and technology
SADC	Southern African Development Community
SI	Specialization index
STI	Science, technology and innovation
STISA	Science, Technology and Innovation Strategy for Africa
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU-MERIT	United Nations University – Maastricht Economic and Social Research Institute on Innovation and Technology
USA	United States of America
USPTO	United States Patents and Trademark Office
WoS	Web of Science

Preface

The African Union (AU) recognizes the importance of knowledge created through science, technology, and innovation activities. This knowledge improves productivity and competitiveness and ultimately the wellbeing of the people in the AU's 54 member countries. Throughout the AU, there are policies to promote the production of scientific knowledge and innovation, but such policies raise questions. Are there better ways of allocating the resources? What are the outcomes of supporting S&T? How do member countries, and the AU as a whole, compare with the rest of the world? These are important questions, and this publication is part of the response.

The publication has been commissioned by the African Observatory for Science, Technology and Innovation (AOSTI). The creation of AOSTI itself is part of institutionalizing the process of answering questions about knowledge creation and the policies needed to promote knowledge creation. The focus of the publication is scientific knowledge that has been published in peer-reviewed journals and cited in other publications. There is also a discussion of patenting in Africa.

The importance of the publication does not lie just in its findings, but in the methods used to arrive at them. In its discussion of methods, it makes clear that measuring knowledge production in Africa has its challenges, which are highlighted so that more research can be done as part of a process of improving such measures and informing the policy process. This is a research agenda as well as a contribution to knowledge. As Agenda 2063 evolves in the AU, this publication and the work it will stimulate will have an on-going influence on public policy discussion, helping Africa to speak with one voice on matters of S&T and innovation.

AOSTI is to be congratulated on releasing this publication at a time when there is growing interest in and a need for indicators on S&T and innovation. It complements the work of the NEPAD Planning and Coordinating Agency published in the African Innovation Outlook series and raises some immediate policy opportunities. International cooperation is one of them.

The results on co-publication involving authors from Africa and from elsewhere show that these publications exceed those involving co-publication within Africa. Questions are raised about whether a high rate of collaboration outside Africa is desirable or whether it is a measure of dependency. This invites further research, as does the lower rate of co-publication within Africa. A programme similar to the European Framework Programmes could perhaps promote co-publication within Africa.

The *Assessment of Scientific Production in the Africa Union, 2005–2010* is a welcome contribution to knowledge, a stimulus to policy development, and an agenda for future work.

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Executive Summary

It is now accepted that science, technology and innovation (STI) are key components of sustainable development in modern economies and that STI data are pivotal for evidence-based policy-making. As Africa progresses towards sustainable development, its socio-economic and environmental transformations are highly linked to its STI capabilities at national and regional levels (AOSTI 2013). To that end, Africa's Science and Technology Consolidated Plan of Action (CPA) outlined programmes for improving policy conditions by strengthening Africa's capacity to develop and use STI indicators. The successor to the CPA, namely the Science, Technology and Innovation Strategy for Africa (STISA 2024), has brought to the forefront new dimensions of monitoring and evaluation of Africa's development in relation to the impact value chain of the S&T system.

The African Union's interest in and commitment to developing and using STI indicators for evidence-based policy-making has grown significantly, culminating in the Heads of State Decision Assembly/AU/Dec.452 (XX), which created the African Observatory of Science, Technology and Innovation (AOSTI). AOSTI serves as a continental repository of STI statistics and a source of policy analysis.

As a collective, Africa's initiated measurement of STI is still in its infancy. Only South Africa and Tunisia have thus far produced notable S&T statistics. Nonetheless, the first significant attempt to measure S&T activities in Africa commenced in 2007 when the AU–NEPAD launched the African Science, Technology and Innovation Indicators (ASTII) initiative. It is in that context that participating countries have conducted R&D and Innovation surveys and collected data to populate some mutually adopted indicators. For R&D, two main input indicators, namely gross domestic expenditure on research and experimental development (GERD) and R&D personnel, were selected. The resulting outcomes of the implementation of the ASTII project were published as the African Innovation Outlook (AIO 2010). The AIO 2010 included a bibliometric analysis of scientific output, but was limited to only 19 participating countries.

This report expands the scope of the 2010 bibliometric analysis and considers the scientific production of the African Union as a whole.

The output indicators described in this project are based on the use of bibliometric methods, which means that they are primarily measurements of the production and dissemination of scientific publications. There are clearly limitations to these indicators, and they should not be used in isolation. Nonetheless, they serve as a valuable description of gross levels of scientific production and scientific impact, as the communication of scientific results is highly predicated on the publication of journal articles. Furthermore, in this study steps have been taken to mitigate shortcomings wherever possible, including the selection of a bibliometric database with better representation of African publications.

The specific indicators used are as follows:

Number of papers published: This is a gross measurement that can be used as an indicator of total scientific production.

The following indicators are described by ratios, where a value greater than 1 is larger than the world average, and a value lower than 1 is lower than the world average:

Growth index (GI): This is a comparison between the number of papers published in the most recent time period and those published in earlier time periods, indicating the increase in the production of papers.

Specialization index (SI): It measures the relative emphasis on research areas within Africa compared to their prevalence in the world as a whole. The higher the SI, the more papers have been published in that particular area.

Average of relative impact factor (ARIF): This can be used as a marker of the quality of the scientific literature being published. The impact factor is a measurement associated with a journal, and is indicative of how frequently papers from that particular journal are referenced, taking into account the differences in citation levels between areas of scientific specialization. The assumption is that a paper published in a journal with a higher impact factor is of higher quality. This is because a high impact factor suggests that the particular journal tends to publish only papers that are of high value to other researchers, generally through a stringent editorial process.

Average of relative citations (ARC): This is the number of times the papers were referenced and takes into account the differences in citation levels between areas of scientific specialization. This provides a more direct assessment of paper quality and impact, since a large number of references is directly indicative of greater use of the published information by other researchers.

Collaboration index (CI): This key indicator is a measurement of the number of papers that are published with other authors, both in other AU member states and abroad. Scientific collaboration is the backbone of research, and is critical to the establishment of the AU as a world player. It provides a metric for judging the level of interaction between the AU and international scientists, and can also be related to the exposure of African scientists to leading-edge research on-going in the world.

This report is divided into eight principal sections including the introduction (Section 1) and the conclusion (Section 8). Section 2 provides a detailed methodology and describes the principal indicators used in the report. Section 3 reports on the overall scientific production per country and per capita with various metrics, and examines how the scientific output of AU countries and Regional Economic Communities (RECs) has grown compared with the world. Section 4 provides an analysis of production by scientific domain, field and subfield. Section 5 examines the scientific fields of specialization of the AU with positional analyses by field of science. Section 6 analyzes the scientific collaboration profiles of AU countries (within Africa and outside Africa) and how these affect the scientific impact of S&T outputs. Section 7 provides insight into the characteristics of Africa's most active researchers in terms of number of papers, their geographic location, their impact and their collaboration networks. Annex A gives a brief overview of the number of patents granted for the most active countries, as found in various patent offices, and Annex B comprises a series of technical notes that provide additional details and mathematical formulation of the bibliometric indicators used.

This study analyzes the outputs of all 54-member countries of the AU, thus making intra-African comparisons possible. The results are generally positive, showing high levels of growth in both total scientific production and in production quality. In general, this study shows that there are scientific areas in which great production momentum exists and needs to be supported and sustained. It also highlights areas of inertia that require greater investment in order to make Africa's scientific output more competitive.

The major findings of the study are described in the following sections.

1. Scientific production of the AU

The overall raw scientific output (number of scientific papers) showed that scientific activities are polarized around a few countries, with South Africa and Egypt dominating Africa's scientific output, followed by Nigeria, Tunisia and Algeria. However, that picture changes when the output is normalised. For instance, Tunisia is the top performer when scientific production is normalized per capita (million inhabitants), while the Seychelles and Botswana are second and fourth, respectively, in that category. Further comparisons by domain and field of science showed varying pictures in terms of country rankings and specialization by field of science.

2. The growth of scientific production in the AU

The contribution of the AU to the world's scientific production (2005–2010) remains small (1.8% of world production). The low level of contribution to world production shows that much effort still needs to be deployed in strengthening scientific production in Africa in order to catch up with the production levels of the rest of the world.

However, the scientific production of the AU, although small, grew 22% faster than that observed at the world level over the 2005–2010 period. Several African Regional Economic Communities (RECs) saw even faster growth: the Arab Maghreb Union's indexed production grew by 60%, that of the Community of Sahel-Saharan States by 50%, and that of the Common Market for Eastern and Southern Africa and of the Economic Community of West African States by 47% each. The growth has been accompanied by an increased capacity to publish in highly cited journals.

3. Intra-African collaboration and international collaboration in science and technology

Collaboration between AU members is infrequent, occurring in only 4.1% of AU scientific papers in 2005–2007 and in 4.3% of the papers in 2008–2010. Although having a high percentage of external collaboration (with non-African countries) is usually interpreted as a positive aspect in scientific knowledge production, too high a level of external collaboration may denote a situation of dependence. Mostly, external funding and the related grant conditions, compounded with the scarcity of significant funding sources from within Africa, may drive the high weight of international collaboration found in this study. Furthermore, the lack of strong collaboration frameworks in S&T to foster cooperative research within Africa is another drawback.

Despite this very low level of intra-African collaboration, it is noteworthy that 36 of the 54 AU member states increased their level of collaboration within Africa between 2005 and 2010.

4. Concentration of research effort and quality of research by field of science

The areas of science in which the AU has a concentration of research effort and demonstrated research excellence include:

- **Health sciences:** Microbiology, virology, complementary and alternative medicine, general and internal medicine, tropical medicine, health policy and services. The AU is also highly specialized in mycology and parasitology, but the quality of research in these fields remains slightly below the world average.
- **Natural sciences:** The AU is specialized in most of the biology, chemistry, mathematics and statistical fields, but the subfields where it achieves research quality above the world average are zoology and mathematical physics.
- **Applied sciences:** The AU is highly specialized in the field of agriculture, fisheries and forestry but

the research still remains to be published in higher impact factor journals in order to be accessible and used by the wider scientific community. The quality of AU research in the subfields of forestry and horticulture is above the world average.

It is worth noting that in the engineering field (belonging to the domain of applied sciences), the AU is achieving an impact above the world average in most subfields of engineering (meaning that quality research is being conducted), but the specialization index (showing concentration of effort) is below the world average for most subfields except chemical engineering, environmental engineering, mining and metallurgy.

In the subfield of information and communication technologies (ICT), much needs to be done, because the AU is far below the world average in terms of concentration of research effort and quality of research.

In the field of enabling and strategic technologies, including subfields such as bioinformatics, biotechnology, materials, energy, nanoscience and nanotechnology, the impact of research is above the world average, although the concentration of research effort in that field is still below the world level in general, except in biotechnology.

- **Economic and social sciences:** The concentration of research effort is above the world average, but the impact is below the average except in cultural studies and demography (both of which are subfields of the social sciences).
- **Arts and humanities:** The concentration of research effort is above the world average, but the impact is slightly below the world average except in anthropology and archaeology, where the AU is highly specialized, with research quality above the world average.

5. Characteristics of the most active scientists of the AU

A total of 505 researchers in the AU who had published 40 or more papers indexed in Scopus between 2005 and 2010 were labelled 'most active scientists' in this study, and their profiles were dissected in detail. The results showed that half of them (250 out of 505) have an ARC score above 1, meaning they are more highly cited than the world average researcher. Slightly more than half (53%) of the researchers for whom the ARIF indicator can be computed score above the world average. Likewise, 52% of the top researchers have an output growing faster than the world average. Some 245 researchers (49% of the leading researchers) have more than 50% of their publications authored with collaborators from a different country, and these researchers tend to have a greater than average scientific impact (69% of the researchers with more than 50% international collaborations score more than 1 on the ARC).

Recommendations

In light of the above findings and based on the results of this study, the following recommendations are made:

1. Increase the visibility of the AU's scientific production

It is estimated that the vast majority of Africa's scientific publications are not included in the citation indexes used in bibliometric studies to evaluate scientific production, mostly because of the low quality standards of the local journals that publish them. The greatest advantage of using comprehensive international bibliographic databases is that it allows international comparisons, such as a comparison of Africa's production with the rest of the world, which makes sense in the global competitive economy. It is therefore critical to find ways to raise the quality of African local journals for their inclusion in the bibliographic databases. Avenues that could be further explored include:

- Encouraging the creation and operation of S&T publishing houses in Africa;
- Improving the access of African researchers to high impact journals;
- Creating incentives for publishing in journals referenced in the citation index, similar to the South African incentive that rewards scientists per publication in international bibliographic databases. For example, this policy is actually boosting scientific publications in citation index journals by South African researchers and could be replicated by other African countries. Along that line, the National Council for Science and Technology of Kenya has followed suite by offering dollar incentives to scholars in public and private universities, research institutes and the NGO sector for every international publication in a peer-reviewed journal. Although incentives generally increase the number of publications, a careful evaluation of the context is required in order to determine which type of incentive (career, institutional or cash) should be promoted in order to maintain or increase research quality;
- Creating open and free access publication outlets for Africa, with improved review committees. Africa's most active researchers identified through this study, and the leading scientists of the African diaspora, could play a major role in such committees. Indeed, one of the major bottlenecks to publishing in some referenced journals is the publication fee; some of the citation index journals request high costs that African scientists and institutions cannot afford for the publication of a single paper.

2. Monitor and evaluate Africa's scientific production

There have been noticeable efforts to collect statistics on science, technology and innovation in African countries. These include the R&D and Innovation surveys, which are conducted in the framework of the ASTII initiative, and the recent collection of STI policy instruments led by AOSTI and UNESCO in the framework of the GO→SPIN project. The availability of data such as R&D expenditure, R&D personnel in terms of headcount and full-time equivalent (FTE), country population and gross domestic product (GDP) can be used to normalize the publication counts and hence enable comparability and monitoring over time. Therefore, efforts are encouraged to collect STI data in AU member states in order to support policy-making.

3. Boost intra-African cooperation in S&T while maintaining strong collaboration outside Africa

This study showed that in S&T, collaborations by AU member states with the world outside Africa far outpaces intra-African collaborations in terms of S&T production and impact. The insignificant intra-African cooperation in S&T means that synergies and complementarities of African S&T systems are not fully harnessed by Africans. It is suggested that the trend of increased collaboration observed between some African countries be supported, enhanced and replicated in other African countries through pan-African programmes engaging AU member states in common S&T cooperative frameworks.

4. Address gaps in fields of science that are essential to today's competitive knowledge economy

In applied science fields such as engineering, ICT, and enabling and strategic technologies, the gaps (areas with a low concentration of research efforts and/or low research quality) need to be addressed urgently due to the strategic importance of these fields for today's economic growth:

- In engineering, a higher concentration of research efforts is needed;
- In ICT, more research efforts and quality research are needed;
- In enabling and strategic technologies, a higher concentration of research efforts is needed.

5. Sustain the current growth trend of Africa's scientific production by adequate policy measures

The growth of scientific production observed at the AU has been substantial at the regional and individual country levels. These growth figures, although coming from an initially small stock of production, show that efforts undertaken to promote STI in Africa are starting to show results and need to be scaled up and sustained in order to have a long-lasting effect on economic growth and development. Policy-makers need to be provided with detailed projections of potential growth in order for them to take the necessary actions.

Conclusion

The AU's output is relatively small, but is growing rapidly, with a growth rate similar to that of India, China and Brazil between 2005 and 2010. Moreover, the propensity to publish in highly cited journals has grown rapidly between 2005 and 2010. One of the most important findings of this study is how infrequently African countries collaborate – only 4.3% of the papers in 2008–2010 included intra-African country collaboration. This contrasts with a score of 40% for extra-African collaboration between at least one African and one non-African country. A programme to foster cooperative research might help increase the rate of cooperation and accelerate the pace of STI development in Africa. In terms of specialization and impact by field of science, the recommendations contained in this report are based on the profile of the AU as a whole. At the levels of individual countries and Regional Economic Communities, however, the patterns of specialization and impact follow the general trends observed at the AU level but are varied in places, and would necessitate specific country and REC bibliometric profiling. The profiling of individual countries and RECs can be done on request and in collaboration with AOSTI. Overall, the trend of S&T improvement in the AU is quite promising, and further investigation in a number of areas at a more granular level is warranted.

Résumé Exécutif

Il est désormais admis que la science, la technologie et l'innovation (STI) sont des éléments clés du développement durable dans les économies modernes et que les données sur les STI sont essentielles pour l'élaboration de politiques basées sur des preuves. Alors que l'Afrique progresse vers le développement durable, ses transformations socio-économiques et environnementales sont fortement liées à ses capacités en STI au niveau national et régional (OASTI 2013). À cette fin, le Plan d'Action Consolidé (PAC) des sciences et de la technologie de l'Afrique a décrit les programmes pour l'amélioration des conditions des politiques en renforçant la capacité des pays africains à développer et utiliser les indicateurs de la STI. En outre, le successeur du PAC, à savoir la «Stratégie de la Science, la technologie et l'innovation pour l'Afrique (STISA 2024)» a mis en avant de nouvelles dimensions de suivi et d'évaluation du développement de l'Afrique par rapport à la chaîne de valeurs d'impact du système S&T.

L'intérêt et l'engagement de l'Union Africaine (UA) dans le développement et l'utilisation d'indicateurs de STI pour l'élaboration des politiques factuelles ont considérablement augmenté. Cela s'est traduit dans la décision Assembly/AU/Dec.452 (XX) des chefs d'État créant l'Observatoire Africain de la Science, la Technologie et l'Innovation (OASTI). L'Observatoire (OASTI) sert de référentiel continental en matière de statistiques STI, et de source d'analyse des politiques.

Dans l'ensemble, la mesure de STI initiée par l'Afrique est encore à ses débuts. Seules l'Afrique du Sud et la Tunisie pourraient émerger de ce lot, en ayant produit des statistiques notables en S&T. Néanmoins, la première expérience importante pour mesurer les activités S&T en Afrique a commencé en 2007 lorsque l'UA et le NEPAD ont lancé l'initiative africaine des indicateurs de la science, la technologie et de l'innovation (ASTII). C'est dans ce contexte que les pays participants ont mené des enquêtes sur la Recherche-Développement (R&D) et l'innovation et recueilli des données pour alimenter un certain nombre d'indicateurs commun. Pour la R&D, les deux principaux indicateurs d'intrants, à savoir les dépenses intérieures brutes en recherche et développement expérimental (DIRD) et le personnel de R&D ont été choisis. Les résultats découlant de la mise en œuvre du projet ASTII ont été publiés dans la Perspective de l'Innovation Africaine (AIO-2010). L'AIO-2010 comprenait une analyse bibliométrique de la production scientifique, mais limitée à seulement 19 pays participants.

Ce présent rapport élargit la portée de l'analyse bibliométrique de l'AIO-2010 et aborde la production scientifique de l'ensemble de l'Union Africaine.

Les indicateurs d'extrants décrits dans le présent rapport reposent sur l'utilisation de méthodes bibliométriques, ce qui signifie qu'ils sont essentiellement des mesures de la production et de la diffusion de publications scientifiques. Il y a clairement des limites à ces indicateurs, et ils ne devraient pas être utilisés isolément. Néanmoins, ils servent comme une description précieuse de l'enveloppe globale de la production scientifique et l'impact scientifique, compte tenu du fait que la communication des résultats scientifiques est fortement fondée sur la publication d'articles de journaux. En outre, dans cette étude, des mesures ont été prises pour mitiger autant que possible les lacunes, y compris le choix d'une base de données avec une meilleure représentation des publications africaines.

Les indicateurs utilisés sont les suivants:

Nombre d'articles publiés: Il s'agit d'une mesure brute qui peut être utilisée comme un premier indicateur de la production scientifique totale.

Les indicateurs suivants sont décrits de façon proportionnelle par rapport à la moyenne mondiale. Une valeur supérieure à 1 est au dessus de la moyenne mondiale et une valeur inférieure à 1 en deçà de la moyenne mondiale.

Index de croissance (GI): Il s'agit d'une comparaison entre le nombre d'articles publiés dans la période la plus récente à celles publiées dans des périodes antérieures, indiquant l'augmentation de la production de papiers.

Index de spécialisation (SI): cet index mesure l'importance relative des domaines de recherche en Afrique par rapport à leur prévalence dans le monde entier. Plus le SI est élevé, plus les articles ont été publiés dans ce domaine particulier.

Moyenne du facteur d'impact relatif moyen (ARIF): Il peut être utilisé comme un marqueur de la qualité de la littérature scientifique publiée. Le facteur d'impact est une mesure associée à un journal, et indique à quelle fréquence les articles de ce journal particulier sont référencés. Il tient compte de la différence des niveaux de citation entre les spécialités scientifiques. L'hypothèse est qu'un article publié dans un journal avec un facteur d'impact supérieur est de meilleure qualité. En effet, un facteur d'impact élevé suggère que ce journal a tendance à ne publier que des articles qui sont d'une grande valeur à la communauté scientifique, généralement a travers un processus éditorial rigoureux.

Moyenne des citations relatives (ARC): C'est le nombre de fois où ces documents ont été référencés, et tient compte de la différence des niveaux de citation entre les spécialités scientifiques. Ceci fournit une évaluation plus directe de la qualité de l'article et de l'impact, car un grand nombre de références est une indication directe d'une plus grande utilisation des informations publiées par d'autres chercheurs.

Index de collaboration (CI): cet indicateur clé est une mesure du nombre d'articles publiés en collaboration avec d'autres auteurs, aussi bien dans d'autres États membres de l'UA qu'à l'étranger. La collaboration scientifique est l'épine dorsale de la recherche, et est essentielle au positionnement de l'UA en tant qu'acteur mondial. Il offre une mesure du niveau d'interaction entre l'UA et les scientifiques internationaux, et peut également être lié à l'exposition des scientifiques africains à la recherche de pointe en cours dans le monde.

Ce rapport est divisé en 8 sections principales, y compris l'introduction (section 1) et la conclusion (section 8). La section 2 décrit la méthodologie et les principaux indicateurs utilisés dans le présent rapport. La section 3 rend compte de la production scientifique globale par pays et par habitant avec diverses métriques, et examine comment la production scientifique des pays de l'UA et des Communautés Économiques Régionales a augmenté par rapport à celle du monde. La section 4 fournit une analyse de la production par domaines, champs et sous-champs scientifiques. La section 5 examine les domaines scientifiques de spécialisation de l'Union Africaine à travers des analyses de position par domaine scientifique. La section 6 analyse les profils de collaborations scientifiques des pays de l'UA (collaborations en Afrique et hors d'Afrique) et comment cela affecte l'impact de la production scientifique et technologique. La section 7 donne un aperçu sur les caractéristiques des chercheurs les plus actifs d'Afrique en termes de nombre de publications, l'impact de leur production relatif à la moyenne mondiale, leur emplacement géographique et leurs réseaux de collaboration. Enfin, la partie Annexe A donne un bref aperçu des demandes de brevets numériques pour la plupart des pays actifs que l'on trouve dans différents bureaux de brevets, et l'Annexe B comprend une série de notes techniques qui fournissent des détails supplémentaires et la formulation mathématique des indicateurs bibliométriques utilisés.

Cette étude analyse les résultats des 54 pays membres de l'UA, ce qui rend les comparaisons intra-africaines possibles. Les résultats sont généralement positifs, montrant des niveaux élevés de croissance de la production scientifique totale et la qualité de la production. En général, cette étude montre qu'il y a des domaines scientifiques dans lesquels il existe un grand élan de production qui doit être soutenu pour être durable. Il met également en lumière les zones d'inertie qui nécessitent des investissements plus importants afin de rendre la production scientifique de l'Afrique plus compétitive.

Les principales conclusions de l'étude sont les suivantes:

1. Production scientifique de l'Union Africaine

La production scientifique brute globale (nombre d'articles scientifiques) montre que les activités scientifiques et technologiques sont polarisées autour de quelques pays, avec l'Afrique du Sud et l'Égypte dominant la production scientifique de l'Afrique, suivie par le Nigeria, la Tunisie et l'Algérie. Cependant, cet ordre change lorsque la production est normalisée. Par exemple, la normalisation de la production scientifique par habitant (millions d'habitants) emmène la Tunisie en tête comme le plus performant, alors que les Seychelles et le Botswana arrivent en deuxième et quatrième position respectivement dans cette catégorie. D'autres comparaisons par domaines et disciplines de science montrent différentes images en termes de classement des pays et de spécialisation par domaine scientifique.

2. La croissance de la production scientifique dans l'UA

La contribution de l'Union Africaine à la production scientifique mondiale (2005-2010) reste faible (1,8% de la production mondiale). Ce faible niveau de contribution à la production mondiale montre que beaucoup d'efforts doivent encore être déployés dans le développement de systèmes de STI en Afrique afin de rattraper les niveaux de production du reste du monde, et d'utiliser efficacement les STI pour le développement durable.

Cependant, la production scientifique de l'Union Africaine, bien que petite, a augmenté de 22% plus rapidement que celle observée au niveau mondial au cours de la période 2005-2010. Plusieurs communautés régionales africaines ont connu une croissance encore plus rapide: la production indexée de l'Union du Maghreb arabe a augmenté de 60%, celle de la Communauté des États sahélo-saharienne de 50%, et celle du Marché commun pour l'Afrique orientale et australe, et celle de la Communauté économique des États ouest-africaine de 47% chacune. La croissance a été accompagnée par une augmentation de la capacité à publier dans les revues les plus citées.

3. Collaboration intra-africaine et collaboration internationale en science et technologie

Les collaborations entre les membres de l'UA sont rares, se produisant dans seulement 4,1% des publications scientifiques de l'UA de 2005-2007 et 4,3% des publications de 2008-2010. Bien qu'un pourcentage élevé de collaboration externe (avec les pays non-africains) soit généralement considéré comme un aspect positif dans la production de connaissances scientifiques, un niveau trop élevé de collaboration externe peut indiquer une situation de dépendance. Surtout, le financement externe et les conditions de subventions connexes, aggravés par la rareté des sources de financement importantes venant de l'Afrique peuvent conduire à la part élevée de la collaboration internationale observée dans la présente étude. En outre, l'absence de cadres de collaboration forts en science et technologie pour encourager la recherche coopérative en Afrique peut également être citée comme un inconvénient.

Malgré ce très faible niveau de collaborations interafricaines, il est à noter que 36 des 54 États membres de l›UA ont augmenté leur niveau de collaboration en Afrique de 2005 à 2010.

4. Concentration des efforts de recherche et qualité de la recherche par domaines scientifiques

Les domaines scientifiques où l'UA a une concentration de l'effort de recherche supérieure ou égale à la moyenne mondiale et où elle a montré une excellence en matière de recherche scientifique comprennent:

- **Sciences de la santé:** microbiologie, virologie, médecine complémentaire et alternative, médecine générale et interne, médecine tropicale, les politiques et les services de santé.

  Dans les sciences de la santé, l'UA est hautement spécialisée également dans la mycologie et la parasitologie mais l'impact dans ces domaines reste légèrement en dessous de la moyenne mondiale.

- **Sciences naturelles:** l'UA est spécialisée dans la majeure partie de la biologie, la chimie, les mathématiques et les domaines statistiques, mais les sous-domaines où elle réalise un impact scientifique au-dessus de la moyenne mondiale sont la zoologie et la physique mathématique.

- **Sciences appliquées:** L'UA est hautement spécialisée dans le domaine de l'agriculture, de la pêche et de la sylviculture/foresterie, mais les travaux de recherche doivent encore être publiés dans des revues à facteurs d›impact plus élevés afin d›être accessibles et utilisés par la communauté scientifique au sens large. L›impact des travaux de recherche de l'UA dans les sous-domaines de la foresterie et de l›horticulture est au-dessus de la moyenne mondiale.

  Il est à noter que dans le domaine de l›ingénierie (appartenant au domaine des sciences appliquées), l›UA réalise un impact supérieur à la moyenne mondiale dans la plupart des sous-domaines de l›ingénierie (ce qui atteste de la bonne qualité de la recherche en cours), mais l›index de spécialisation (concentration d›effort) est inférieure à la moyenne mondiale pour la plupart des sous-domaines à l›exception du génie chimique, du génie de l›environnement, des mines et de la métallurgie. Ceci revient à dire que l'UA doit accroitre ses efforts de recherche en ingénierie pour rattraper le reste du monde mais elle peut déjà compter sur une recherche initiale de très bonne qualité en cours en Afrique dans ce domaine.

  Dans le sous-domaine des Technologies de l›Information et de la Communication (TIC), beaucoup reste à faire, parce que l›UA est bien en deçà de la moyenne mondiale en termes de concentration de l›effort de recherche et de la qualité de la recherche.

  Dans le domaine des technologies habilitantes et stratégiques, y compris les sous-domaines comme la bioinformatique, la biotechnologie, les matériaux, l›énergie, les nanosciences et les nanotechnologies, l›impact de la recherche est au-dessus de la moyenne mondiale ce qui atteste de la bonne qualité des travaux de recherche en cours, mais la concentration de l›effort de recherche de l'UA dans ces domaines est encore en dessous du niveau mondial en général, sauf dans les biotechnologies.

- **Sciences économiques et sociales:** la concentration de l'effort de recherche de l'UA est au-dessus de la moyenne mondiale, mais la qualité est inférieure à la moyenne, sauf dans les études culturelles et la démographie (les deux étant des sous-domaines des sciences sociales).

- **Arts et Lettres:** La concentration de l'effort de recherche de l'UA est au-dessus de la moyenne mondiale, mais la qualité est légèrement inférieure à la moyenne mondiale, à l'exception de l'anthropologie et de l'archéologie où l'UA est hautement spécialisée, avec un impact supérieur à la moyenne mondiale.

5. Caractéristiques des scientifiques les plus actifs de l'Union Africaine

Un total de 505 chercheurs de l'Union africaine qui avait publié 40 articles ou plus, indexés dans Scopus entre 2005 et 2010 ont été identifiés «scientifiques les plus actifs» et leurs profils ont été disséqués en détail. Tout d›abord, la moitié d›entre eux (250 sur 505) ont un score d'ARC au dessus de 1, ce qui signifie qu›ils sont plus cités que le chercheur moyen mondial. Un peu plus de la moitié (53%) des chercheurs les plus actifs pour qui l›indicateur ARIF peut être calculé ont un score supérieur à la moyenne mondiale. De même, 52% de ces chercheurs ont une production qui s'accroît plus vite que la moyenne mondiale. Quelques 245 chercheurs (49% des chercheurs les plus actifs) ont plus de 50% de leurs publications rédigées avec des collaborateurs d›un pays différent et ces chercheurs ont tendance à avoir un plus grand impact scientifique que la moyenne (69% des chercheurs ayant plus de 50% de collaborations internationales ont un score ARC supérieur à 1).

Recommandations

À la lumière des conclusions ci-dessus et sur la base des résultats de la présente étude, les recommandations suivantes sont faites:

1. Accroître la visibilité de la production scientifique de l'Union Africaine

On estime que la grande majorité des publications scientifiques de l'Afrique ne sont pas incluses dans l'index de citation utilisé par les études bibliométriques pour évaluer la production scientifique, principalement en raison des faibles normes de qualité des revues dites locales qui les publient. Le plus grand avantage de l'utilisation de publications des bases de données bibliographiques internationales est qu'elle permet des comparaisons internationales, ce qui signifie par exemple la comparaison de la production Africaine à celle du reste du monde, ce qui est logique dans la compétitivité de l'économie mondiale. Par conséquent, il est essentiel de trouver des moyens pour améliorer la qualité des revues locales africaines pour leur inclusion dans des bases de données bibliogrphiques.Dans ce sens, les voies à explorer comprennent:

- Encourager la création et le fonctionnement des maisons d›édition de science et technologie en Afrique.
- Améliorer l›accès des chercheurs africains à des revues à fort-impact.
- Créer des incitatifs pour la publication dans des revues référencées dans des bases de données bibliographiques internationales. Par exemple, l›Afrique du Sud récompense les scientifiques pour des publications dans l›index de citation. Cette politique est effectivement entrain de stimuler la publication scientifique dans les revues d›index de citations par des chercheurs sud-africains et pourrait être reproduite par d›autres pays africains. Dans le même sens, le Conseil National des Sciences et de la Technologie du Kenya offre aussi une incitation en espèces (dollar) pour les chercheurs dans les universités publiques et privées, les instituts de recherche et les ONG pour chaque publication internationale dans des revues spécialisées. En général, les incitations

augmentent le nombre de soumissions et de publications. Cependant, il faut soigneusement évaluer selon les contextes le type de mesures incitatives (carrière, institutionnel ou espèces) à promouvoir afin de maintenir ou d›améliorer la qualité des publications et de la recherche.

- Créer des débouchés pour les publications en libre accès et gratuit pour l›Afrique, avec des comités de lecture améliorés. Les chercheurs les plus actifs africains trouvés par cette étude et les principaux scientifiques de la diaspora africaine pourraient jouer un rôle majeur dans ces comités. En effet, l›un des principaux freins à la publication dans certains journaux référencés est les frais de publication, certaines des revues d›index de citations demandent des coûts élevés que les scientifiques et les institutions africaines peuvent difficilement mettre pour la publication d›un seul article.

2. Surveiller et évaluer la production scientifique en Afrique

Il y a des efforts notables pour collecter des statistiques sur la science, la technologie et l'innovation dans les pays africains. Cela inclut les enquêtes de R&D et d'innovation qui sont menées dans le cadre de l'initiative ASTII et la récente collecte de données sur les instruments de politique conduite par l'AOSTI et l'UNESCO dans le cadre du projet GO-SPIN. La disponibilité des données telles que les dépenses de R&D, le personnel de R&D, l'effectif en équivalent temps plein (ETP), la population du pays, le produit intérieur brut (PIB) peuvent être utilisés pour normaliser le nombre de publications et donc permettre la comparabilité et le suivi dans le temps. Par conséquent, des efforts sont encouragés à collecter des données sur la STI dans les États membres de l'UA afin de soutenir l'élaboration des politiques

3. Stimuler la coopération intra-africaine en matière de STI tout en maintenant de solides collaborations à l'extérieur de l'Afrique

Cette étude a montré que les collaborations scientifiques et technologiques des États membres de l'UA avec le monde extérieur dépassent de loin, les collaborations intra-africaines en termes de production et d'impact scientifiques et technologiques. Le fait que la coopération intra-africaine est négligeable en science et technologie signifie que les synergies et les complémentarités des systèmes de STI africains ne sont pas pleinement exploitées par les Africains. Il est suggéré que la tendance de collaboration accrue observée entre certains pays africains soit soutenue, renforcée et reproduite dans les autres pays africains à travers des programmes panafricains engageant les États membres de l'UA dans des cadres communs de coopération scientifique et technologique.

4. Combler les lacunes dans les domaines de la science qui sont essentiels à l'économie de la connaissance compétitive d'aujourd'hui

Dans les domaines des sciences appliquées telles que l'ingénierie, les technologies de l'information et de la communication (TIC), les technologies habilitantes et stratégiques, les lacunes (faible concentration des efforts de recherche et/ou qualité de recherche en dessous de la moyenne mondiale) mises en exergue par cette étude doivent être traitées d'urgence en raison de l'importance stratégique de ces disciplines pour la croissance économique d'aujourd'hui.

- • En ingénierie: une plus forte concentration des efforts de recherche est nécessaire.
- • En Technologies de l'information et de la communication, davantage d'efforts de recherche et de recherche de qualité sont nécessaires.

- Dans les technologies habilitantes et stratégiques: une plus grande augmentation des efforts de recherche est nécessaire.

5. Maintenir la tendance de croissance actuelle de la production scientifique de l'Afrique par des mesures politiques adéquates

La croissance de la production scientifique observée au niveau de l'UA, au niveau régional, et au niveau des pays individuels est considérable. Ces chiffres de la croissance, bien que venant d'un petit stock initial de production montrent que les efforts entrepris pour promouvoir la science, la technologie et l'innovation en Afrique commencent à porter leurs fruits et doivent être renforcées et soutenues pour un effet durable sur la croissance économique et le développement. Des images détaillées de la croissance doivent être fournies aux décideurs politiques pour des actions concrètes.

Conclusion

La production de l'Union africaine est relativement faible par rapport à la production mondiale, mais cette production est en croissance rapide, avec un taux de croissance similaire à celui de l'Inde, la Chine et le Brésil entre 2005 et 2010. En outre, la propension à publier dans les revues les plus citées a augmenté rapidement entre 2005 et 2010. Une des conclusions les plus importantes de cette étude est la faible collaboration entre les pays africains. Seulement 4,3% des publications pour la période 2008-2010 impliquent une collaboration interafricaine. Cela contraste avec le score de 40% pour la collaboration extra-africaine entre au moins un pays africain et un pays en dehors de l'Afrique. Un programme visant à encourager la recherche collaborative peut contribuer à augmenter le taux de coopération et permettre d'accélérer le rythme de développement des STI en Afrique. En termes de spécialisation et de l'impact par domaines scientifiques, les recommandations contenues dans ce rapport sont basées sur le profil de l'Union Africaine considérée comme un ensemble. Au niveau des pays pris individuellement et des communautés économiques régionales cependant, le profil de spécialisation et l'impact suivent les tendances générales observés au niveau de l'UA mais sont variés par endroits, et nécessiteraient des profilages bibliométriques spécifiques aux pays et aux CERs. Ces profilages de pays et CERs peuvent être réalisées sur demande et en collaboration avec OASTI. Globalement, la tendance de l'amélioration de la science et de la technologie dans l'Union africaine est très prometteuse, et une enquête plus approfondie dans un certain nombre de domaines à un niveau plus granulaire est justifiée.

1 Introduction

It is now generally accepted that science, technology and innovation (STI) are key components of sustainable development in today's knowledge economy. African countries have embodied this concept in various continental policy-making structures, including the Summits of Heads of State and Government and those of the Regional Economic Communities (RECs). Countries have embedded STI in various forms in their development agendas.

Along the same lines, national capacity to use STI for economic development features in several international collaboration and cooperation frameworks between Africa and its partners. Examples of these partnerships include the European Union–Africa Joint Strategy, the India–Africa science and technology (S&T) initiatives and the China–Africa Science and Technology Partnership (CASTEP), to mention but a few. It is equally important to note the pivotal role assigned to the STI pillar in the framework of the United Nations (UN) Millennium Development Goals (MDGs) (UN Millennium Project, 2005).

A common feature among the aforementioned initiatives is the low investment in coherent policies and practices for the collection, storage and use of STI data as far as the African side is concerned. By and large, STI statistics remain scarce, as highlighted in a recent AOSTI working paper (AOSTI, 2013). This paucity of STI data has led to the African Union (AU) to create the African Observatory for STI (AOSTI) to serve among other things as the continental repository for such data.

In rolling out the AOSTI programme of work, the intergovernmental meeting held in Malabo, Equatorial Guinea in May 2012 recommended that the thematic area on the 'Development and management of STI indicators' be prioritized for urgent implementation. The present initiative on bibliometric indicators is one of the projects emanating from that theme. Thus, with this report, AOSTI has commenced a series of detailed studies of the scientific production and performance of African countries.

Bibliometrics refers to the application of quantitative methods to books and other communication media (Pritchard, 1969). This definition translates into the statistical analysis of data on S&T literature and constitutes a method for measuring the production and dissemination of knowledge. Indeed, bibliometrics is a tool by which the state of S&T can be observed through the overall production of scientific literature to situate a country in relation to the world, an institution in relation to a country, and even individual scientists in relation to their own communities (Okubo, 1997). Bibliometrics is used in research performance evaluation by governments, policy-makers, research directors and administrators, information specialists, librarians, and researchers themselves. However, it is worth noting that using bibliometric analysis alone cannot justify a decision or replace evaluations by experts. Bibliometric indicators are practical tools that must be used with other indicators and peer judgements for better decision-making (Okubo, 1997).

This study uses bibliometric approaches with a variety of output and impact statistics to analyze the S&T production of all 54-member states of the African Union for the 2005–2010 period. In evaluating the S&T systems, output and impact indicators have been used in conjunction with input indicators. Output indicators complement input indicators and represent a proxy of the overall output of scientific research to gauge the general health of science systems (Tijssen, 2007).

Research outputs from relatively small sets of African countries or regions have been analyzed in the past (Adams, King and Hook, 2010; Boshoff, 2009, 2010; Pouris and Pouris, 2009; Tijssen, 2007; Toivanen and Ponomariov, 2011; Megnigbeto, 2013; Onyancha and Resenga Maluleka, 2011). While these studies have shed light on various aspects of Africa's S&T production, there is a need to increase awareness of the use of bibliometric data among the STI community, including policy-makers, and economic, scientific and social players.

This study acknowledges that international bibliographic databases fall short with regard to capturing research outputs published in many local African journals, especially in the social and human sciences. Yet a combination of local and international knowledge is a key ingredient of innovation and design-related policy support. In setting the foundation for periodic assessment of the quantity, quality and impact of African scientific research, follow-up projects will address and capture such knowledge, especially when focusing on domestic and regional issues and problems.

The rest of the report comprises ten main sections, including this introduction and two annexes.

Section 2 details the methodology and defines the principal indicators used in the report. Section 3 discusses the overall scientific production per country and per capita with various metrics, and examines how the scientific output of AU countries and Regional Economic Communities (RECs) has grown in comparison with the rest of the world. Section 4 analyses production by the various scientific domains, fields and subfields. Section 5 examines the scientific fields of specialization of the AU, including positional analyses by field of science. Section 6 analyzes the scientific collaboration profiles of AU countries (within Africa and outside Africa) and the way in which such profiles affect the scientific impact of S&T outputs. Section 7 provides insight on the characteristics of Africa's most active researchers in terms of the number of papers, their geographic location and their collaboration networks. Section 8 concludes the report. Annex A gives a brief overview of the number of patents granted for the most active countries, as found in various patent offices. Lastly, Annex B comprises a series of technical notes that provide additional details and mathematical formulation of the bibliometric indicators used.

2 Methodological and analytical frameworks

Bibliometrics is a method for indirectly measuring the production and dissemination of scientific knowledge. In addition to the caveats of individual indicators, some of the shortcomings associated with bibliometrics are related to the databases used to conduct the analyses. Currently, there are only two comprehensive databases that offer extensive coverage of international scientific literature and index the bibliographic information required to perform robust and extensive bibliometric analyses. The Web of Science (WoS) produced by Thomson Reuters and covering about 12,000 peer-reviewed journals, and Scopus produced by Elsevier and covering about 18,000 peer-reviewed journals.

A relevant question for the present project is: How appropriate are these two databases for measuring scientific outputs in Africa?

The two databases differ in terms of scope, volume of data, data quality and coverage policy. The WoS has traditionally indexed mainly papers published in highly cited journals, while Scopus aims to be as comprehensive as possible in its coverage. The extended coverage of Scopus limits to a certain extent the linguistic bias observed in the WoS towards countries that publish in English-language journals. Thus, scientific production is underestimated for countries whose researchers publish more often in languages other than English, which is an important factor in relation to the linguistic diversity observed in Africa. In previous analysis of the robustness of bibliometric indicators as measures of scientific production by comparing statistics obtained from WoS and Scopus, indicators based on counts of refereed articles and on counts of citations to these papers were found to be stable in various fields (Archambault et al., 2009). Importantly, however, Scopus has a noticeably higher number of papers from Africa, and it can thus be expected that scientific knowledge production in Africa can be measured with greater precision using Scopus. The full-counting method was used, in which each paper is counted once for each entity in the address field of papers (e.g., individual researcher, institution, country, region, etc.). The method used in this report avoids double counting of units within the same aggregate level (e.g., authors within the same country, countries within the same geographic region, etc... are counted once at these levels).

So far, one of the most detailed studies of Africa's science production has been that of Tijssen (2007), covering scientific publications up to 2004 for several African countries. It is worth noting that works published in citation index journals from many scientific research fields require citation windows of at least three to four years to produce reliable citation indicators of impact on scientific visibility and influence (Tijssen and Van Leeuwen, 2003). The present study, undertaken in 2012, uses the Scopus bibliographic database compiled by Elsevier, as standardized and conditioned by Science-Metrix, to produce bibliometric statistics on the AU's production for the 2005–2010 period, by applying the full-counting method and where each paper is counted once for each entity considered in the address field of the paper to compile the following indicators:

Number of papers: As an indicator of scientific knowledge production, this indicator provides a simple count of scientific papers, the great majority being peer-reviewed, as indexed in the Scopus database. It is a means of measuring and comparing the overall production of various aggregations such as institutions, regions and countries. A number of other indicators can also be derived from these simple counts. Ways of normalizing publication counts include dividing the number of publications by a country's population, gross national product and R&D expenditure, as well as researchers (headcount and full-time equivalent [FTE]) when dealing with institutions or departments.

Growth index (GI): This is an indicator of the speed at which output is growing compared with growth observed at the global level. This index is typically calculated over two periods: in the present report, the number of papers published in 2008–2010 is compared with the number published in 2005–2007. This indicator is increasingly used in bibliometric studies, as it is relatively immune to the presence of noisy data and highly fluctuating levels of outputs that are typical in computing statistics for smaller or less active countries, or when the analysis concentrates on highly desegregated data.

Average of relative impact factor (ARIF): The impact factor is the most popular bibliometric measure today (Glanzel and Moed, 2002). It is an indicator of research output quality based on the propensity to publish in highly cited journals. This indicator reflects the fact that the number of citations that an article is likely to receive varies by scientific specialization and by journal. Because journals that are more highly cited tend to be more sought after by researchers, these can generally afford to be more selective, which explains why this indicator can be considered to reflect the quality of scientific knowledge production. Its strength lies in its comprehensibility, stability and rapid availability.

Average of relative citation (ARC): This is an indicator of scientific impact, which like the ARIF indicator reflects the varying likelihood of a paper being cited in various scientific specializations. Indeed, one way of increasing the finesse of the citation counts indicator is to calculate them relative to the size of the publication pool analyzed, or, better, to the citation performance expected for the scientific field or subfield. The assumption is that the number of citations received by an individual, institution or country is closely linked to the number of articles published in the field or subfield.

Specialization index (SI): This indicator reflects the concentration of papers in given fields, taking the world proportion as the baseline. Thus, the SI indicator translates the research intensity or effort of a given geographic or organizational entity (e.g., a country), in a given research area (e.g., domain, field), relative to the effort of the reference entity (e.g., the world) in the same research area. For instance, if a country has 10% of its papers in a single field and these papers represent 5% of the world papers in that field, then the specialization index of that country would be 2 (or 10% divided by 5%). An index value above 1 (world level) means that a given entity is specialized relative to the reference entity, while an index value below 1 means the opposite. The specialization index is a fairly widespread indicator in the bibliometric literature, although it is very often designated under different names such as the activity index (Tuzi, 2005) and the Revealed Literature Advantage (RLA) (Verbeek et al., 2002).

Use of positional analyses in conjunction with classification of science and technology

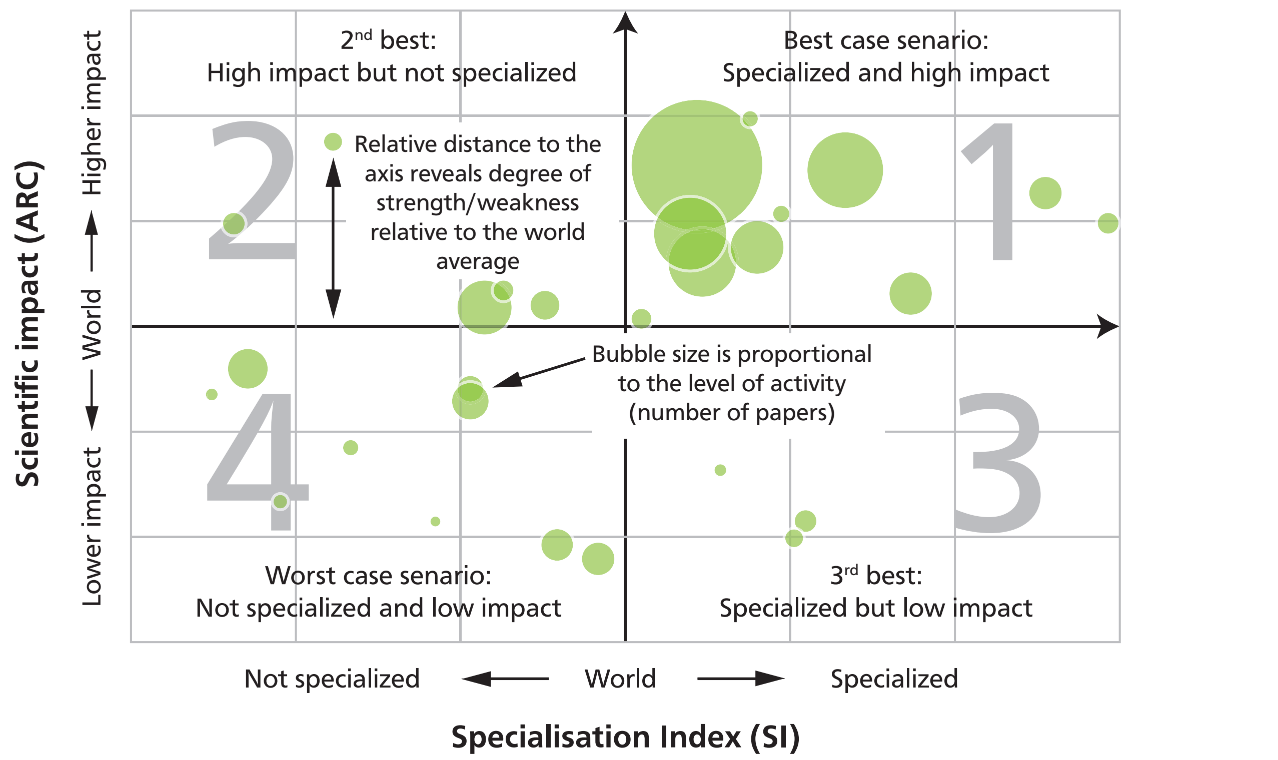
Positional analyses are widely used to aid in the interpretation of relative strengths and weaknesses of an entity (e.g., a country or an institution) and/or to compare different entities through the combination of three indicators in a two-dimensional space. The horizontal axis of quadrant charts corresponds to the specialization index (SI), and the vertical axis to the scientific impact or impact factors of journals in which the work is published (i.e., ARC or ARIF).

In quadrant charts, the SI and ARC scores are transformed to obtain a symmetrical distribution of possible scores around the world level (i.e., the origin in the Cartesian coordinate system). Thus, the strengths of an entity are to be found in the top right quadrant (high level of specialization, high level of impact). The third dimension is obtained by making the size of data points in the graph proportional to the number of publications produced by the corresponding entities; the colours of data points in the graph can be customized, for example, to differentiate countries from different continents.

The position of a country or institution in one of four quadrants can therefore be interpreted as follows (see Figure 1):

- **Quadrant 1:** Located at the top right of the graph, this quadrant is synonymous with excellence. Institutions and countries in this quadrant specialize in the given domain and their activities have a high impact, meaning that their papers are more frequently cited than the world average in this field.
- **Quadrant 2:** Located at the top left of the graph, this quadrant is synonymous with high-impact scientific production, but the countries or institutions are not specialized in the field.
- **Quadrant 3:** Located at the bottom right of the graph, this quadrant signals specialization in the field, whereas the entity's impact is below the world average.
- **Quadrant 4:** Located at the bottom left of the graph, this quadrant indicates that the entity does not specialize in the given area and that its impact is below the world average.

Figure 1: Explanation of positional analysis graph



Collaboration index (CI): Scientific collaboration has gained considerable attention in recent years. In general, collaboration seems to be increasingly associated with conducting excellent research, and as such is an interesting goal to be pursued through science policy. Bibliometrics can be used to measure collaboration between individual scientists, departments, institutions or countries, through the analysis of information contained in papers with two or more authors. This indicator takes into account the propensity to collaborate, and the relationship between collaboration and the size of scientific production. This is used to complement the indicator based on the percentage of collaboration, as the latter indicator varies greatly with country size (researchers in small countries collaborate frequently, and those in larger countries less so). The CI indicates whether a country collaborates more or less than expected for its size, given the way in which collaboration scales among countries of different size. Importantly, collaboration is less frequent in certain fields of science: experimental science has more collaborations than theoretical science.

National collaboration rate: This is an indicator of the relative importance of national collaboration, that is, collaboration between institutions within a single country. The rate is calculated by dividing the number of papers with at least two institutional addresses within the country by that country's total number of papers.

Regional collaboration rate: Collaboration can also be calculated at the regional level, and usually falls into the category of either intra-regional collaboration (within a single region), or inter-regional collaboration (e.g., between RECs).

A number of regional economic organizations play major roles in economic development across Africa. This study analyzed the scientific production of the following eight Regional Economic Communities (RECs):

- Arab Maghreb Union (AMU)
- Community of Sahel-Saharan States (CEN-SAD)
- Common Market for Eastern and Southern Africa (COMESA)
- East African Community (EAC)
- Economic Community of Central African States (ECCAS)
- Economic Community of West African States (ECOWAS)
- Intergovernmental Authority on Development (IGAD)
- Southern African Development Community (SADC).

It is important to mention that the membership of some of those regional organizations overlaps with others. Therefore, care should be taken by readers when adding up the scientific production of at least two regional organizations to check whether they overlap.

International collaboration rate: This is an indicator of the relative importance of international collaboration. The rate is calculated by dividing the number of papers with at least one author at a foreign country address by the entity's total number of papers.

Scientific production per domain and field of science: In order to cover emerging scientific fields, this study uses a new scientific journal-level classification described by Archambault et al. (2011) and available at www.science-metrix.com. This classification includes newer fields of science, general and multidisciplinary journals, and the range of arts and humanities disciplines. Thus, it analyzes many more fields of science than the standardized classification available in the Frascati family of manuals. However, if the need arises to compare this study with other studies conducted using the standard classification, it is possible to match the six fields of science devised in Frascati by grouping at different levels.

Readers interested in the technical formulation of the indicators listed in this section can refer to Annex B and the references therein.

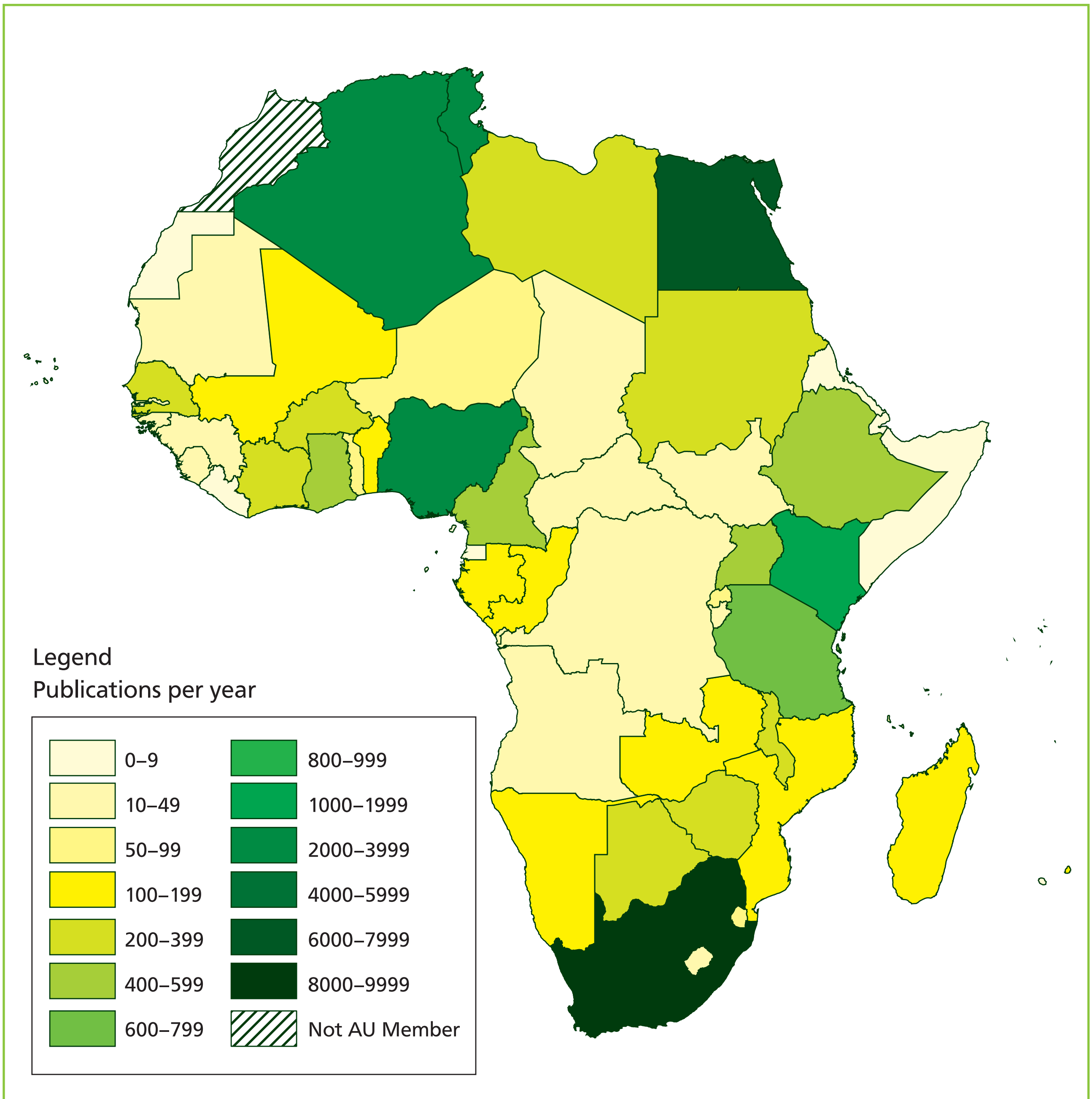
Source of data

The Tables and Figures contained in this report were computed by Science-Metrix using data from the Scopus database.

3 Scientific output in the African Union

The African Union (AU) comprises 54 member states, for which the scientific production is mapped in Figure 1, and the detailed bibliometric data provided in Table I. Within the AU, scientific output is concentrated mostly in South Africa and in the northern part of Africa, while the more central countries of the continent (with the exception of Nigeria) typically publish fewer papers (Figure 2 and Table I).

Figure 2: Map of scientific output of the African Union, 2005–2010



Source: computed with data from the Scopus database

The data on scientific publications of the AU and European countries retrieved from the Scopus database and analyzed by the present study showed that the scientific production of the AU was about the same size as that of Switzerland, Sweden and Poland in 2005. Ranking countries by the total number of their publications in this study showed also that AU ranks 19th in the World in 2005, when considered as a single country. Though some might find it discouraging that a whole continent published the same amount as some relatively small countries, there is a positive aspect to note, namely that considering the whole of the AU as one, and examining the growth in scientific production of only the largest 20 countries, the AU would have ranked fourth between 2005 and 2010, just behind India, China and Brazil and ahead of the Republic of Korea (Figure 3). Because of this important growth, the AU would have ranked 15th in 2010 if it were considered a country. Importantly, the AU published more papers than Russia in 2010 (with respectively 39,390 and 35,700 papers that year).

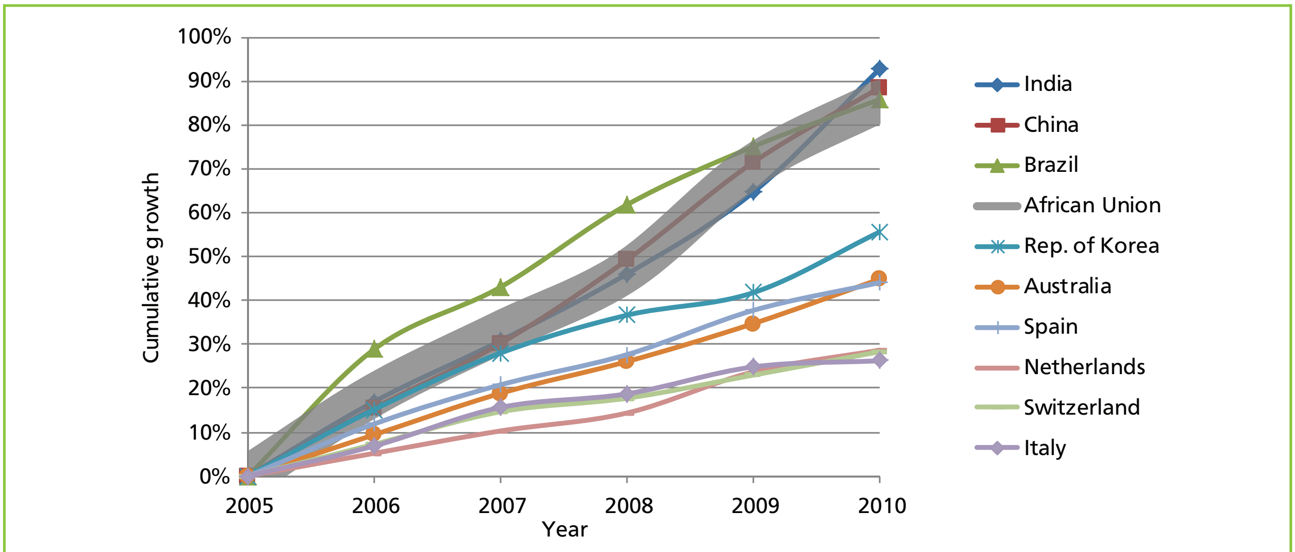
Table I: Papers and growth in scientific production by world-leading countries and by AU members, 2005–2010

Country/Group	2005	2006	2007	2008	2009	2010	2005-2007	2008-2010	% change 2008-2010/2005-2007	Growth Index
World	1,443,998	1,542,026	1,633,499	1,721,635	1,817,608	1,897,208	4,619,523	5,436,451	18%	100
United States	430,526	443,236	454,603	461,260	467,195	480,260	1,328,365	1,408,715	6%	090
China	195,915	226,307	255,136	292,410	336,005	369,328	677,358	997,743	47%	125
United Kingdom	108,759	115,450	122,227	123,375	126,949	130,057	346,436	380,381	10%	093
Japan	116,494	118,448	116,287	114,466	115,349	114,914	351,229	344,729	-2%	083
Germany	103,459	106,751	112,472	115,751	119,095	122,362	322,682	357,208	11%	094
France	75,326	79,387	82,880	86,414	89,656	91,887	237,593	267,957	13%	096
Canada	60,892	64,340	68,995	71,300	73,956	75,493	194,227	220,749	14%	097
Italy	56,232	60,095	65,027	66,771	70,219	71,010	181,354	208,000	15%	097
African Union	21,237	25,175	28,217	31,165	36,270	39,390	74,629	106,825	43%	122
South Africa	6,748	7,544	8,039	8,852	9,840	10,477	22,331	29,169	31%	111
Egypt	4,485	5,003	5,562	6,247	7,816	8,469	15,050	22,532	50%	127
Nigeria	2,090	2,971	3,487	3,714	4,498	4,977	8,548	13,189	54%	131
Tunisia	1,994	2,390	2,876	3,400	3,994	4,328	7,260	11,722	61%	137
Algeria	1,170	1,597	1,831	2,323	2,789	2,874	4,598	7,986	74%	148
Kenya	848	961	1,122	1,190	1,326	1,430	2,931	3,946	35%	114
United Rep of Tanzania	431	574	623	609	692	790	1,628	2,091	28%	109
Cameroon	435	559	586	612	662	699	1,580	1,973	25%	106
Ethiopia	392	499	574	600	663	780	1,465	2,043	39%	118
Uganda	358	436	535	547	676	847	1,329	2,070	56%	132
Ghana	332	358	470	464	618	706	1,160	1,788	54%	131
Senegal	328	278	342	358	368	371	948	1,097	16%	098
Sudan	156	189	254	283	394	469	599	1,146	91%	163
Zimbabwe	245	291	335	287	264	301	871	852	-2%	083
Botswana	210	290	253	283	258	238	753	779	3%	088
Côte d' Ivoire	174	196	246	311	294	302	616	907	47%	125
Malawi	164	188	261	291	269	324	613	884	44%	123
Burkina Faso	160	243	233	267	288	290	636	845	33%	113
Libya	108	135	158	210	321	467	401	998	149%	211
Benin	120	158	189	201	245	230	467	676	45%	123
Zambia	123	157	185	202	192	241	465	635	37%	116
Madagascar	126	142	183	188	172	183	451	543	20%	102
Congo	110	135	149	148	171	203	394	522	32%	113
Mali	89	135	132	134	150	160	356	444	25%	106
Mozambique	69	101	104	122	137	136	274	395	44%	122
Gambia	85	112	96	107	113	113	293	333	14%	097

Country/Group	2005	2006	2007	2008	2009	2010	2005-2007	2008-2010	% change 2008-2010/2005-2007	Growth Index
World	1,443,998	1,542,026	1,633,499	1,721,635	1,817,608	1,897,208	4,619,523	5,436,451	18%	100
Gabon	100	110	87	102	114	109	297	325	9%	093
Namibia	114	112	101	92	100	100	327	292	-11%	076
Mauritius	82	88	83	100	116	131	253	347	37%	117
Niger	52	59	59	82	107	134	170	323	90%	161
Rwanda	20	44	54	60	83	130	118	273	131%	197
Togo	44	47	60	68	68	78	151	214	42%	120
Swaziland	32	34	33	48	71	112	99	231	133%	198
Angola	27	27	28	31	34	39	82	104	27%	108
Eritrea	29	39	37	23	24	18	105	65	-38%	053
Guinea	15	35	29	32	26	29	79	87	10%	094
Seychelles	14	21	35	33	23	27	70	83	19%	101
Central African Republic	20	26	22	26	27	28	68	81	19%	101
Lesotho	14	19	25	29	31	27	58	87	50%	127
Chad	25	36	19	22	26	14	80	62	-23%	066
Dem Rep of the Congo	14	16	17	20	33	39	47	92	96%	166
Mauritania	29	25	22	21	19	19	76	59	-22%	066
SierraLeone	14	14	20	21	30	34	48	85	77%	150
Guinea-Bissau	22	14	29	20	21	22	65	63	-3%	082
Burundi	9	10	21	9	12	33	40	54	35%	115
Djibouti	5	6	11	7	15	13	22	35	59%	135
Equatorial Guinea	4	7	10	5	15	10	21	30	43%	121
CapeVerde	1	10	4	8	10	14	15	32	113%	181
South Sudan	3	5	4	4	14	10	12	28	133%	198
Liberia	3	8	4	8	4	11	15	23	53%	130
Comoros	3	1	8	2	3	6	12	11	-8%	078
Somalia		3		4	2	11	3	17	467%	482
Sao Tome and Principe	1	3	4		3	4	8	7	-13%	074
Western Sahara	1			1	4	8	1	13	1200%	1105

Source: computed with data from the Scopus database

Figure 3: Scientific production of fastest-growing countries among 20 largest producers, 2005–2010



Source: computed with data from the Scopus database

As shown in Table II, the growth rate in scientific production in the AU was high. Production in the AU grew by 43% in the period 2008–2010 compared with the preceding three years (2005–2007), and compared with 18% growth at the world level over the same period. This translates into a growth index (GI) of 1.22, meaning that growth in the AU was 22% faster than that observed at the world level. Several African communities saw even faster growth: the Arab Maghreb Union's indexed production grew by 60%, that of the Community of Sahel-Saharan States by 50%, and that of the Common Market for Eastern and Southern Africa and of the Economic Community of West African States each by 47%. The incremental increase (the delta) in the number of papers between 2005–2007 and 2008–2010, and the comparisons between African countries, the AU as a whole, and eight non-African countries including China are given in Table I.

The countries with the greatest raw production in the AU were South Africa (1st), Egypt (2nd), Nigeria (3rd), Tunisia (4th) and Algeria (5th). The production of each of these countries grew faster than that observed at the world level, with Algeria growing fastest (74%) among these five. Among the AU countries with at least 100 papers between 2005 and 2010, growth was fastest in Libya, Swaziland, Rwanda, the Democratic Republic of the Congo (DRC) and Sudan.

Table III presents the output of AU members alongside the output normalized per capita (in papers per year per one million inhabitants), the ranking for these two metrics (raw output and output per capita), and the difference in rank by country for these two measures (namely, how many ranks up or down a country moved between the per capita and raw paper output). When the total production is normalized per capita, South Africa, Egypt and Nigeria shift to the third, fifth and seventeenth positions respectively, and the top three countries for per capita production are Tunisia (1st), Seychelles (2nd) and South Africa (3rd). This shows the importance of data normalization in bibliometric studies in various instances of data interpretation. A number of indicators, including the number of researchers, full-time equivalent (FTE) data, and gross domestic expenditure on R&D (GERD), can be used for normalization in order to assess the efficiency of scientific paper production units (e.g., by institution, country or region). Recent efforts of the African Science, Technology and Innovation Initiative (ASTII), an initiative of the New Partnership for Africa's Development (NEPAD), are producing data on some of these key input indicators. For instance, data on the number of researchers, FTE and GERD have been collected in recent surveys by the ASTII programme in several countries (AU–NEPAD, 2010). As these data become more detailed and more accurate through surveys in more AU countries, it will be possible to normalize the scientific output data (e.g., papers) using several indicators.

The number of papers per capita used in this report to normalize the raw output presents a proxy for the production by headcount of the inhabitants of countries. The advantage of this measure is that it provides a more level ground for evaluating countries, because examining only scientific output tends to favour the larger countries.

Table II: Number of papers and growth in scientific production by AU member states, 2005–2010

Country/Group	2005-2010	2005-2007	2008-2010	% Increase 2003-2010/2005-2007	Growth Index
World	10,055,974	4,619,523	5,436,451	18%	1.00
African Union	181,454	74,629	106,825	43%	1.22
Community of Sahelo-Saharan Stales	108,575	43,507	65,068	50%	1.27
Southern African Development Community	61,778	27,006	34,772	29%	1.09
Common Market for Eastern and Southern Africa	60,239	24,357	35,882	47%	1.25
Arab Maghreb Union	42,836	16,461	26,375	60%	1.36
Economic Community of West African States	32,456	13,117	19,339	47%	1.25
Intergovernmental Authority on Development	15,237	6,248	8,989	44%	1.22
East African Community	13,688	5,759	7,929	38%	1.17
Economic Community of Central African States	5,239	2,343	2,896	24%	1.05

Source: computed with data from the Scopus database

Note: Some of the Regional Economic Communities (RECs) overlap (some countries belong to two or more RECs). Care should be taken to avoid double counting the outputs of such countries when adding up the outputs of overlapping RECs.

Although South Africa is the country with the greatest scientific raw output, Tunisia ranks first for papers per capita. Among the countries that publish an average of 100 or more papers per year, those that show the greatest difference in production compared with their production are Mauritius, Gabon, Namibia, the Gambia, Congo and Botswana. In contrast, countries (with 100 papers or more per year) where production seems to be commensurate with their population size are Ethiopia, Sudan, Tanzania, Mozambique, Côte d'Ivoire, Nigeria and Madagascar.

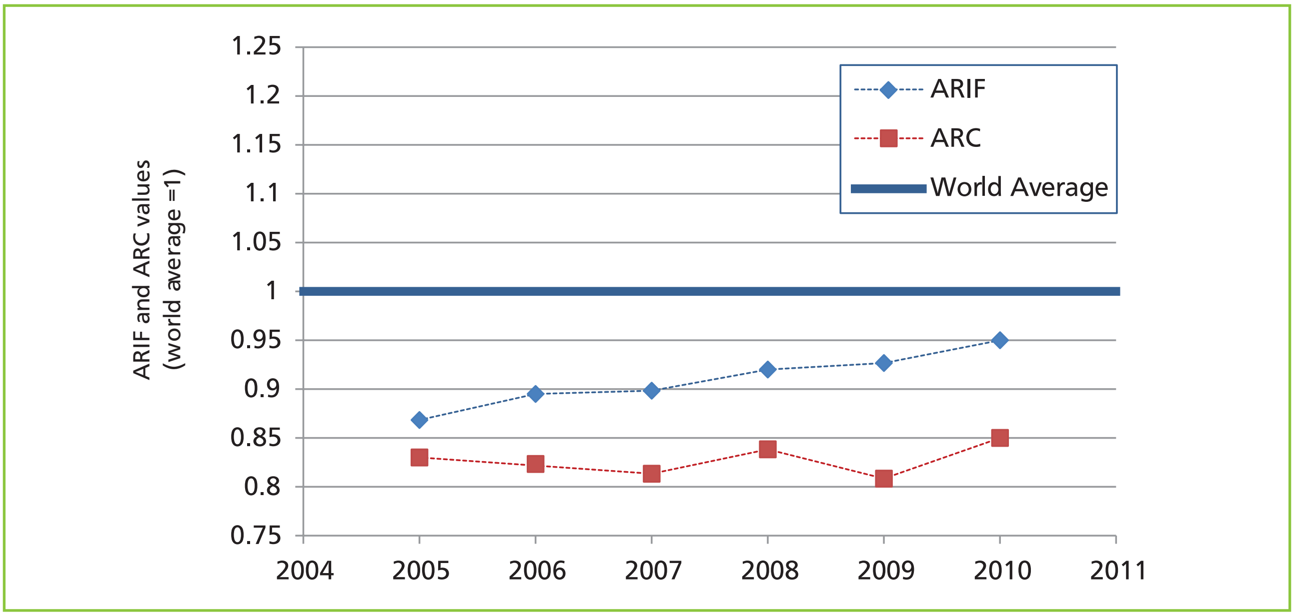
It is evident that there are large variations among countries that are more productive or less productive than expected, given their population size. Production can therefore not be accounted for merely on the basis of language, geographic location, or the presence of peace or unrest. This shows the multitude of variations in the African STI landscape and the need to undertake detailed country studies to examine historical, social and economic factors that might have contributed to accelerating or inhibiting the pace of scientific development, and to develop policies adapted to the particular national context.

The growth in the output of the AU has been accompanied by an increased ability to publish in highly cited journals. This can be seen by calculating an impact factor for every journal (an indicator of how frequently the papers in a journal are cited on average), which, as mentioned in the methodological notes, takes into consideration differences in citation patterns between scientific disciplines. This normalized measure of journal impact, the average of relative impact factors (ARIF), is presented in Figure 4. It shows that, year on year, AU papers are on average increasingly being published in higher-quality journals. The situation is not as clear-cut with the level of citations received, as indicated by the average of relative citations (ARC). In this area, the AU's output is relatively stable, although progressively greater impact (and thus ARC values) could be expected in the future, as there is usually a correlation between the ability to publish in highly cited journals and the capacity of the papers to receive many citations (namely, papers published in journals with a high impact factor can be expected to receive more citations).

Another indication that the quality of the scientific output produced in African countries is increasing is the number of AU member states that obtained an ARIF value above the world average (ARIF > 1). That score increased from 12 countries in 2005 to 19 countries in 2010. Likewise, there were 10 AU members with an ARC score above 1 in 2005, and 17 in 2010.

The five countries that had the greatest propensity to publish in highly cited journals were the Gambia, Guinea-Bissau, Zambia, Malawi and Mozambique. Conversely, the five countries that published papers with the greatest relative scientific impact were South Sudan, the Gambia, the Seychelles, Mozambique and Zambia (as indicated by the ARC). Some countries have the ability to publish in highly cited journals and to publish papers with demonstrated scientific impact. More research is needed to explain why these countries have managed to achieve such outstanding scores. The Leadership concept by Scimago (Scimago Journal and Country Rank at www.scimagojr.com) could be applicable in such further study as a tool for an initial investigation of the characteristics of the output.

Figure 4: Evolution of ability to publish in highly cited journals (ARIF) and level of scientific impact (ARC) of the AU, 2005–2010



Source: computed with data from the Scopus database

Table III: Number of papers and papers per capita by AU member states, 2005–2010

Country	Output		Output/capita		Δrk
	Papers	rk ↑	Papers	rk	
South Africa	51,500	1	177.1	3	-2
Egypt	37,582	2	81.9	5	-3
Nigeria	21,737	3	25.0	17	-14
Tunisia	18,982	4	306.2	1	3
Algeria	12,584	5	62.5	8	-3
Kenya	6,877	6	30.6	15	-9
United Rep. of Tanzania	3,719	7	15.6	25	-18
Cameroon	3,553	8	32.4	14	-6
Ethiopia	3,508	9	7.2	37	-28

Continued on next page

Country	Output		Output/capita		Δrk
	Papers	rk ↑	Papers	rk	
Uganda	3,399	10	18.4	21	-11
Ghana	2,948	11	21.2	20	-9
Senegal	2,045	12	29.5	16	-4
Sudan	1,745	13	7.1	38	-25
Zimbabwe	1,723	14	25.0	18	-4
Botswana	1,532	15	132.1	4	11
Côte d'Ivoire	1,523	16	12.7	31	-15
Malawi	1,497	17	17.3	22	-5
Burkina Faso	1,481	18	16.4	23	-5
Libya	1,399	19	38.1	13	6
Benin	1,143	20	22.6	19	1
Zambia	1,100	21	14.6	27	-6
Madagascar	994	22	8.4	35	-13
Congo	916	23	39.6	12	11
Mali	800	24	10.3	33	-9
Mozambique	669	25	5.3	43	-18
Gambia	626	26	61.0	9	17
Gabon	622	27	70.5	7	20
Namibia	619	28	49.6	10	18
Mauritius	600	29	78.8	6	23
Niger	493	30	5.7	40	-10
Rwanda	391	31	6.3	39	-8
Togo	365	32	9.9	34	-2
Swaziland	330	33	42.0	11	22
Angola	186	34	2.5	48	-14
Eritrea	170	35	5.2	44	-9
Guinea	166	36	2.8	47	-11
Seychelles	153	37	296.1	2	35
Central African Republic	149	38	5.4	41	-3
Lesotho	145	39	12.6	32	7
Chad	142	40	2.4	49	-9
Dem. Rep. of the Congo	139	41	0.4	54	-13
Mauritania	135	42	7.5	36	6
Sierra Leone	133	43	4.5	46	-3
Guinea-Bissau	128	44	14.3	28	16
Burundi	94	45	1.7	51	-6
Djibouti	57	46	13.5	30	16
Equatorial Guinea	51	47	14.0	29	18
Cape Verde	47	48	16.0	24	24
South Sudan	40	49	0.8	52	-3
Liberia	38	50	1.9	50	0
Comoros	23	51	5.3	42	9
Somalia	20	52	0.4	53	-1
Sao Tome and Principe	15	53	15.0	26	27
Western Sahar	14	54	5.1	45	9

Source: computed with data from the Scopus database

Note: The output per capita is in papers per year per one million inhabitants.

4 Scientific production by scientific domain, field and subfield

The scientific impact of the AU is not evenly distributed, and several important observations can be made on those areas where Africa already has a concentration of research effort (indicated by a specialization index [SI] value above 1) and has shown research excellence (ARIF or ARC above 1) (see Figure 5 and Table IV). Figure 5 shows that based on the results on this study there is only one field, namely historical studies, where African science is firmly above the world average citation level. In terms of ARC values, the leading two subfields of historical studies with the highest values are anthropology and archaeology (with ARC values of 1.84 and 1.88 respectively (Table IV). The high weight of these two subfields can be explained by the many studies (both national and international) taking place in Africa, the fact that the African continent is the birthplace of humanity and civilization, and the subsequent publications in high impact factor journals.

Some fields of engineering, and public health and health services are achieving levels similar to or higher than the world average of 1.00 in terms of research quality, impact and intensity (effort), which is certainly positive, as these areas are important development stepping-stones. The scientific impact in public health & health services can be traced to the heavy involvement of African governments in the health sector and the many national and international health-related initiatives on-going on the continent through collaborative programmes aimed mostly at eradicating infectious diseases such as HIV/AIDS. In engineering subfields, ARIF (1.74) and ARC (1.38) values higher than the world average (1.00) are achieved in civil engineering, which is understandable for countries that are placing an emphasis on building roads, houses etc. These levels of ARIF and ARC show that research works of high quality are on-going in civil engineering in the AU. Despite that quality, The AU's research effort in civil engineering still remains below the world average (SI of 1.00) as indicated by a specialization index of 0.53.

In the engineering field as a whole, the ARIF of 1.08 and ARC of 1.00 from the AU match the world average (1.00), but the research effort deployed by the AU in engineering (SI of 0.79) is below the world average (SI of 1.00). Thus, this study shows that in engineering, the AU must increase its research effort to catch up with the world average by building on the high-quality research on-going in the AU in that field.

Science and technology in most African countries is focused mostly on land and primary resources, in areas such as agriculture, ecology, geosciences and plant and animal sciences in general (Pouris and Pouris, 2009). Whether or not particular countries or the effects of international collaborations are driving the overall high values of ARIF and ARC in some fields needs to be analyzed further through individual country profiling.

Table IV: Number of papers, production growth, SI, ARIF and ARC in the AU by scientific domain, field and subfield, 2005–2010

Domain/Field/Subfield	2005-2007	2008-2010	Growth index 2008-2010/2005-2008	SI	ARIF	ARC
TOTAL	**74,629**	**106,825**	**1.22**	**1.00**	**0.91**	**0.83**
Health Sciences	**24,959**	**34,569**	**1.26**	**0.96**	**0.92**	**0.89**
Biomedical Research	**6,153**	**8,632**	**1.30**	**1.22**	**0.95**	**0.90**
Anatomy & Morphology	121	160	1.13	1.67	0.66	0.49
Biochemistry & Molecular Biology	384	414	1.08	0.27	0.84	0.66
Biophysics	40	77	1.86	0.21	0.77	0.65
Developmental Biology	181	207	1.01	0.22	0.78	0.94
Genetics & Heredity	157	255	1.63	0.76	1.05	0.92
Microbiology	2,086	2,955	1.30	2.02	1.02	1.02
Microscopy	15	26	1.23	0.31	1.36	0.79
Mycology & Parasitology	787	942	1.11	4.21	0.92	0.98
Nutrition & Dietetics	783	1,355	1.36	2.63	0.73	0.50
Physiology	125	149	1.28	0.51	0.72	0.60
Toxicology	380	612	1.42	1.19	0.91	0.71
Virology	1,094	1,478	1.15	2.87	1.11	1.19
Clinical Medicine	**16,079**	**21,967**	**1.25**	**0.90**	**0.91**	**0.87**
Allergy	70	148	2.08	0.76	1.02	1.03
Anesthesiology	297	403	1.30	0.97	0.75	0.59
Arthritis & Rheumatology	160	244	1.35	0.66	0.74	0.72
Cardiovascular System & Hematology	476	850	1.60	0.45	0.87	0.81
Complementary & Alternative Medicine	101	132	1.02	1.15	2.25	1.35
Dentistry	492	691	1.22	1.06	0.73	0.60
Dermatology & Venereal Diseases	376	489	1.20	0.88	0.92	0.71
Emergency & Critical Care Medicine	111	182	1.40	0.45	0.89	0.82
Endocrinology & Metabolism	282	416	1.39	0.49	0.73	0.64
Environmental & Occupational Health	96	70	0.81	0.70	1.11	0.79
Gastroenterology & Hepatology	222	409	1.72	0.41	1.04	0.79
General & Internal Medicine	3,384	3,775	0.99	1.79	1.02	1.14
General Clinical Medicine	327	539	1.94	1.49	0.99	0.65
Geriatrics	21	29	1.26	0.19	0.84	0.80
Immunology	512	643	1.20	0.61	0.78	0.72
Legal & Forensic Medicine	81	141	1.38	1.21	0.94	0.96
Neurology & Neurosurgery	563	988	1.69	0.35	0.72	0.58
Nuclear Medicine & Medical Imaging	363	584	1.58	0.50	0.63	0.51
Obstetrics & Reproductive Medicine	1,056	1,491	1.31	1.69	0.87	0.83
Oncology & Carcinogenesis	542	823	1.33	0.40	0.87	0.64
Ophthalmology & Optometry	303	365	1.12	0.62	0.94	0.86
Orthopedics	248	393	1.37	0.51	0.84	0.60
Otorhinolaryngology	197	317	1.53	0.70	0.98	0.80
Pathology	220	333	1.37	1.02	0.71	0.50
Pediatrics	510	739	1.33	1.14	0.91	1.00
Pharmacology & Pharmacy	607	1,224	1.79	0.80	0.81	0.69
Psychiatry	388	541	1.29	0.67	0.89	0.86
Respiratory System	213	345	1.53	0.54	0.98	1.46
Sport Sciences	175	303	1.37	1.03	1.09	1.14
Surgery	417	466	1.03	0.54	0.81	0.63
Tropical Medicine	2,878	3,320	0.98	14.87	1.00	1.06
Urology & Nephrology	391	574	1.40	0.73	0.90	0.70

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Domain/Field/Subfield	2005-2007	2008-2010	Growth index 2008-2010/2005-2008	SI	ARIF	ARC
Health Sciences (cont'd)	**24,959**	**34,569**	**1.26**	**0.96**	**0.92**	**0.89**
Psychology & Cognitive Sciences	**711**	**868**	**1.01**	**0.53**	**0.68**	**0.64**
Behavioral Science & Comparative Psychology	207	232	1.00	1.34	0.85	0.93
Clinical Psychology	24	41	1.51	0.18	0.61	0.52
Developmental & Child Psychology	108	129	1.01	0.55	0.86	0.52
Experimental Psychology	45	47	0.82	0.12	0.79	0.95
General Psychology & Cognitive Sciences	12	73	4.79	0.99	n.c.	0.29
Human Factors	28	52	1.40	0.28	1.07	0.57
Psychoanalysis	9	14	1.52	n.c.	n.c.	n.c.
Social Psychology	278	280	0.83	0.96	0.42	0.48
Public Health & Health Services	**2,016**	**3,102**	**1.33**	**1.11**	**0.98**	**1.00**
Epidemiology	151	209	1.31	1.01	0.94	0.96
Gerontology	32	59	1.65	0.36	0.81	0.54
Health Policy & Services	161	325	1.75	1.09	1.01	1.28
Nursing	258	302	1.03	0.46	1.04	0.86
Public Health	1,195	1,882	1.25	2.42	0.99	1.03
Rehabilitation	113	165	1.21	0.52	0.76	0.60
Speech-Language Pathology & Audiology	57	55	1.07	0.50	0.97	0.76
Substance Abuse	49	105	1.89	0.49	0.98	1.13
Natural Sciences	**22,601**	**29,829**	**1.20**	**1.13**	**0.84**	**0.76**
Biology	**6,888**	**9,578**	**1.18**	**2.54**	**0.83**	**0.78**
Ecology	1,456	1,966	1.16	2.53	0.89	0.98
Entomology	831	941	1.04	2.85	1.02	0.96
Evolutionary Biology	704	798	0.94	1.87	0.80	0.85
Marine Biology & Hydrobiology	818	1,006	1.13	2.00	0.85	0.95
Ornithology	214	210	1.03	2.65	0.68	0.71
Plant Biology & Botany	2,471	4,186	1.36	2.98	0.68	0.53
Zoology	394	471	0.95	2.17	1.08	1.08
Chemistry	**6,108**	**7,526**	**1.13**	**1.08**	**0.76**	**0.63**
Analytical Chemistry	585	890	1.35	0.75	0.87	0.61
General Chemistry	804	957	1.02	1.05	0.48	0.24
Inorganic & Nuclear Chemistry	1,017	1,153	1.04	1.22	0.81	0.69
Medicinal & Biomolecular Chemistry	1,082	1,714	1.21	2.07	0.87	0.82
Organic Chemistry	1,210	1,205	0.93	0.98	0.55	0.46
Physical Chemistry	391	493	1.11	0.67	0.95	0.68
Polymers	1,019	1,111	1.23	1.00	0.89	0.80
Earth & Environmental Sciences	**2,581**	**3,432**	**1.14**	**1.21**	**0.94**	**0.85**
Environmental Sciences	780	1,248	1.17	1.41	0.88	0.77
Geochemistry & Geophysics	559	841	1.32	1.03	1.04	0.94
Geology	509	488	0.93	3.33	0.92	0.96
Meteorology & Atmospheric Sciences	653	766	1.10	0.92	0.93	0.78
Oceanography	80	88	1.09	0.56	1.18	1.08
Mathematics & Statistics	**1,929**	**2,756**	**1.19**	**1.20**	**0.83**	**0.79**
Applied Mathematics	346	537	1.16	1.15	0.85	0.82
General Mathematics	845	1,254	1.31	1.13	0.86	0.80
Numerical & Computational Mathematics	550	671	0.99	1.82	0.86	0.86
Statistics & Probability	188	294	1.27	0.80	0.62	0.56

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Domain/Field/Subfield	2005-2007	2008-2010	Growth index 2008-2010/2005-2008	SI	ARIF	ARC
Natural Sciences (cont'd)	**22,601**	**29,829**	**1.20**	**1.13**	**0.84**	**0.76**
Physics & Astronomy	**5,095**	**6,537**	**1.23**	**0.63**	**0.90**	**0.83**
Acoustics	145	177	1.26	0.46	1.22	1.04
Applied Physics	1,497	1,942	1.30	0.62	0.94	0.77
Astronomy & Astrophysics	475	471	1.18	0.72	0.99	1.32
Chemical Physics	527	705	1.25	0.65	0.83	0.78
Fluids & Plasmas	564	615	1.01	0.53	0.87	0.73
General Physics	767	1,250	1.50	0.72	0.68	0.58
Mathematical Physics	369	400	0.95	2.08	0.99	1.31
Nuclear & Particles Physics	649	831	1.22	0.63	0.94	0.85
Optics	102	146	1.12	0.21	0.94	0.58
Applied Sciences	**20,211**	**29,249**	**1.20**	**0.89**	**1.01**	**0.86**
Agriculture, Fisheries & Forestry	**5,096**	**6,471**	**1.06**	**2.12**	**0.94**	**0.85**
Agronomy & Agriculture	1,730	1,836	0.83	2.64	0.97	0.80
Dairy & Animal Science	1,041	1,755	1.28	2.99	0.81	0.73
Fisheries	338	395	1.05	1.40	0.98	1.01
Food Science	767	1,064	1.12	2.04	0.97	0.84
Forestry	371	388	1.02	1.36	1.10	1.28
Horticulture	167	241	1.16	2.46	1.09	1.03
Veterinary Sciences	682	792	1.03	1.45	0.94	0.89
Built Environment & Design	**459**	**612**	**1.06**	**0.89**	**1.10**	**0.94**
Architecture	11	12	0.87	n.c.	n.c.	n.c.
Building & Construction	238	324	1.17	1.09	1.24	0.88
Design Practice & Management	46	75	1.12	0.30	0.90	1.10
Urban & Regional Planning	164	201	1.03	1.47	0.96	1.02
Enabling & Strategic Technologies	**5,403**	**8,400**	**1.34**	**0.84**	**1.07**	**0.92**
Bioinformatics	87	150	1.09	0.33	0.85	1.19
Biotechnology	1,521	2,085	1.03	2.78	0.75	0.51
Energy	1,658	2,617	1.26	0.96	1.25	1.13
Materials	1,384	2,276	1.48	0.75	1.12	0.99
Nanoscience & Nanotechnology	121	287	1.79	0.33	0.65	0.49
Optoelectronics & Photonics	351	491	1.46	0.28	1.45	0.95
Strategic, Defence & Security Studies	281	494	1.65	0.98	1.25	1.58
Engineering	**5,633**	**7,294**	**1.09**	**0.79**	**1.08**	**1.00**
Aerospace & Aeronautics	155	170	1.24	0.28	1.44	1.48
Automobile Design & Engineering	30	30	0.87	0.29	1.12	1.09
Biomedical Engineering	178	234	1.09	0.34	1.00	0.90
Chemical Engineering	743	1,021	1.10	1.07	1.14	1.20
Civil Engineering	227	334	1.24	0.53	1.74	1.38
Electrical & Electronic Engineering	938	1,276	1.23	0.96	0.80	0.80
Environmental Engineering	782	937	1.02	1.80	0.85	0.69
Geological & Geomatics Engineering	277	437	1.40	0.80	1.03	0.85
Industrial Engineering & Automation	574	983	1.33	0.54	1.06	0.86
Mechanical Engineering & Transports	934	1,084	0.91	0.79	1.05	1.08
Mining & Metallurgy	607	421	0.67	1.52	1.50	1.48
Operations Research	188	367	1.40	0.67	0.94	0.87

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Domain/Field/Subfield	2005-2007	2008-2010	Growth index 2008-2010/2005-2008	SI	ARIF	ARC
Applied Sciences (cont'd)	**20,211**	**29,249**	**1.20**	**0.89**	**1.01**	**0.86**
Information & Communication Technologies	**3,620**	**6,472**	**1.40**	**0.63**	**0.79**	**0.61**
Artificial Intelligence & Image Processing	1,133	2,893	1.72	0.59	0.97	0.69
Computation Theory & Mathematics	277	456	1.53	0.82	0.64	0.77
Computer Hardware & Architecture	88	50	0.51	0.31	n.c.	0.35
Distributed Computing	45	58	1.53	0.32	0.73	0.87
Information Systems	120	240	1.80	0.51	1.18	0.51
Medical Informatics	137	255	1.62	1.10	0.89	0.60
Networking & Telecommunications	1,711	2,357	1.15	0.72	0.66	0.51
Software Engineering	109	163	1.37	0.32	0.85	0.48
Economic & Social Sciences	**3,552**	**5,917**	**1.26**	**1.08**	**0.85**	**0.68**
Economics & Business	**1,561**	**2,665**	**1.26**	**1.10**	**0.67**	**0.60**
Accounting	18	23	0.97	0.45	n.c.	0.51
Agricultural Economics & Policy	113	255	1.76	2.69	0.89	1.02
Business & Management	202	566	1.84	0.75	0.59	0.57
Development Studies	559	722	1.12	8.22	0.67	0.64
Econometrics	1	53	46.04	0.85	n.c.	0.38
Economic Theory	12	19	1.30	0.37	n.c.	0.48
Economics	250	481	1.44	0.69	0.53	0.51
Finance	54	197	2.74	0.89	0.54	0.30
Industrial Relations	9	24	2.09	0.48	n.c.	0.69
Logistics & Transportation	240	101	0.34	0.78	0.86	0.33
Marketing	40	136	2.52	0.58	0.60	0.47
Sport, Leisure & Tourism	63	88	1.05	1.14	0.91	1.09
Social Sciences	**1,991**	**3,252**	**1.26**	**1.07**	**0.99**	**0.75**
Criminology	33	61	1.40	0.35	0.94	0.83
Cultural Studies	249	391	1.12	3.70	1.65	1.54
Demography	93	95	0.79	2.73	1.28	1.05
Education	579	1,296	1.56	1.18	0.89	0.64
Family Studies	17	21	1.13	0.40	0.46	0.30
Gender Studies	53	60	0.93	1.53	0.70	0.66
Geography	239	244	0.90	1.11	0.97	0.89
Information & Library Sciences	305	431	1.32	1.78	0.64	0.44
International Relations	67	71	0.93	0.68	0.86	0.97
Law	56	120	1.80	0.48	0.85	0.40
Political Science & Public Administration	102	150	1.07	0.49	0.91	0.68
Science Studies	28	53	1.53	0.53	1.01	0.88
Social Sciences Methods	12	26	1.85	0.42	0.84	0.70
Social Work	121	179	1.14	1.73	1.10	0.48
Sociology	37	52	1.09	0.35	0.80	0.42

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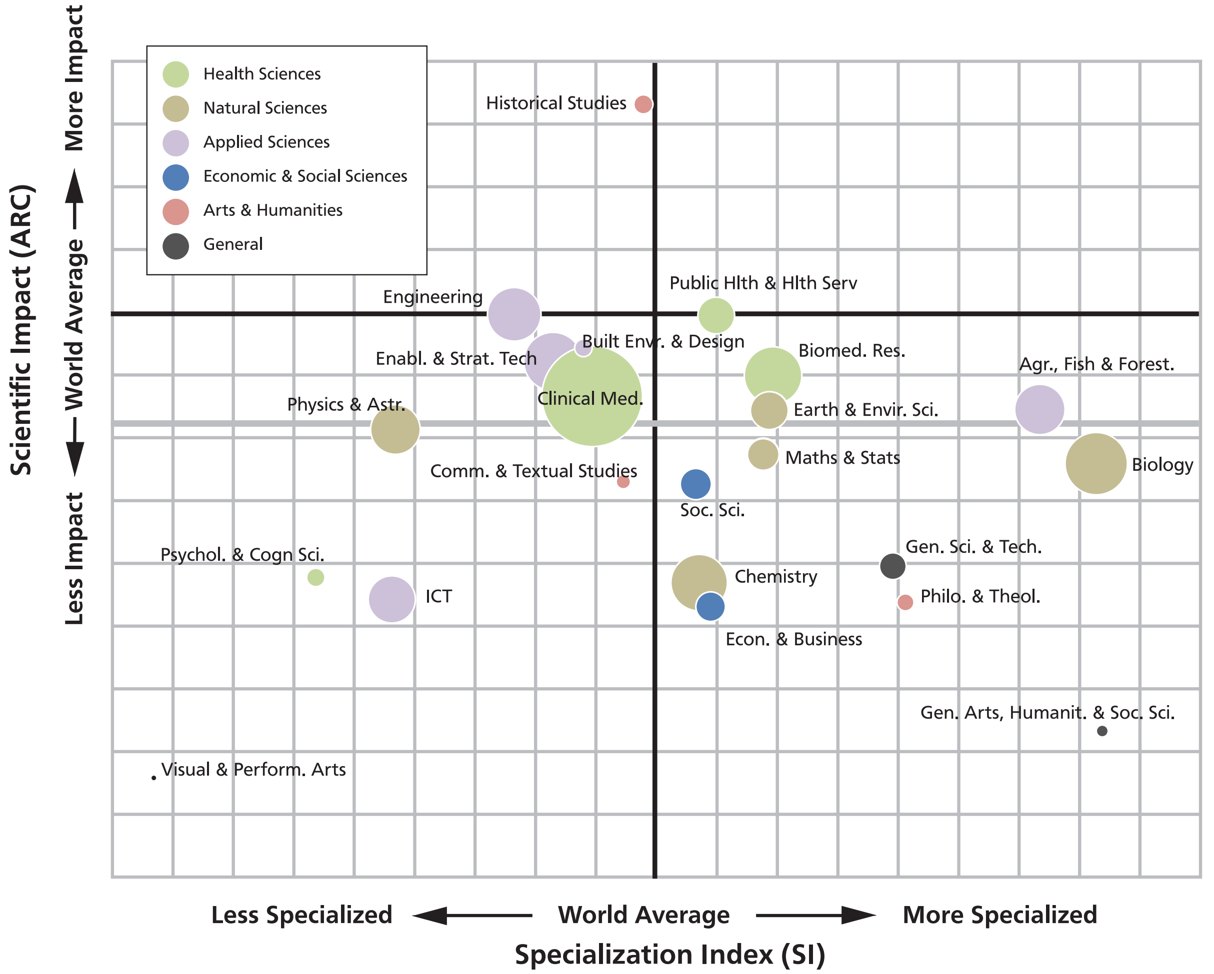
Domain/Field/Subfield	2005-2007	2008-2010	Growth index 2008-2010/2005-2008	SI	ARIF	ARC
Arts & Humanities	1,406	1,999	1.10	1.06	0.95	0.97
Communication & Textual Studies	**378**	**577**	**1.14**	**0.95**	**0.73**	**0.76**
Communication & Media Studies	30	42	0.97	0.34	0.83	0.66
Languages & Linguistics	271	333	0.93	1.62	0.66	0.66
Literary Studies	77	202	1.99	0.67	0.88	0.99
Historical Studies	**583**	**792**	**1.08**	**0.98**	**1.20**	**1.42**
Anthropology	146	181	0.95	1.43	1.47	1.84
Archaeology	125	197	1.27	1.63	1.23	1.88
Classics	10	4	0.33	n.c.	n.c.	n.c.
History	41	54	0.92	0.29	1.25	1.28
History of Science, Technology & Medicine	7	10	1.19	n.c.	n.c.	n.c.
History of Social Sciences	6	13	1.59	n.c.	n.c.	n.c.
Paleontology	248	333	1.18	1.32	1.06	0.97
Philosophy & Theology	**427**	**604**	**1.10**	**1.55**	**0.69**	**0.60**
Applied Ethics	78	190	1.93	1.20	1.19	0.92
Philosophy	70	106	1.18	0.68	0.53	0.59
Religions & Theology	279	308	0.84	3.21	0.44	0.46
Visual & Performing Arts	**18**	**26**	**1.08**	**0.30**	**0.80**	**0.38**
Art Practice, History & Theory	3	10	2.67	n.c.	n.c.	n.c.
Drama & Theater	4	7	1.06	n.c.	n.c.	n.c.
Folklore	2	3	1.39	n.c.	n.c.	n.c.
Music	9	6	0.48	n.c.	n.c.	n.c.
General	**1,415**	**2,460**	**1.29**	**1.60**	**0.90**	**0.62**
General Science & Technology	**1,258**	**2,121**	**1.25**	**1.52**	**0.88**	**0.65**
General Arts, Humanities & Social Sciences	**157**	**339**	**1.63**	**2.58**	**1.05**	**0.44**

Source: computed with data from the Scopus database

5 Specialization of the African Union member states

The specialization index (SI) indicates whether a country has a relatively higher or lower share in world publications in particular fields of science than its overall share in total world publications. Stated otherwise, the SI indicates whether a country has higher-than-average activity in a scientific field (SI > 1) or lower-than-average activity (SI < 1) (see Table V, Table VI, Table VII, Table VIII and Table IX). As shown in Figure 5, positional analyses that consider scientific impact and the specialization index can reveal fields of science in which entities such as institutes, countries and regions are specialized.

Figure 5: Positional analysis of the AU by scientific field, 2005–2010



Source: computed with data from the Scopus database

The areas in which Africa also scores relatively high and above the average of relative citations received by the AU (indicated by the grey AU ARC line in Figure 5) include the built environment and design; enabling and strategic technologies; biomedical research; clinical medicine; earth and environmental sciences; and agriculture, fisheries and forestry. Africa is highly specialized in biology and in agriculture, fisheries and forestry, as it is responsible for more of the world's papers in these fields than expected given its overall share of world scientific production.

In general the AU achieves critical mass, defined here as research effort above the world average (or having a higher concentration of papers in a particular area of science than the world baseline, with SI > 1), in general and internal medicine, tropical medicine, microbiology and virology, which are thus four areas of scientific specialization that Africa could use as a platform for further developing its scientific capabilities. Within the health sciences, there is also established strength (SI > 1) in health policy and services, sport sciences, and complementary and alternative medicine.

In the natural sciences, the AU has established strengths in zoology and mathematical physics. In the applied sciences, important areas of interest include forestry and horticulture. In these fields of the natural sciences and health sciences, the AU conducts quality research at levels higher than the world averages, as expressed by the ARIF and ARC indexes.

The AU also shows some strength in energy and in strategic, defence and security studies in terms of the quality of research papers, but the level of research efforts in these areas is still below the world average. Whether this quality of research is driven by just a few AU countries or not remains to be further researched. The same observations apply to the engineering field, where the AU scores well above the world average in chemical engineering and mining and metallurgy in terms of the quality of research and research intensity. In the field of engineering as whole, however, the AU displays research effort below the world average.

When the RECs are considered, the East African Community and the Intergovernmental Authority on Development are the country groups with the highest performance in health research. This is established by examining countries whose growth, specialization, ARIF and ARC were above the world average (namely, all these indicators had a score above the threshold of 1).

The most active countries in health research (by number of papers over the 2005–2010 period) were South Africa, Egypt, Nigeria and Tunisia. The most active countries, with exceptional performance with respect to growth, specialization and research impact, were Kenya, Uganda, Tanzania and Ghana. Smaller countries with noteworthy performances include Malawi, Burkina Faso, Zambia and Mali.

By comparison with the health sciences, the natural sciences offer a less encouraging portrait. Although research output in the natural sciences has grown considerably in the last six years (20% more than the world average), and despite the AU's specializing in the natural sciences as a whole (SI > 1), this production is not published in the best journals (ARIF < 1) and its impact on the scientific community is limited (ARC < 1). The Southern African Development Community shows tangible growth and specialization in that domain, and slightly above-average scientific impact, but this is essentially because of the performance of South Africa. Still, it is noteworthy that there have been substantial rates of growth in the Maghreb countries (especially in Algeria and Tunisia) and Egypt, and in Ghana, Sudan and Libya, although the high growth rate in the latter three countries should be considered in the context of starting from a relatively low base.

African representation in the applied sciences is somewhat more positive than in the natural sciences, due to relatively high specialization, growth and scientific impact in some countries. There is a concentration of research activity and excellence in the Maghreb countries, with the Arab Maghreb Union, particularly Tunisia and Algeria, having higher than world average scores for growth, specialization and ARIF. It is also noteworthy that South Africa has a sizeable output in the applied sciences, although it is not specialized in this domain: its growth equals the world average, but its ARIF and ARC are slightly above the world average. Likewise, Senegal stands out with respect to its growth, and ARIF and ARC scores, although it does not specialize in the applied sciences.

Few observations can be made about research in economics and the social sciences in the AU. On the whole, the AU is slightly specialized in this domain, and its growth rate is substantially higher than the world average. However, the level of output remains low, and there are consequently comparatively few countries for which robust statistics can be computed (namely, with more than 30 data points for a given indicator such as the ARC). Again, South Africa leads with respect to the number of publications, and Egypt has lower than expected production (it is clearly under-specialized in this domain, with SI = 0.24). Countries with strong growth and specialization include South Africa, Nigeria, Kenya, Ghana, Ethiopia, Tanzania and Uganda, but in all these cases the level of output and the impact remain relatively low. Kenya, Tanzania, Malawi, Zambia and Mozambique all perform relatively well, but only Kenya had more than 300 papers over the last six years.

As with the social sciences and economics, the AU is slightly specialized in the arts and humanities, and saw faster growth than the world average in this domain over the last six years. Only 12 of the 54 AU members published at least 30 papers over the last six years. South Africa had the largest number of papers by far, publishing more papers than all the other AU members combined. It is noteworthy, but not surprising considering the sizeable output just described, that South Africa is highly specialized in the arts and humanities (SI = 2.38). Moreover, its production in this domain is growing faster than the world average, and its papers are also more frequently cited. Tanzania is rapidly growing its scientific production, publishing in highly cited journals and producing highly cited papers, although at a relatively low level of production.

Table V: Papers, growth, SI, ARIF and ARC by AU members in the Health Sciences, 2005–2010

Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,635,675**	**1,795,865**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**24,959**	**34,569**	**1.26**	**0.96**	**0.92**	**0.89**
Community of Sahelo-Saharan States	15,276	22,080	1.32	1.01	0.76	0.66
South African Development Community	9,032	11,769	1.19	0.99	1.13	1.25
Common Market for Eastern and Southern Africa	7,777	12,083	1.42	0.97	1.04	1.00
Economic Community of West African States	6,030	8,094	1.22	1.28	0.78	0.64
Arab Maghreb Union	4,306	6,222	1.32	0.72	0.52	0.44
East African Community	2,866	3,992	1.27	1.47	1.29	1.47
Intergovernmental Authority on Development	2,779	4,042	1.32	1.31	1.18	1.30
Economic Community of Central African States	966	1,151	1.09	1.18	1.00	0.95
South Africa	6,926	9,144	1.20	0.91	1.08	1.22
Egypt	3,684	6,188	1.53	0.77	0.86	0.73
Nigeria	3,612	5,274	1.33	1.20	0.61	0.43
Tunisia	2,757	3,623	1.20	0.98	0.51	0.47
Kenya	1,281	1,774	1.26	1.30	1.25	1.50
Uganda	779	1,216	1.42	1.72	1.37	1.65
United Rep. of Tanzania	849	1,144	1.23	1.57	1.39	1.52
Ghana	507	683	1.23	1.18	1.25	1.28
Ethiopia	474	703	1.35	0.98	0.99	0.88
Cameroon	489	619	1.15	0.91	0.99	0.93

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Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,635,675**	**1,795,865**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**24,959**	**34,569**	**1.26**	**0.96**	**0.92**	**0.89**
Senegal	556	552	0.90	1.59	0.78	0.72
Malawi	397	517	1.19	1.79	1.49	1.62
Algeria	260	520	1.82	0.18	0.76	0.79
Sudan	287	491	1.56	1.31	0.87	0.76
Burkina Faso	330	444	1.23	1.53	1.08	1.17
Zimbabwe	343	359	0.95	1.19	1.28	1.24
Zambia	283	410	1.32	1.85	1.52	1.61
Côte d' Ivoire	325	360	1.01	1.32	0.78	0.85
Congo	241	295	1.11	1.71	0.97	0.97
Gambia	249	269	0.98	2.42	1.50	1.73
Mali	202	256	1.15	1.68	1.15	1.18
Benin	173	250	1.32	1.08	0.86	0.95
Libya	88	325	3.36	0.87	0.61	0.33
Gabon	201	201	0.91	1.89	1.05	1.08
Mozambique	152	210	1.26	1.59	1.48	2.01
Madagascar	151	205	1.24	1.05	0.84	0.96
Botswana	149	173	1.06	0.62	1.27	1.79
Rwanda	75	133	1.62	1.56	1.38	1.37
Togo	76	116	1.39	1.54	0.48	0.36
Niger	77	91	1.08	1.00	1.11	0.98
Guinea-Bissau	61	54	0.81	2.63	1.46	1.27
Mauritius	51	61	1.09	0.55	0.93	0.82
Central African Republic	48	54	1.02	2.01	0.86	0.78
Guinea	52	48	0.84	1.77	0.94	0.86
Swaziland	25	69	2.51	0.83	1.18	1.85
Angola	33	54	1.49	1.37	1.03	0.88
Dem. Rep. of the Congo	24	51	1.94	1.58	1.37	1.51
Namibia	28	35	1.14	0.30	0.93	0.79
Seychelles	28	34	1.11	1.19	1.32	1.71
Sierra Leone	19	43	2.06	1.37	1.16	1.05
Eritrea	34	12	0.32	0.79	1.16	1.05
Lesotho	22	23	0.95	0.91	1.07	1.54
Chad	21	16	0.69	0.76	1.28	0.91
Burundi	20	15	0.68	1.09	0.83	1.05
Djibouti	14	20	1.30	1.75	n.c.	0.42
South Sudan	11	18	1.49	n.c.	n.c.	n.c.
Equatorial Guinea	13	15	1.05	n.c.	n.c.	n.c.
Mauritania	15	13	0.79	n.c.	n.c.	n.c.
Liberia	7	13	1.69	n.c.	n.c.	n.c.
Comoros	10	6	0.55	n.c.	n.c.	n.c.

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Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,635,675**	**1,795,865**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**24,959**	**34,569**	**1.26**	**0.96**	**0.92**	**0.89**
Somalia	3	10	3.04	n.c.	n.c.	n.c.
Sao Tome and Principe	6	5	0.76	n.c.	n.c.	n.c.
Cape Verde	4	5	1.14	n.c.	n.c.	n.c.
Western Sahara	1	7	6.38	n.c.	n.c.	n.c.

Source: computed with data from the Scopus database

Table VI: Papers, growth, SI, ARIF and ARC by AU members in the Natural Sciences, 2005–2010

Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,226,443**	**1,346,124**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**22,601**	**29,829**	**1.20**	**1.13**	**0.84**	**0.76**
Community of Sahelo-Saharan States	13,305	17,982	1.23	1.13	0.78	0.64
Common Market for Eastern and Southern Africa	8,303	10,905	1.20	1.25	0.78	0.69
South African Development Community	7,831	9,450	1.10	1.09	0.95	1.02
Arab Maghreb Union	5,907	8,170	1.26	1.28	0.82	0.64
Economic Community of West African States	2,514	3,838	1.39	0.77	0.70	0.53
Intergovernmental Authority on Development	1,528	2,036	1.21	0.91	0.85	0.81
East African Community	1,298	1,646	1.16	0.84	0.90	0.85
Economic Community of Central African States	847	1,008	1.08	1.38	0.86	0.71
South Africa	6,783	8,308	1.12	1.15	0.96	1.06
Egypt	6,016	7,864	1.19	1.44	0.75	0.66
Algeria	1,993	3,056	1.40	1.57	0.80	0.63
Tunisia	2,044	2,947	1.31	1.03	0.83	0.63
Nigeria	1,567	2,420	1.41	0.72	0.59	0.41
Kenya	731	930	1.16	0.94	0.93	0.90
Cameroon	683	803	1.07	1.63	0.86	0.69
Ethiopia	422	518	1.12	1.05	0.78	0.76
United Rep. of Tanzania	334	389	1.06	0.76	0.95	0.87
Uganda	281	357	1.16	0.73	0.77	0.76
Ghana	233	365	1.43	0.79	0.80	0.64
Botswana	250	225	0.82	1.21	0.86	0.64
Senegal	190	267	1.28	0.87	0.90	0.71
Madagascar	232	224	0.88	1.79	0.89	0.85
Benin	176	259	1.34	1.49	0.84	0.80
Zimbabwe	201	195	0.88	0.90	0.79	0.71
Sudan	118	270	2.08	0.87	0.79	0.64
Libya	122	242	1.81	1.02	0.67	0.46

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Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,226,443**	**1,346,124**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**22,601**	**29,829**	**1.20**	**1.13**	**0.84**	**0.76**
Côte d'Ivoire	138	213	1.41	0.90	0.84	0.60
Namibia	188	155	0.75	2.17	0.89	1.33
Burkina Faso	117	198	1.54	0.83	0.86	0.73
Congo	99	122	1.12	0.94	0.88	0.75
Mauritius	88	117	1.21	1.34	0.93	0.70
Niger	37	120	2.95	1.24	0.84	0.92
Mali	66	81	1.12	0.72	0.96	0.93
Malawi	50	78	1.42	0.33	0.77	0.72
Gabon	56	71	1.16	0.80	0.91	0.84
Mozambique	53	74	1.27	0.74	0.88	0.83
Zambia	65	60	0.84	0.44	0.94	0.74
Swaziland	32	88	2.51	1.42	0.88	0.60
Togo	42	56	1.21	1.05	0.76	0.67
Rwanda	20	50	2.28	0.70	0.81	0.61
Mauritania	42	26	0.56	1.97	0.86	0.56
Eritrea	39	22	0.51	1.40	0.89	0.72
Seychelles	23	34	1.35	1.46	1.08	1.32
Guinea	15	30	1.82	1.06	0.80	0.69
Angola	18	24	1.21	0.88	0.84	0.70
Chad	24	16	0.61	1.10	0.88	0.82
Dem. Rep. of the Congo	15	25	1.52	1.12	0.97	1.17
Lesotho	16	20	1.14	0.97	0.85	0.71
Burundi	13	20	1.40	1.37	n.c.	0.57
Central African Republic	15	14	0.85	n.c.	n.c.	n.c.
Cape Verde	5	18	3.28	n.c.	n.c.	n.c.
Sierra Leone	2	16	7.29	n.c.	n.c.	n.c.
Djibouti	5	12	2.19	n.c.	n.c.	n.c.
Gambia	7	5	0.65	n.c.	n.c.	n.c.
Equatorial Guinea	3	6	1.82	n.c.	n.c.	n.c.
Comoros	2	4	1.82	n.c.	n.c.	n.c.
Guinea-Bissau	2	3	1.37	n.c.	n.c.	n.c.
Liberia	3	2	0.61	n.c.	n.c.	n.c.
Sao Tome and Principe	2	1	0.46	n.c.	n.c.	n.c.
Somalia		1		n.c.	n.c.	n.c.
South Sudan		1		n.c.	n.c.	n.c

Source: computed with data from the Scopus database

Table VII: Papers, growth, SI, ARIF and ARC by AU members in the Applied Sciences, 2005–2010

Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,391,674**	**1,682,121**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**20,211**	**29,249**	**1.20**	**0.89**	**1.01**	**0.86**
Community of Sahelo-Saharan States	12,294	18,992	1.28	0.94	0.99	0.82
Common Market for Eastern and Southern Africa	6,864	10,011	1.21	0.92	1.02	0.89
Arab Maghreb Union	5,638	9,836	1.44	1.18	1.06	0.87
South African Development Community	6,220	7,133	0.95	0.71	1.04	0.98
Economic Community of West African States	3,267	4,597	1.16	0.79	0.80	0.60
Intergovernmental Authority on Development	1,403	1,817	1.07	0.69	0.97	0.91
East African Community	1,100	1,246	0.94	0.56	1.00	0.93
Economic Community of Central African States	357	479	1.11	0.52	1.10	0.81
Egypt	4,768	7,313	1.27	1.05	1.05	0.92
South Africa	5,233	6,262	0.99	0.73	1.05	1.01
Tunisia	2,242	4,323	1.60	1.13	1.05	0.86
Nigeria	2,467	3,472	1.16	0.89	0.67	0.49
Algeria	2,149	3,679	1.42	1.52	1.06	0.88
Kenya	635	695	0.91	0.63	1.03	1.00
Ethiopia	452	582	1.07	0.96	0.94	0.98
Cameroon	299	400	1.11	0.64	1.09	0.75
Ghana	258	412	1.32	0.74	0.96	0.69
United Rep. of Tanzania	332	293	0.73	0.55	0.93	0.85
Libya	174	355	1.69	1.24	0.74	0.39
Sudan	172	302	1.45	0.89	0.77	0.57
Zimbabwe	243	190	0.65	0.82	1.04	1.04
Uganda	166	266	1.33	0.42	0.98	0.85
Botswana	176	158	0.74	0.71	1.02	0.65
Senegal	139	186	1.11	0.52	1.20	1.26
Burkina Faso	154	157	0.84	0.69	1.16	1.12
Côte d’Ivoire	97	151	1.29	0.53	0.99	0.55
Benin	101	129	1.06	0.66	1.04	0.87
Malawi	95	104	0.91	0.43	0.95	0.70
Zambia	90	83	0.76	0.51	1.13	0.87
Mauritius	70	84	0.99	0.84	0.97	0.49
Mali	66	67	0.84	0.54	1.37	1.20
Namibia	71	56	0.65	0.67	0.96	0.80
Niger	36	76	1.75	0.74	1.08	1.13
Mozambique	49	55	0.93	0.51	1.11	0.76
Congo	38	63	1.37	0.36	1.16	0.91
Madagascar	31	56	1.49	0.29	1.34	1.46
Swaziland	31	44	1.17	0.74	0.98	0.81

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Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**1,391,674**	**1,682,121**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**20,211**	**29,249**	**1.20**	**0.89**	**1.01**	**0.86**
Rwanda	15	47	2.59	0.52	1.08	0.79
Togo	30	32	0.88	0.56	1.34	1.11
Angola	19	18	0.78	0.65	n.c.	0.41
Eritrea	14	20	1.18	0.65	n.c.	0.73
Gabon	18	14	0.64	0.17	n.c.	1.02
Mauritania	16	16	0.83	0.78	1.32	1.66
Sierra Leone	13	18	1.15	0.76	n.c.	0.31
Lesotho	9	19	1.75	n.c.	n.c.	n.c.
Gambia	13	14	0.89	n.c.	n.c.	n.c.
Seychelles	15	9	0.50	n.c.	n.c.	n.c.
Chad	11	11	0.83	n.c.	n.c.	n.c.
Dem. Rep. of the Congo	7	10	1.18	n.c.	n.c.	n.c.
Guinea	10	5	0.41	n.c.	n.c.	n.c.
Burundi	2	11	4.55	n.c.	n.c.	n.c.
Cape Verde	5	5	0.83	n.c.	n.c.	n.c.
Liberia	3	5	1.38	n.c.	n.c.	n.c.
Central African Republic	2	4	1.65	n.c.	n.c.	n.c.
Equatorial Guinea	3	3	0.83	n.c.	n.c.	n.c.
South Sudan	1	4	3.31	n.c.	n.c.	n.c.
Western Sahara		5		n.c.	n.c.	n.c.
Djibouti	3	1	0.28	n.c.	n.c.	n.c.
Somalia		4		n.c.	n.c.	n.c.
Comoros		1		n.c.	n.c.	n.c.
Guinea-Bissau		1		n.c.	n.c.	n.c.

Source: computed with data from the Scopus database

Table VIII: Papers, growth, SI, ARIF and ARC by AU members with at least 30 papers in Economic and Social Sciences, 2005–2010

Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**208,728**	**275,349**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**3,552**	**5,917**	**1.26**	**1.08**	**0.85**	**0.68**
South African Development Community	2,240	3,404	1.15	1.90	0.91	0.76
Community of Sahelo-Saharan States	1,149	2,237	1.48	0.65	0.76	0.56
Economic Community of West African States	655	1,266	1.47	1.23	0.65	0.44
Common Market for Eastern and Southern Africa	678	1,159	1.30	0.63	0.94	0.86
Intergovernmental Authority on Development	357	607	1.29	1.31	0.97	0.91
East African Community	324	598	1.40	1.40	0.97	0.89
Arab Maghreb Union	188	422	1.70	0.30	0.74	0.47
Economic Community of Central African States	83	96	0.88	0.71	0.63	0.58
South Africa	1,853	2,846	1.16	1.90	0.91	0.77
Nigeria	411	926	1.71	1.28	0.57	0.36
Kenya	180	308	1.30	1.47	0.99	1.03
Egypt	141	286	1.54	0.24	0.92	0.68
Tunisia	110	261	1.80	0.41	0.76	0.49
Ghana	123	212	1.31	2.36	0.83	0.66
Botswana	143	166	0.88	4.19	0.80	0.64
Ethiopia	84	149	1.34	1.38	0.99	0.93
United Rep. of Tanzania	69	146	1.60	1.20	1.02	0.77
Uganda	79	125	1.20	1.25	0.94	0.74
Cameroon	74	65	0.67	0.81	0.62	0.52
Malawi	46	60	0.99	1.47	1.04	1.04
Zimbabwe	54	52	0.73	1.28	0.94	1.13
Mauritius	37	67	1.37	3.60	0.71	0.75
Senegal	43	40	0.71	0.84	0.74	0.74
Algeria	23	58	1.91	0.13	0.45	0.38
Zambia	21	39	1.41	1.13	1.17	1.24
Mozambique	17	34	1.52	1.58	1.09	0.99
Namibia	17	24	1.07	1.38	n.c.	0.39
Benin	14	19	1.03	0.60	n.c.	0.67
Burkina Faso	23	10	0.33	0.46	n.c.	0.92
Sudan	8	25	2.37	0.39	n.c.	0.47
Rwanda	5	27	4.09	1.70	n.c.	0.98
Niger	10	21	1.59	1.31	n.c.	1.22

Table IX: Papers, growth, SI, ARIF and ARC by AU members with at least 30 papers in the Arts and Humanities, 2005–2010

Country/Group	Time period		Growth Index	SI	ARIF	ARC
	2005-2007	2008-2010	2008-10/2005-07	2005-2010		
World	**77,718**	**100,734**	**1.00**	**1.00**	**1.00**	**1.00**
African Union	**1,406**	**1,999**	**1.10**	**1.06**	**0.95**	**0.97**
South African Development Community	991	1,426	1.11	2.20	0.94	1.04
Community of Sahelo-Saharan States	412	598	1.12	0.52	0.92	0.82
Common Market for Eastern and Southern Africa	260	390	1.16	0.61	1.03	0.91
Arab Maghreb Union	144	210	1.13	0.47	0.82	0.88
Economic Community of West African States	111	187	1.30	0.52	0.96	0.67
Intergovernmental Authority on Development	89	117	1.01	0.76	1.30	1.36
East African Community	81	110	1.05	0.79	1.26	1.44
Economic Community of Central African States	38	46	0.93	0.90	1.06	1.04
South Africa	910	1,262	1.07	2.38	0.92	1.06
Egypt	114	143	0.97	0.39	0.83	0.62
Nigeria	64	126	1.52	0.49	0.94	0.48
Kenya	45	57	0.98	0.84	1.25	1.27
Tunisia	34	61	1.38	0.28	0.77	0.81
Malawi	13	74	4.39	3.27	n.c.	0.66
United Rep. of Tanzania	18	37	1.59	0.83	1.37	1.67
Algeria	23	27	0.91	0.22	0.64	0.28
Ethiopia	23	27	0.91	0.80	1.42	1.47
Ghana	21	27	0.99	0.92	1.12	1.22
Botswana	22	25	0.88	1.73	1.09	1.01
Zimbabwe	20	26	1.00	1.50	0.45	0.43

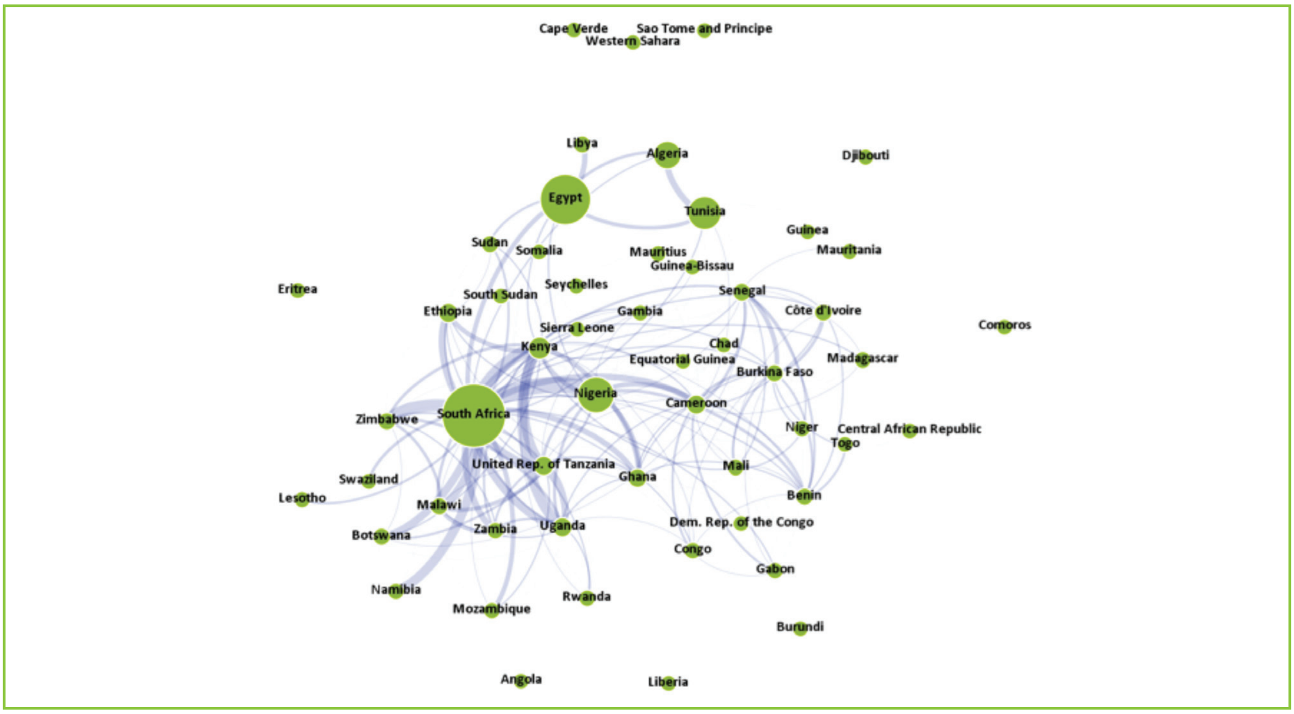
Source: computed with data from the Scopus database

6 Scientific collaboration at the African and international levels

Many angles can be used to examine scientific collaboration, one of which is to examine how frequently AU member states collaborate with one another. Overall, collaborations between AU members are infrequent, as they occurred in only 4.1% of AU papers in the period 2005–2007 and in 4.3% of the papers in 2008–2010 (data not shown). Despite this slight increase, it is noteworthy that 36 of the 54 AU country members increased their level of collaboration in Africa over the last six years. The non-weighted average, calculated by taking into account the level of inter-African country collaboration for each AU member country, moved from 26% to 27% between 2005–2007 and 2008–2010.[1] The level of inter-African country collaboration seems to be low, and more research is needed to understand the reasons. A programme to foster cooperative research, possibly along similar lines to the European Framework Programme, might help increase the rate of cooperation while accelerating the pace of STI development in Africa.

The collaboration network among AU countries is shown in Figure 6. The position of South Africa as a central hub in the network is unsurprising, considering that it has many more publications than many other African countries. There are certainly regional influences in collaboration, as shown for example in collaboration among North African countries due to their geographic proximity. It may be difficult to disentangle linguistic factors from geographic factors, as witnessed by the close collaboration of countries such as Cameroon, Burkina Faso, Niger, Togo, Mali, Congo, Benin and Gabon, which are in relatively close geographic proximity and all share French as an official language.

Figure 6: Collaboration among AU countries, 2005–2010



Source: computed with data from the Scopus database

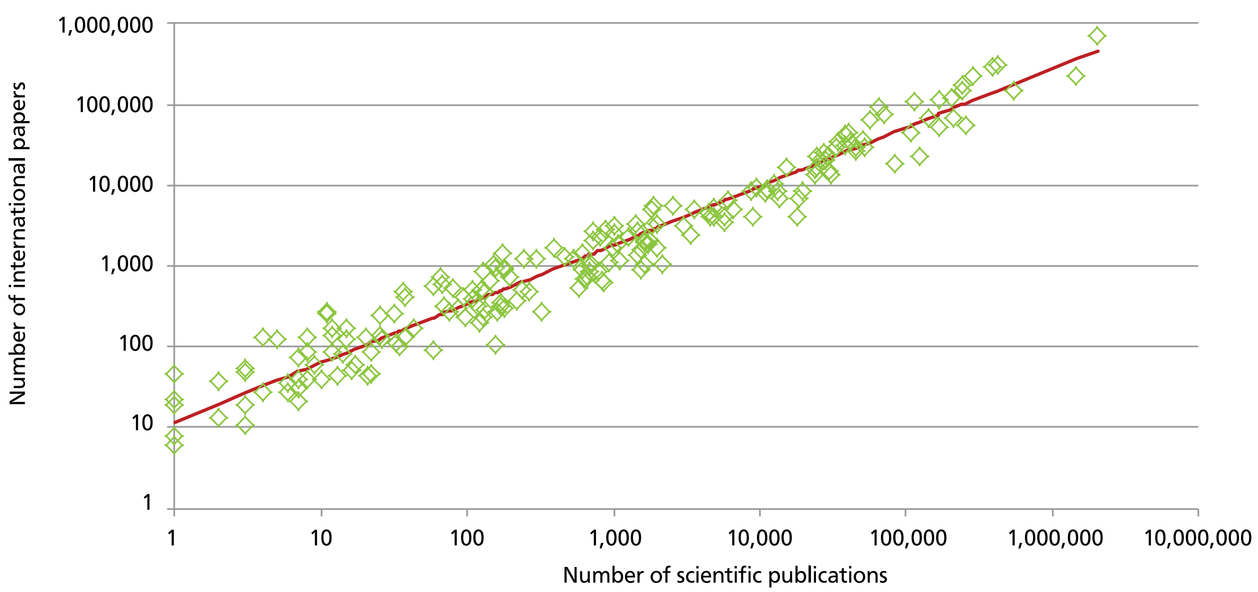
1 Calculated collaboration levels are always substantially larger for smaller ensembles, which is why the aggregate figure for the AU is so much lower than the average computed at the country level.

The portrait of extra-African collaboration is radically different from that of bilateral AU collaboration. For instance, if the proportion of papers co-authored with only non-AU countries is examined (namely, international collaboration solely with countries not in Africa), the AU-level percentage is 40%. When computed by taking the score measured for each country instead, the non-weighted average dropped somewhat from 51% in 2005–2007 to 49% in 2008–2010. Although having a high percentage of external collaboration is frequently regarded as a positive aspect in scientific knowledge production (for example, some countries use it as a performance indicator), it also has to be considered that too high a level can sometimes mean a situation of dependence.

Determining whether the level of collaboration is high based on the percentage of international collaboration is difficult, as this may vary according to the size of a country, and size effects are many and can create confusion. In Europe, for example, large countries such as Germany are less likely to collaborate with others, as there is a greater probability that scientists in a large country will find partners in their own country to work on a given subject. Conversely, scientists from a smaller country are more likely to have to look abroad to find other specialists in their field with whom to engage in fruitful collaboration. In such cases, it is appropriate to use scale-adjusted indicators, which take into account how scientific collaboration scales as a function of national output.

Figure 7 presents the relationship between the number of scientific publications and the number of publications in international collaboration (with authors from at least two countries). This is used to compute a scale-adjusted indicator of international collaboration intensity, namely the collaboration index (CI). Countries with scores above the regression curve (in the graph, this curve appears as a line because of the x and y axes being on a logarithmic scale) are said to have a high propensity to collaborate given their size (CI > 1), and countries with several collaborations below the line can be said to collaborate less than expected given their size (CI < 1), and given how international collaboration scales among all countries at the world level.

Figure 7: Relationship between the number of scientific publications and the number of papers in international collaboration, 2005–2010



Source: computed with data from the Scopus database

Table V presents detailed results of the number of national and international papers and the total number of papers alongside the ARC scores for these papers, the citation index and the percentage of international collaboration. One of the most striking results of segregating national papers from those produced in international collaboration is that none of the 36 AU countries with 30 or more papers between 2005 and 2010 had an ARC above the world average (ARC > 1) for papers with national authors only. This contrasts with internationally authored papers, where 25 of the 36 countries had an ARC above the world level. Although at first glance this might seem alarming, these data have to be placed in a larger context. At the world level, 150 countries published at least 30 national papers over the last six years. Of these countries only 14 had an ARC score above 1 for their national papers, but 125 had an ARC above 1 when undertaking international collaboration. It is sobering to realize that Germany and France had ARC scores below 1 for their nationally authored papers.

For Africa, the large producers (with more than 1,000 papers over the last six years), with the largest ARC scores for national-only papers are South Africa, Egypt, Ethiopia and Algeria. Countries with smaller production levels and comparatively high ARC scores include the Gambia, Swaziland and Malawi.

Although more research is required to investigate in greater detail the reasons for the important differences between the national and international levels of performance, some phenomena certainly have an influence. The first is that for a national paper, it is likely that there will be a single author or a limited number of authors, although this is infrequent in international collaboration.[2] The more authors there are, the more likely it is that the authors will make subsequent self-citations to the paper produced by these authors.

The second important factor is that national papers are more often published by national journals of the countries in which they are produced than by international journals. In general, these types of papers address national issues with a targeted audience in the particular country. This may not apply to the impact of national papers from countries such as the USA, Germany, the Netherlands and others that have a strong tradition of scientific publication and host some of the biggest publishing houses, producing journals with moderate to high impact factors and worldwide outreach. In the case of Africa, however, most of the national journals listed in the citation index still have very low impact factors and limited distribution. The likelihood of these African national papers being read and cited by the international community (outside the country of production) is very small. This drastically reduces the scientific impact of African national papers, even if some of these papers address issues of international relevance.

A third factor to consider is that the principal collaborator of most countries is the USA, which is one of the few countries where the ARC is always above 1. Importantly, however, the USA itself has a substantially greater impact in international collaboration, so this factor alone is not sufficient to explain the wide difference observed.

This difference needs to be investigated for African countries to better understand how its research system is evolving. In this project, the scientific impact obtained through different types of collaboration was dissected for African countries that reached the baseline of more than 30 papers published between 2005 and 2010, as well as for the RECs and for the AU as a whole (Figure 8). The analysis shows a clear gradient in scientific impact according to the types of collaboration and demonstrates that the impact of the research increases as the complexity of the collaboration increases. Scientific work performed without international collaboration achieved the lowest scientific impact, while scientific work involving at least two AU countries and one non-AU country achieved the highest scientific impact (in fact, higher than scientific work involving a single African country and international

2 A case where this could happen is that of a paper by a single author with affiliations in at least two countries. This is considered a case of international collaboration, though it does not involve multiple authorships.

collaborators outside the AU). The high impact obtained when at least two AU countries work in collaboration with an international partner or partners may come from the fact that these types of scientific work take into account both the regional (intra-African) and the international dimensions of the issue under investigation, and the work is therefore more likely to be published in international journals with a high impact factor. Thus, while more questions need to be addressed to explain these figures (see below), it is reasonable to think that intra-African approaches (including African countries and RECs), that take the international inputs and context into account, would produce greater outcomes for Africa.

Additional questions to be addressed include the following.

- What factors explain why there is such an impressive increase in scientific impact associated with international collaboration, or how international collaboration increases scientific impact?
- Are the authors involved in international collaboration the same as those writing strictly national papers?
- What is the role of alumni of foreign postgraduate programmes in scientific production in the AU?
- What role does the mobility of PhD students and postdoctoral researchers play in scientific production in the AU?
- Are the research projects carried out locally substantially different from those performed in international collaboration?
- What is the contribution of African nationals to internationally co-authored papers?
- What are the benefits of international collaboration for each researcher's later scientific production and research career?

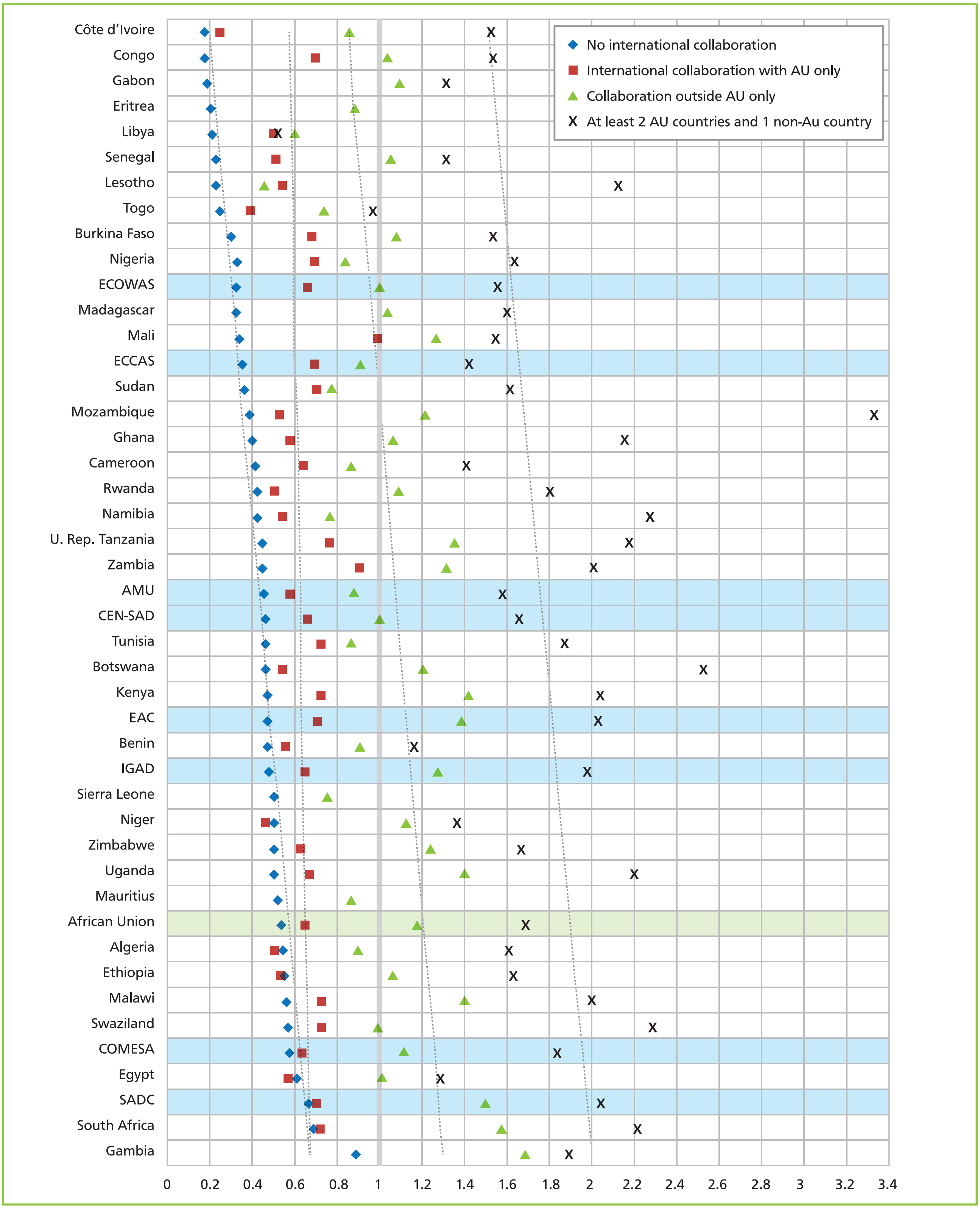
The AU countries with at least 30 national papers and with the greatest propensity to collaborate are the Gambia, Mozambique, Madagascar and Zambia. Conversely, among countries with at least 30 papers published between 2005 and 2010 by national authors only, Nigeria, Mauritius, Libya and Togo had the smallest propensity to collaborate internationally when size was taken into account. A systematic study of collaboration intensity in Africa could be immensely valuable in explaining the large variations between countries, and in examining possible advantages and disadvantages associated with intra-African and international collaboration.

Table X: National, international and total papers, ARC and international collaboration index by AU members, 2005–2010

Country	↓National papers	ARC	Int'l Coll.	ARC	CI	Total papers	ARC	% International
South Africa	29,010	0.69	22,490	1.56	1.07	51,500	1.07	44%
Egypt	24,003	0.61	13,579	1.01	0.74	37,582	0.76	36%
Nigeria	17,728	0.32	4,009	0.91	0.27	21,737	0.43	18%
Tunisia	10,905	0.46	8,077	0.91	0.78	18,982	0.65	43%
Algeria	6,003	0.54	6,581	0.92	0.98	12,584	0.74	52%
Kenya	1,825	0.47	5,052	1.50	1.80	6,877	1.23	73%
Ethiopia	1,272	0.55	2,236	1.08	1.04	3,508	0.89	64%
Ghana	1,084	0.40	1,864	1.23	0.97	2,948	0.93	63%
Cameroon	1,004	0.41	2,549	0.93	1.40	3,553	0.79	72%
United Rep. of Tanzania	872	0.45	2,847	1.48	1.74	3,719	1.24	77%
Uganda	725	0.50	2,674	1.53	1.86	3,399	1.31	79%
Sudan	703	0.37	1,042	0.90	0.74	1,745	0.69	60%
Botswana	678	0.47	854	1.26	0.63	1,532	0.91	56%
Libya	673	0.21	726	0.59	0.53	1,399	0.41	52%
Senegal	620	0.23	1,425	1.07	1.11	2,045	0.81	70%
Côte d'Ivoire	615	0.17	908	0.97	0.71	1,523	0.65	60%
Zimbabwe	462	0.50	1,261	1.23	1.22	1,723	1.03	73%
Mauritius	325	0.52	275	0.86	0.34	600	0.68	46%
Malawi	298	0.56	1,199	1.47	1.60	1,497	1.29	80%
Burkina Faso	240	0.30	1,241	1.19	1.94	1,481	1.05	84%
Congo	196	0.17	720	1.15	1.30	916	0.94	79%
Benin	179	0.47	964	0.93	1.86	1,143	0.86	84%
Zambia	154	0.45	946	1.50	2.04	1,100	1.35	86%
Mali	142	0.34	658	1.34	1.50	800	1.16	82%
Madagascar	129	0.33	865	1.12	2.12	994	1.01	87%
Togo	129	0.24	236	0.75	0.58	365	0.57	65%
Niger	109	0.50	384	1.14	1.06	493	1.00	78%
Namibia	108	0.42	511	1.29	1.43	619	1.14	83%
Swaziland	96	0.57	234	1.22	0.71	330	1.03	71%
Gabon	79	0.19	543	1.15	1.90	622	1.03	87%
Rwanda	69	0.42	322	1.22	1.25	391	1.08	82%
Mozambique	68	0.39	601	1.61	2.35	669	1.48	90%
Gambia	59	0.89	567	1.70	2.46	626	1.62	91%
Eritrea	37	0.21	133	1.00	0.81	170	0.83	78%
Sierra Leone	34	0.50	99	0.88	0.64	133	0.78	74%
Lesotho	33	0.23	112	1.02	0.74	145	0.84	77%
Guinea	25	n.c.	141	1.01	1.14	166	0.89	85%
Central African Republic	20	n.c.	129	0.84	1.23	149	0.76	87%
Angola	15	n.c.	171	0.78	2.01	186	0.73	92%
Dem. Rep. of the Congo	15	n.c.	124	1.40	1.46	139	1.27	89%
Djibouti	13	n.c.	44	0.84	0.57	57	0.70	77%
Seychelles	12	n.c.	141	1.59	1.95	153	1.49	92%
Burundi	8	n.c.	86	0.77	1.60	94	0.74	91%
Chad	8	n.c.	134	0.97	2.49	142	0.92	94%
Liberia	7	n.c.	31	0.72	0.63	38	0.66	82%
Guinea-Bissau	5	n.c.	123	1.24	3.22	128	1.24	96%
Mauritania	4	n.c.	131	0.84	4.03	135	0.82	97%
Equatorial Guinea	3	n.c.	48	1.13	1.82	51	1.09	94%
Western Sahara	3	n.c.	11	n.c.	0.42	14	n.c.	79%
Sao Tome and Principe	2	n.c.	13	n.c.	0.66	15	n.c.	87%
South Sudan	2	n.c.	38	1.63	1.94	40	1.67	95%
Cape Verde	1	n.c.	46	1.35	3.89	47	1.35	98%
Comoros	1	n.c.	22	n.c.	1.86	23	n.c.	96%
Somalia	1	n.c.	19	n.c.	1.61	20	n.c.	95%

Source: computed with data from the Scopus database

Figure 8: Scientific impact of papers derived from different types of collaboration for 36 AU countries that published more than 30 national papers between 2005 and 2010, and for the RECs and AU as a whole



Source: computed with data from the Scopus database

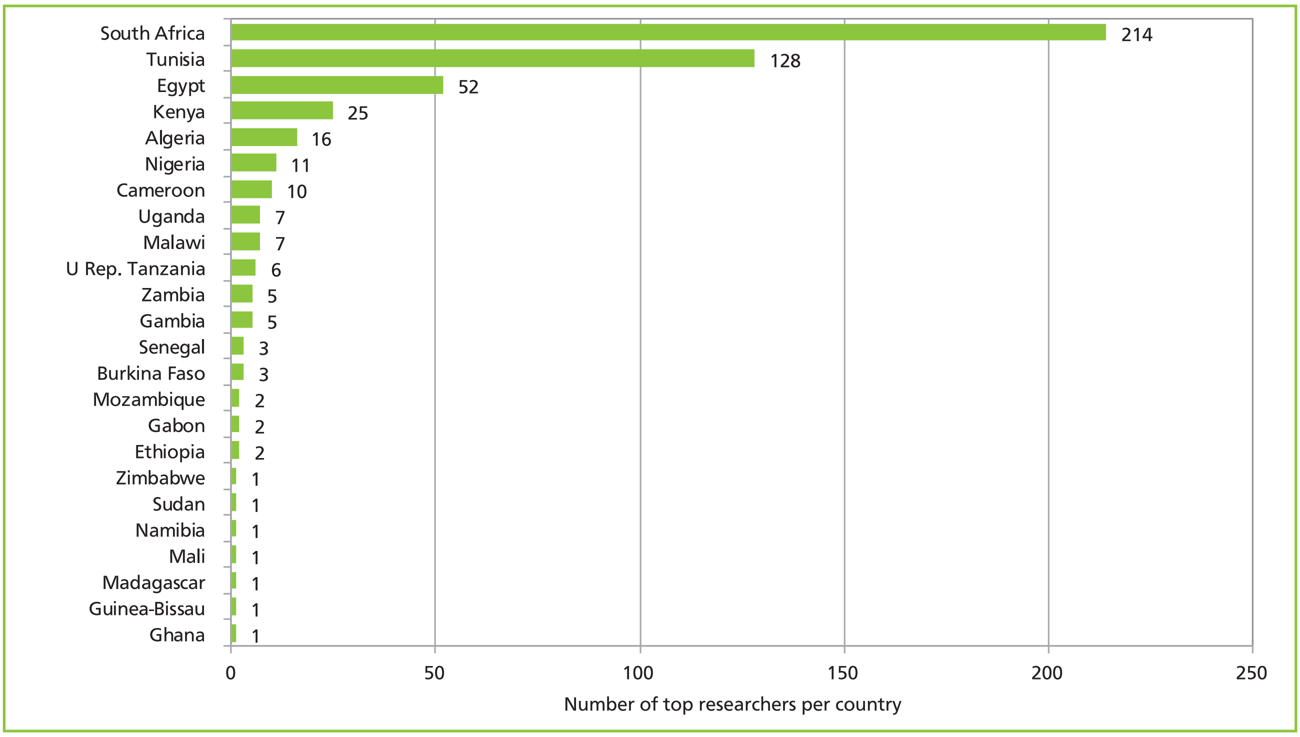
7 Characteristics of the 500 most active scientists

Bibliometric studies allow an analysis of the scientific production profile of institutions, countries, regions or individual scientists. The terms 'highly active scientists', 'leading scientists', 'top researchers' used in this study mean African scientists who published 40 or more papers indexed in Scopus between 2005 and 2010. The names and publication portfolio of the leading African scientists were cleaned and harmonized based on extensive and careful name disambiguation and validation. This process led to the identification of 505 top researchers in AU member states.

What are the characteristics of these 500 researchers? First, almost half of them (250 out of 505) have an ARC score above 1, meaning they are more highly cited than the world average researcher. Slightly more than half (53%) of the researchers for whom the ARIF indicator can be computed score above the world average. Likewise, 52% of the top researchers have an output that is growing faster than the world average. Some 245 researchers (49% of the leading researchers) have more than 50% of their publications co-authored with collaborators from a different country, and these researchers tend to have a greater than average scientific impact (69% of the researchers with more than 50% international collaborations scored more than 1 on the ARC).

As shown in Figure 9, South Africa hosts the largest number of leading scientists, consistent with its leading role in African science. The second leading country is Tunisia, which is somewhat more surprising as it is fourth in terms of the number of papers in the AU, although it was first in terms of papers per capita. This confirms that relative to its population size, Tunisia is one of the most fertile countries in the AU in scientific research. Egypt, Kenya, Algeria, Nigeria and Cameroon all have at least ten of the most active researchers in the AU. The leading seven countries host 90% of the most active scientists in the AU.

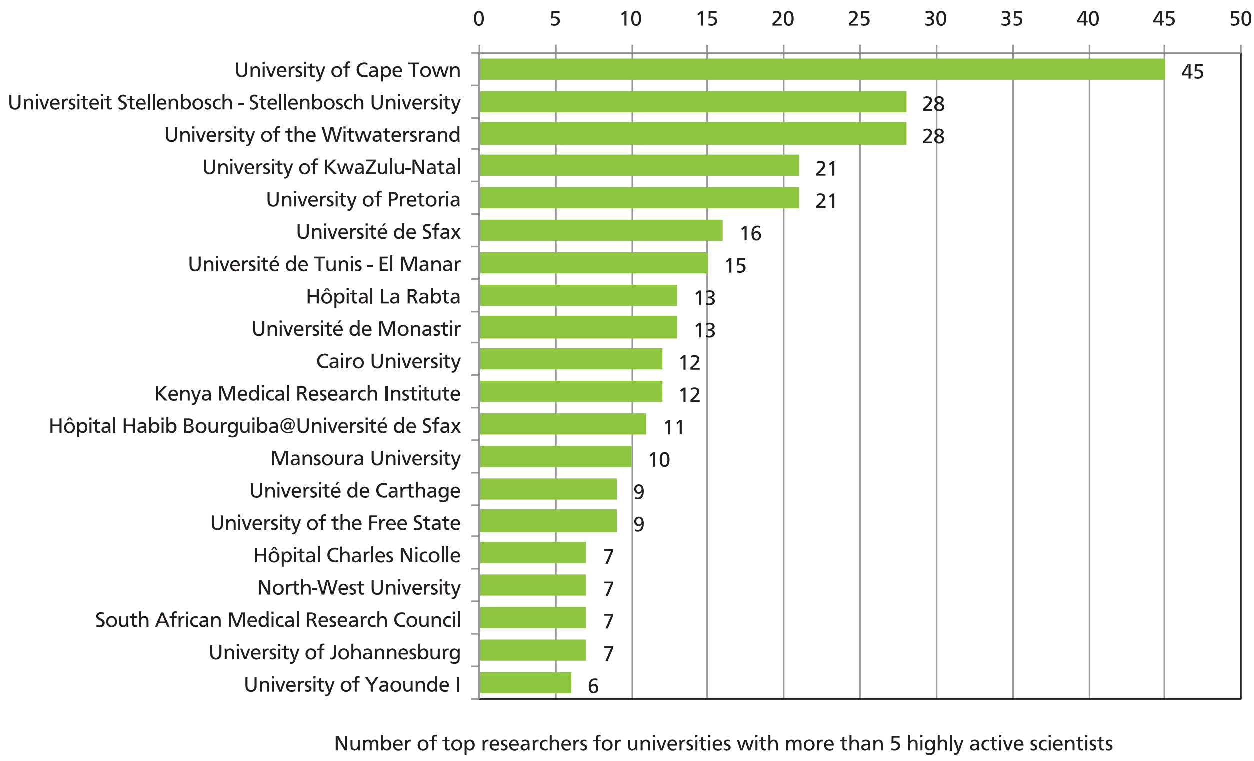
Figure 9: Number of highly active scientists per AU member state, 2005–2010



Source: computed with data from the Scopus database

Examining where the leading researchers are located yields results consistent with the previous findings. For example, the top five leading institutions with the largest number of highly active scientists are in South Africa (namely, the universities of Cape Town, Stellenbosch, the Witwatersrand, KwaZulu-Natal and Pretoria), followed by four from Tunisia (namely, the universities of Sfax, Tunis - El Manar and Monastir, and the La Rabta hospital) (Figure 10). Other AU countries with institutions with more than five highly active researchers are Egypt, Kenya and Cameroon.

Figure 10: Institutions with the largest number of highly active scientists, 2005–2010



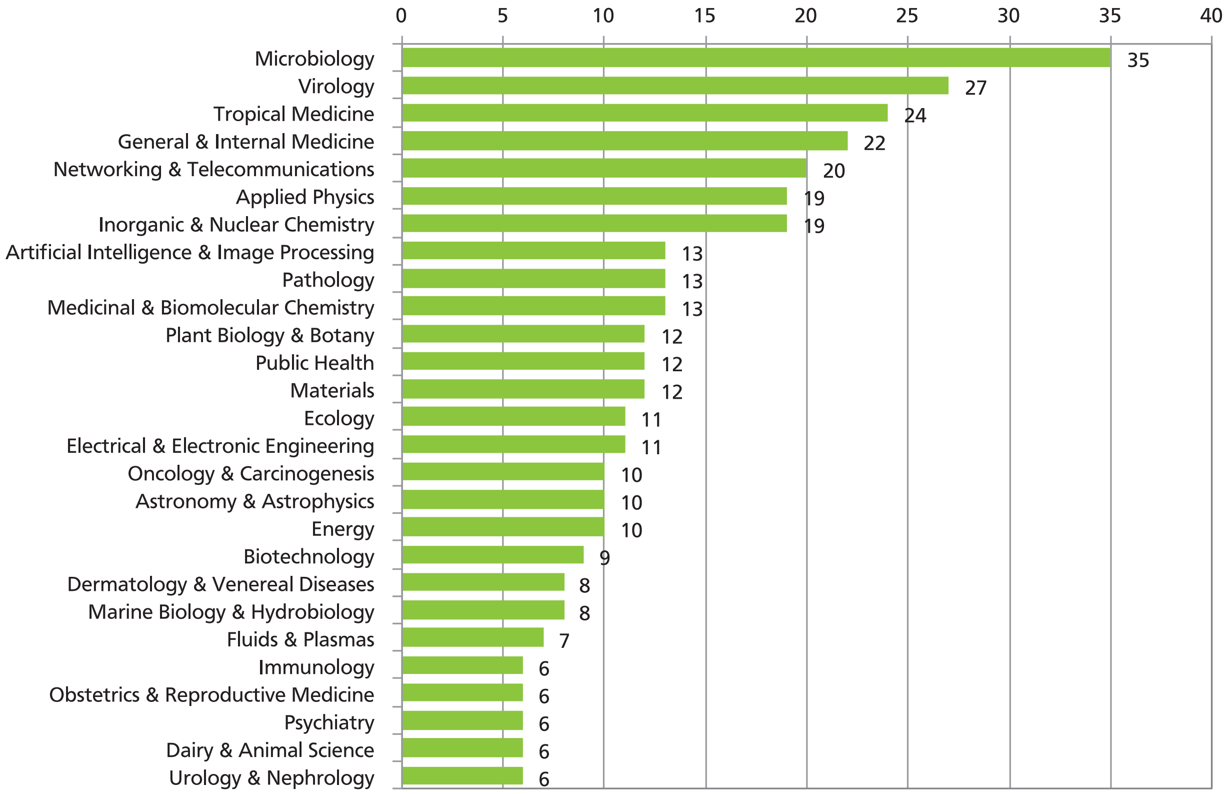
Source: computed with data from the Scopus database

Also consistent with the previous findings, highly active scientists can frequently be found in the health sciences, and most frequently in microbiology; virology; tropical medicine; general and internal medicine (Figure 11). Scientists are actively present in relatively large numbers in many areas of specialization in the computer sciences (networking and telecommunications; artificial intelligence and image processing) and in applied areas of the natural sciences (applied physics; inorganic and nuclear chemistry; medicinal and biomolecular chemistry; materials, energy and biotechnology).

Examining the collaboration between the most active researchers yields results consistent with the previous findings: the level of collaboration between member states of the AU is relatively infrequent. Frequent collaborations occur between top researchers at the national level, and it has been shown that half the researchers have more than 50% of their publications internationally co-authored, primarily with researchers outside Africa. Further, the networks between the most active researchers are polarized in just a few countries (Figure 12).

Due to some differences in publication and citation habits between different fields of science, however, it would be interesting in further analyses to establish profiles of most the active researchers by domains and fields of science.

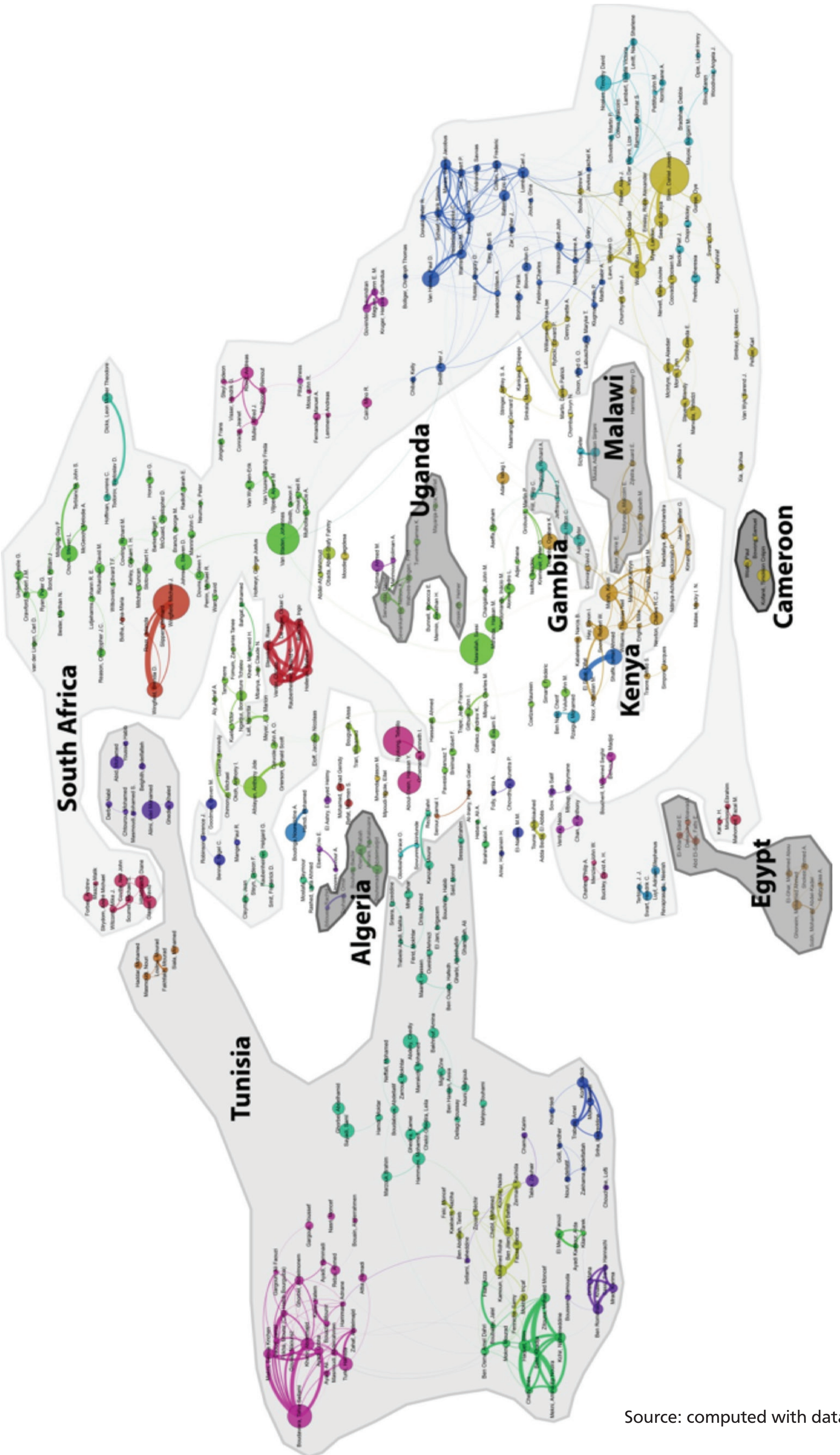
Figure 11: Number of top researchers by area of specialization with more than 5 highly active scientists, 2005-2010



Number of top researchers by specialties with more than 5 highly active scientists

Source: computed with data from the Scopus database

Figure 12: Network of collaboration between highly active scientists in Africa, 2005–2010



Source: computed with data from the Scopus database

8 Conclusion

The output of the African Union (AU) is relatively small, and similar to that of single European countries. As stated earlier in Section 3 of the report, using the same dataset from the Scopus database on African and European countries, the present study found that the scientific production of the AU was about the same size as that of Switzerland, Sweden and Poland in 2005. However, this output is growing rapidly, with a growth rate similar to that of India, China and Brazil between 2005 and 2010 as shown earlier in Figure 3 (Section 3 of this Report). If the AU had been a country, it would have ranked 15th in 2010 for the number of papers, ahead of Russia. This compares with a rank of 19th in 2005, thus showing the extent of its progress.

Overall, the propensity to publish in highly cited journals has grown rapidly over the last six years. However, the AU's output is relatively stable with respect to scientific impact, although progressively higher impact might be expected in the future (as measured by higher ARC values), as there is usually a correlation between the ability to publish in highly cited journals and the capacity of the papers to receive many citations (in other words, papers published in high-impact journals can be expected to receive more citations).

African countries have performed well in the health sciences and applied sciences, but not as well in the natural sciences. Indeed, the growth, specialization, ARIF and ARC of several countries were above the world average in both the health sciences and applied sciences. The level of output in the social and economic sciences as well as in the humanities is relatively low, and it is therefore difficult to make conclusive remarks on the state of African science in these domains.

Scientific collaboration provides a rich canvas for analysing the evolution of African research. Perhaps one of the most important findings of this study is how infrequently African countries collaborate – only 4.3% of the papers in 2008–2010 included inter-African country collaboration. This contrasts with a score of 40% for extra-African collaboration between at least one African and one non-African country. A programme to foster cooperative research, possibly along the lines of the European Framework Programme, might help increase the rate of cooperation and accelerate the pace of STI development in Africa.

It has long been established that international collaboration is a worthwhile undertaking, and the international collaboration of African countries certainly confirms this observation. None of the AU countries achieved a level of scientific impact above the world average based on national-only papers (namely, papers whose authors are from a single country). However, when papers with addresses from at least two countries are considered, the ARC value is above the world average for 25 of the 36 AU countries that published more than 30 national papers between 2005 and 2010. These international collaborations probably produced some leading-edge science, which is likely to help African researchers sustain the rapid development in the knowledge production system of Africa witnessed during the last six years.

It may also be worth distinguishing between international collaboration driven by programmes funded by international donors, and international collaboration on programmes funded solely by Africa. Where funding opportunities from local African donors are absent or scarce, African researchers may accept scientific projects driven by international donors. Such projects driven from outside Africa have been of great help in some instances in addressing critical issues facing the continent, but they present the danger of attracting African researchers who are interested in the funds only for the sake of achieving personal agendas (e.g., career advancement), rather than pursuing scientific interests for Africa. Scientific publications derived from such international collaboration grants could be published in high-impact factor journals without necessarily solving Africa's most urgent S&T

needs. Where international collaboration takes place on projects funded from within Africa, it is likely that the agendas would be set by African stakeholders to solve problems of relevance to them, with the participation of international collaborators for capacity building. The latter case will become the norm in Africa only if Africa funds its own STI agendas. In fact, the lack of sustained funding of STI programmes by African governments remains a major bottleneck to the contribution of STI to development in Africa.

It is worth recaling that, in 1980, the Organization of African Unity, predecessor of the African Union adopted the Lagos Plan of Action in which, it acknowledged the importance of science and technology in the continent's development by calling for African countries to allocate 1% of their respective gross domestic product (GDP) to R&D. Almost 30 years later, 2007 was declared the year of science and technology for Africa and the African Heads of States set the same target of 1% GDP allocation to R&D (AU, 2007). So far, the great majority of African countries have not reached the target. The reasons for this lack of commitment and/or the failure to reach the baseline need to be investigated and overcome if Africa is to move to sustainable development through the contribution of S&T.

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ANNEX A: Patents

Patents are useful, if partial, indicators of technological activities and research, but there are important differences in the propensity of various industries to apply for patents, and they do not always provide adequate protection for technology. Consequently, some companies prefer industrial secrets to a patent, which requires the disclosure of important parts of an invention in exchange for a temporary monopoly over the commercial exploitation of inventions in a given jurisdiction. Although scientific papers are relevant the world over, patents must be applied for in the countries or region where protection for the intellectual property (IP) is sought. It is therefore necessary to compile statistics for patent offices in order to produce relevant indicators. Traditionally, statistics have been produced based on the United States Patents and Trademark Office (USPTO) database, and increasingly the European Patent Office (EPO) database. Although these are important patent offices, they are not the only ones.

Countries are often compared based on their patents in the USPTO database, and increasingly the EPO database, or as the Organization for Economic Cooperation and Development (OECD) is doing, using the so-called triadic patent family (EPO–Japan Patent Office–USPTO). The African Regional Intellectual Property Organization (ARIPO) is an intergovernmental organization comprising mostly English-speaking countries, which oversees patents and registered trademarks for the 18 member states.[3] According to the EPO Worldwide Patent Statistical Database (PATSTAT) database, between 2005 and 2010, only some 80 patent applications were made to ARIPO. The French-language counterpart, namely the Organisation Africaine de la Propriété Intellectuelle (OAPI), comprises 16 mostly French-speaking member states.[4] For the last six years for which data are available in PATSTAT (2002–2007), some 280 patent applications were made to OAPI by AU member states.

The largest national issuer of patents in Africa is South Africa. Importantly, however, other African countries seldom apply for patents to that office. Between 2005 and 2010, only 41 patent applications were from AU members other than South Africa, while South Africa itself made some 1,677 applications to its national patent office during that period (97.6% of AU patent applications).

In this context, it is relevant to ask whether AU countries apply more frequently for IP protection in the large and relatively monolithic markets of the USA and Europe. In both these markets, most patent applications by an AU member state are from South Africa (90% of the applications in Europe, and 87% in the USA). The extent of the domination of South Africa in patent applications is somewhat surprising, since several North African countries, for example, had sizeable publication numbers, including papers in engineering and applied sciences, indicating an interest in technology and, therefore, activities that might require IP protection. More research is needed to understand why the propensity to apply for patents is so low in most AU member states. These issues will be investigated as part of a forthcoming study by AOSTI.

Table XI shows the number of patent applications by AU member states in the period 1991–2010.

3 Botswana, Gambia, Ghana, Kenya, Lesotho, Liberia, Malawi, Mozambique, Namibia, Rwanda, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe.

4 Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, Togo.

Table XI: Number of patent applications by AU member states, 1991–2010

	EPO		USPTO
South Africa	859	South Africa	1522
Mauritius	27	Mauritius	41
Seychelles	13	Egypt	30
Egypt	10	Côte d’Ivoire	23
Tunisia	10	Liberia	22
Namibia	6	Seychelles	22
Zimbabwe	6	Kenya	19
Sierra Leone	4	Nigeria	18
Algeria	3	Burkina Faso	13
Dem. Rep. of the Congo	2	Niger	10
Kenya	2	Tunisia	6
Madagascar	2	Zimbabwe	6
Nigeria	2	Guinea	3
Senegal	2	Burundi	2
Benin	1	Comoros	2
Côte d’Ivoire	1	Ghana	2
Ghana	1	Madagascar	2
Liberia	1	Rwanda	2
Togo	1	Senegal	2
Zambia	1	Uganda	2
		Algeria	1
		Botswana	1
		Cameroon	1
		Gambia	1
		Namibia	1
		Sierra Leone	1
		Swaziland	1
		Togo	1
	954		**1757**

Source: computed with data from the Scopus database

ANNEX B: Technical notes on the indexes of bibliometric indicators used

1. Number of papers

The traditional widespread publication count is one means of measuring and comparing the production of various aggregates such as institutions, regions and countries. It can also be used to evaluate output in individual disciplines, such as philosophy and economics, and to track trends in research fields, collaborative research and many other aspects of research output. A number of other indicators can also be derived from these simple counts.

Scientific papers, by way of their authors' addresses, can be associated with given geographic areas (e.g., countries, cities), sectors or organizations, which means they can be computed at the level of Africa, AU member states, African institutions and so forth. The publication count, or the number of articles (but also publications, which might include books, grey articles, etc.) produced by the research units studied, is the main output indicator used in bibliometrics. Publication counts can be considered a "reasonable measure of scientific production, i.e. the extent to which a consumption of the inputs to research creates a body of scientific results".[5] Such counts do not inform us, however, of the contribution of these publications to the progress of science, which is measured mostly through citation analysis. Publication counts at the country level are sometimes normalized to account for the varying sizes of the countries studied. Ways of normalizing publication counts include dividing the number of publications by a country's population, gross national product and R&D expenditure,[6] as well as researchers (headcount, full-time equivalent) when dealing with institutions or departments.

2. Growth rate: CAGR and GI

The growth rate of a publication pool is calculated using the percentage of annual growth of the exponential model that best fits the bibliometric data, which produces statistics on the compound annual growth rate (CAGR). Put simply, this means that the indicator is the percentage of annual growth that would be calculated if the percentage of growth was the same for every year of the period. For example, the number of papers in 2004 should be the number of papers in 2003 multiplied by the growth rate, and then added to the number of papers in 2003. Countries' effective growth is rarely perfectly exponential, but an approximation is usually sufficient to produce accurate descriptive statistics. Statistics can be computed over two time periods (e.g., the most recent six-year period compared with an earlier six year period) when exponential growth rates cannot be observed for all countries or entities being compared. This has been referred to in this study as the growth index (GI), a measure that is increasingly being used, as it is relatively immune to the presence of noisy data and highly fluctuating levels of output that are typical when computing statistics for smaller or less active countries and also when the analyses concentrate on highly desegregated data.

5 Verbeek, A., Debackere, K., Luwel, M. and Zimmerman, E. 2002. Measuring progress and evolution in science and technology I: the multiple uses of bibliometric indicators, *International Journal of Management Reviews*, 4(2): 179–211.

6 Noyons, E.C.M., Luwel, M. and Moed H.F. 1998. Assessment of Flemish R&D in the field of information technology: a bibliometric evaluation based on publication and paten data, combined with OECD research input statistics, *Research Policy*, 27: 285–300.

3. Specialization index

The specialization index (SI) is the intensity of research of a given geographic or organizational entity (e.g., a country) in a given research area (e.g., domain, field) relative to the intensity of the reference entity (e.g., the world) in the same research area. The SI can be formulated as follows:

$$SI = \frac{(X_S/X_T)}{(N_S/N_T)}$$

Where

X_S Papers from entity *X* in a given research area (e.g., Kenya in physics)

X_T Papers from entity *X* in a reference set of papers (e.g., Kenya in the whole database)

N_S Papers from the reference entity *N* in a given research area (e.g., world in physics)

N_T Papers from the reference entity *N* in a reference set of papers (e.g., world in the whole database).

An index value above 1 means that a given entity is specialized relative to the reference entity, while an index value below 1 means the opposite. The specialization index is a fairly widespread indicator in the scientometric literature, although it is very often designated by different names. Some call it the activity index,[7] [8] others the Revealed Literature Advantage (RLA)[9]. It is also possible to use the specialization index formula for citations and patents by replacing publication counts with citation counts or patent counts

4. Scientific impact analysis: citations and journal impact factors

An important part of scientific excellence is gaining recognition from colleagues for one's scientific accomplishments. Although this recognition can be expressed in many different ways, references to scientific publications are often considered to be explicit acknowledgements of an intellectual contribution. As such, the more a scientific article or publication is cited, the greater its impact on the scientific community, and the more likely it is to be a work of great quality. This is the basic assumption that underlies the various indicators grouped under 'citation analysis': citation counts, journal impact factors, and the various ways of normalizing them.

Before discussing the details of specific indicators, it is important to highlight a number of issues related to the act of citing itself. One issue of contention regarding citation analysis concerns what exactly is being measured through citation analysis. References are the practice of acknowledging previous work that has been important in the production of the referencing article. However, the notion that measuring citations will be a good indication of the quality of a paper has been widely debated. Motivations for citing can be unclear, which would undermine the idea that papers are cited because they make an important contribution to science. A variety of reasons can explain why a citation is given by a scientific article to another, and not all of them are linked to the quality of the work resulting in the article. Critics have thus questioned the validity of citations

7 Noyons, E.C.M., Luwel, M. and Moed, H.F. 1998. Ibid.

8 Tuzi, F. 2005. The scientific specialisation of the Italian regions, *Scientometrics*, 62(1): 87–111.

9 Verbeek, A., Debackere, K., Luwel, M. and Zimmerman, E. 2002. Ibid.

as measures of research visibility, impact or scientific quality,[10 11] but these measures remain widely used, as few alternatives actually exist that would be more objective and cost-effective. In fact, when the law of large numbers is maintained and studies are correctly designed, the idiosyncratic uses of citations are largely ironed out, and citations can therefore be used with a high level of confidence.

5. Citation count

The number of citations received by a scientific article or publication is considered a measure of the impact of that contribution on the scientific community, and the higher the number of citations, the greater the scientific impact. The number of citations can be aggregated to establish citation counts for an individual scientist, a research group, a department, an institution or a country. A number of problems can be associated with absolute citation counts. Citation practices are different between sub-fields of science, such as physical chemistry and colloidal chemistry.[12.13] It thus seems that the validity of comparing the performance of scientists working in different fields is uncertain. This is particularly true considering the fact that citations accrue at different rates depending on the field. Citation counts are indeed affected by the time period over which they are counted, and the importance of this factor has been characterized by a number of authors (Frandsen and Rousseau, 2005; Moed et al., 1985; Van Raan, 2003).[14 15 16]

Absolute citation counts are a very rough way to benchmark scientific performance, as some of the above critiques demonstrate. The preferred way to use citations for ranking is through the use of normalized, relative citation counts.

5.1. Average of relative citations (ARC)

A high-quality paper in a field where fewer citations are given could receive fewer citations than an average paper in a field with heavy citing practices. It would not be fair to compare these papers on absolute terms. A number of indicators have been developed to take these field specificities into account. They are called average relative citation measures.17

One way of increasing the finesse of citation counts is to calculate them relative to the size of the publication pool analyzed, or better, to the citation performance expected for the scientific field or subfield. In the first instance, the number of citations accrued by an individual scientist, an institution or a country for a specific

10 Tijssen R.J.W., Visser, M.S. and Van Leeuwen, T.N. 2002. Benchmarking international scientific excellence: Are highly cited research papers an appropriate frame of reference? *Scientometrics*, 54(3): 381–397.

11 Van Dalen, H.P. and Henkens, K. 2001. What makes a scientific article influential? The case of demographers, *Scientometrics*, 50(3): 455–482.

12 Braun, T. 2003. The reliability of total citation rankings, *Journal of Chemical Information and Computer Sciences*, 43: 45–46.

13 Frandsen, T.F. 2005. Journal interaction: a bibliometric analysis of economics journals, *Journal of Documentation*, 61(3): 385–401.

14 Frandsen, T.F. and Rousseau, R. 2005. Article impact calculated over arbitrary periods, *Journal of the American Society for Information Science and Technology*, 56(1): 58–62.

15 Moed, H.F., Burger, W.J.M. Frankfort, J.G. et al. 1985. Ibid.

16 Van Raan, A.J.F. 2003. The use of bibliometric analysis in research performance assessment and monitoring of interdisciplinary scientific developments, *Technikfolgenabschätzung*, 12(1): 20–29.

17 Verbeek et al. 2002. Ibid.

set of articles is divided by the total number of articles in that set. The assumption here is that the number of citations received by the individual, institution or country is closely linked to the number of articles published. To further increase the finesse of the citation analysis, the results of this citation per publication ratio can be compared to an expected citation rate, which is the citation per publication ratio of all articles in the journal or the subfield where the research unit publishes. This additional sophistication is based on the assumption that practices in different scientific subfields have an impact on the citations normally received in that field, and that a comparison of the unmodified citation to the publication ratio between different fields is unfair[18].

The average of relative citations (ARC) used in this study is an indicator of the scientific impact of papers produced by a given entity (e.g., a country, an institution) that takes into consideration the fact that citation behaviour varies between fields. Thus, the citation count is divided by the average count of all papers in the relevant subfield (e.g., astronomy and astrophysics) to obtain a relative citation count (RC). The ARC of a given entity (e.g., a country, an institution) is the average of the RC of papers belonging to it. When the ARC is above 1, the entity (e.g., country, institution, researcher) scores better than the world average; when it is below 1, an entity publishes papers that are not cited as often as the world average.

The ARC is calculated by:

$$ARC = \sum_{i_{j,y}=1}^{T} \left(\frac{C_{i_{j,y_t}}}{\sum_{k_{j,y}=1}^{T_{j,y}} \left(\frac{C_{k_{j,y_t}}}{T_{j,y}} \right)} \right)$$

Where

$i_{j,y}$ Paper from an entity that falls in specific subfield *j* and is published in period *y*

$C_{i_{j,y}}$ Citations to paper $i_{j,y}$

T Total number of papers from a given entity

$C_{k_{j,y_t}}$ Citations to paper $k_{j,y}$ during the period *y* which falls in a specific subfield *j* and published in period *y*

$T_{j,y}$ Total number of papers from subfield *j* published in period *y*

y_t Years where citations to paper $i_{j,y}$ are considered.

5.2. Average of relative impact factors (ARIF)

The impact factor is the most popular bibliometric measure today.[19] The factor is calculated for a particular journal. It is equal to the total number of times articles published in the journal in the years X-1 and X-2 have been cited in year X, divided by the total number of citable documents appearing in the journal in years X-1 and X-2. It is thus a ratio expressing the average number of times articles and other citable documents in a journal are cited. As such, using impact factors to evaluate research is equating the quality of research with the quality of the journal in which it is published.

18 Glanzel, W. and Moed, H.F. 2002 Journal impact measures in bibliometric research, *Scientometrics*, 53(2): 171–193.

19 Glanzel, W. and Moed, H.F. 2002. Ibid.

Of all indicators, the impact factor seems to be the one most subject to debate.[20] Its strength lies in its comprehensibility, stability, "seeming reproducibility" and fast availability.[21] The main criticisms levied against the impact factor are related to: the fact that it does not take into account differences in citation practices between scientific fields;[22] the lack of distinction with respect to the merit of the citing journal; a bias in favour of journals with lengthy papers; literature ageing biases; the inappropriateness of the two-year citation window for some journals and fields where it takes longer to achieve the citation peak; the insufficiency of a single measure to describe citation patterns of a scientific journals; inaccuracies due to inadequate operationalization of the concept of the citable document[23]; and errors due to incorrect identification of cited journals.

Many authors [24 25, 26] have obtained results that undermine the validity of the impact factor and, for example, found that the measure of the impact factors of the journals in which a research unit publishes does not correlate well with peer assessment of the performance of that unit. However, this presumes that experts can indeed rank journals adequately. It would seem that the indicator is also affected by: the number of journals in a field; the type and number of publications in a journal,[24 25] the uncitedness of a journal; and the frequency distribution of citations to its papers[26]. The inventor of the impact factor, Eugene Garfield, still defends the impact factor as it stands today[27].

This study uses an approach similar to that used for the average of relative citations, which is called the average of relative impact factors (ARIF). This is an indicator of the quality of papers produced by a given entity (e.g., a country, a specific set of papers, a researcher) based on the journals in which they were published. The IF of papers is calculated by ascribing to them the IF of the journal in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across fields and subfields of science, each paper's IF is divided by the average IF of the papers published the same year in its subfield to obtain a relative impact factor (RIF). The ARIF of a given entity is the average of its RIFs (i.e., if an institution has 20 papers, the ARIF is the average of 20 RIFs, one per paper).

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20 Archambault, É. and Lariere, V. 2009. History of journal impact factor: contingencies and consequences, *Scientometrics*, 79(3): 639–653.

21 Glanzel, W. and Moed H.F. 2002. Ibid.

22 Baudoin, L., Haeffener-Cavaillon, N., Pinhas, N. et al. 2004. Indicateurs bibliométriques : réalités, mythes et prospectives, *Médecine/Sciences*, 20: 909–915.

23 Moed, H.F. and Van Leeuwen, T.N. 1995. Improving the accuracy of Institute for Scientific Information's journal impact factors, *Journal of American Society for Information Science*, 46: 461–467.

24 Cameron, B.D. 2005. Trends in the usage of ISI bibliometric data: uses, abuses, and implications, *Portal: Libraries and the Academy*, 5(1): 105–125.

25 Moed, H.F. and Van Leeuwen, T.N. 1995. Ibid.

26 Van Leeuwen, T.N. and Moed, H.F. 2005. Characteristics of journal impact factors: the effects of uncitedness and citation distribution on the understanding of journal impact factors, *Scientometrics*, 63(2): 357–371

27 Garfield, E. 2000. Use of journal citation reports and journal performance indicators in measuring short and long-term journal impact, *Croatian Medical Journal*, 41(4): 368–374.

The ARIF is given by:

$$ARIF = \sum_{i_{j,y}=1}^{T} \left(\frac{IF_{i_{j,y}}}{\sum_{k_{j,y}=1}^{T_{i,y}} \left(\frac{IF_{k_{j,y}}}{T_{j,y}} \right)} \right)$$

Where

$i_{j,y}$ Paper from an entity that falls in specific subfield *j* and is published in period *y*

$IF_{i_{j,y}}$ Impact factor of the journal where paper $i_{j,y}$ is published

T Total number of papers from a given entity

$T_{j,y}$ Total number of papers from subfield *j* published in period *y*.

$IF_{i_{j,y}}$ Impact factor of the journal in which paper *k* from subfield *j* and period *y* is published.

In contrast to the Thompson Reuter's impact factor, which is an asymmetric indicator counting only the ratio between citations to all items relative to the number of citable items, this indicator is symmetric. It calculates the ratio between citations to citable items (articles, reviews and notes) and the number of citable items. Thus, the impact factor used in this study is calculated in the following manner:

$$IF_{i_{j,y}} = \frac{\sum_{i_{j,y}=1}^{T_{y_t}} C_{i_{y_t}}}{T_{y_t}}$$

Where

$i_{j,y}$ Paper from an entity that falls in a specific subfield *j* and is published in period *y*

$C_{i_{y_t}}$ Citations in period *y* to papers published during period y_t

T_{y_t} Total number of citable items from the y_t period

y_t Years for which impact factors are considered

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