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# 2 **The African Strategy of Fundamental** 3 **and Applied Physics**

4 **Report of the 2020–2024 Community Study**  
5 **on the Current and Future of Fundamental**  
6 **and Applied Physics in Africa**

7 **Organized Through Broad Grassroots**  
8 **Community Consultations**

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12 **Editorial Committee: ..**

13 **International Advisory Committee: ..**

14 **Acknowledgements**

15 The African Strategy of Fundamental and Applied Physics brought together over 600 participants worldwide  
16 to develop a strategic vision, with practical recommendations, to enhance physics research and education in  
17 Africa.

18

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## Foreword

20 In this space, the ASFAP Steering Committee will describe their view of the Study, and thank everyone who  
21 needs to be thanked.





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# Executive Summary

23 Fundamental and applied physics draws on worldwide efforts with a small yet steadily increasing presence  
24 of developing countries from Asia, South America and Africa. While we can be proud of African countries  
25 such as Morocco, Egypt and South Africa gaining footholds in major international projects at the Large  
26 Hadron Collider, the cooperation among African countries and between them and the rest of the world is  
27 not well developed. This is especially the case for sub-Saharan Africa, which is one of the most rapidly  
28 developing regions in the world with great educational needs. In order to extend—or augment—the existing  
29 international scientific ties to this continent, in the development of the strategic visions for fundamental and  
30 applied physics, engagement in physics education, communication and outreach, toward developing countries,  
31 should be strengthened and sustained also in targeted programs toward Africa. The success of these targeted  
32 programs would be sufficiently encouraging to provide motivation for a review of goals and for consideration  
33 of mechanisms of sustainability. The central long-term objective—to be integrated in the development of  
34 strategic visions for science and technology—would be to help improve higher education in Africa across  
35 national borders and in so doing, to contribute in a significant way to the development of this continent.  
36 We believe that maintaining the leadership of the organization of targeted education programs in Africa, in  
37 partnership with other interested institutes and African governments and policy makers, presents a unique  
38 opportunity for the international community to pioneer the scientific and technological development of a  
39 region of more than a billion people with large unmet needs but vast human potential.

40 Africa, a rich continent in natural resources, is still lagging behind in innovation, transfer of knowledge, mass  
41 education, and its economies are not growing as expected to meet the needs of its fast-increasing populations.  
42 The African youth represents more than 70% of the population, and is, very often, unskilled, unemployable,  
43 falls back into poverty, and struggles to cope. Africa further faces the issue of the retention of its qualified  
44 young people.

45 However, African initiatives promoted by African countries with their own resources—in some cases in  
46 partnerships with international institutes—are numerous. Among them in our field, to name a few, we cite  
47 the East Africa Institute for Fundamental Research (EAIFR), the Egyptian Network of High Energy Physics,  
48 the similar one, RUPHE, in Morocco, the excellent infrastructure of HESS experiment in Namibia, not to  
49 forget the prestigious universities in South Africa and its high-level research laboratories.

50 To help address the aforementioned issues effectively, we believe that African educational and research  
51 institutes should develop their own strategic discussions and planning of fundamental and applied physics,  
52 for the short, medium and long terms. We feel that Africans, developing their own strategy for science  
53 and technology, will have major benefits. This would allow the international partners interested in capacity  
54 development and retention in Africa to integrate inputs from Africans themselves, rather than to default to  
55 their own views of how they may want to “help” Africans. In addition, the help—in whichever form it is  
56 delivered—will have more impact. In addition, the process to define an African strategy will bring together  
57 the African scientific communities and more pan-African scientific collaborations may emerge. Furthermore,  
58 we hope that the African strategy will help to inform African policymakers.

59 The African Strategy for Fundamental and Applied Physics (ASFAP) further fosters social transformation  
60 and economic competitiveness, through human capital development and innovation—Africa having the  
61 capacity to use science for the benefit of its people. It is therefore vital for Africans to contribute to long-

62 term sustainable training in Africa that can only be ensured through committed investments in research  
63 and development (R&D) with African-led local and international partnerships. International cooperation  
64 is a large common denominator of the culture of scientific activities. However, there is a lack of skilled  
65 curriculum developers, insufficient resources for effective implementation, persistent shortages of trained  
66 science researchers, and ineffective planning. Hence, the related scientific disciplines should be gathered  
67 through a coherent program by establishing a strong connection between the network of academic institutions  
68 and the associated partners, including the private sectors.

69 Scientific competence and understanding is required to increase the numbers of professionals. It is therefore  
70 timely and strategically important to undertake a strategy that could help. Since the scientific research in  
71 Africa includes the development of human resources, it is critical to ascertain what macro policy perspectives  
72 frame decisions on its nature. We must mobilize and include the involvement of the relevant policymakers  
73 of African science research and education, to develop strategies and participate in Africa's science and  
74 technology projects. Africa must harvest its population demographic dividend, especially the women and  
75 youth, whose energy, creativity and courage must drive its continental development strategy.

76 Considering scarce resources, it is important for the world community of scientists, engineers, technicians,  
77 funding agencies and policymakers to come together and define a concerted physics education and research  
78 strategy. To arrive at the definition of a strategy, many inputs from the regional community are collected in  
79 the form of proposals, letters of interest and white papers (welcoming input from the world community as  
80 well) and then discussed and debated in plenary sessions and topical parallel sessions. It is a process that  
81 may take a few years to culminate into a report—to advise the scientific community, funding agencies and  
82 policymakers on strategic directions to improve research and education. The process to define an African  
83 strategy is a true spirit of international cooperation that forms the common denominator of today's culture of  
84 scientific activities, defining priorities for domestic and inter-regional projects to be supported. In pursuing  
85 the grassroots physics strategy, the African scientific communities emphasize the importance of building  
86 synergy between fundamental physics and practical applications which is crucial for a solid education in  
87 Africa. Investments in education, technical competences and training, and in science, technology, research  
88 and innovation remain critical.

89 Physics strategies, driven at grassroots levels by the community of physicists, are carried out periodically in  
90 other regions. Europe updated its strategy (Update of the European Strategy for Particle Physics, CERN-  
91 ESU-013, June 2020) [1], taking into account inputs from the international community. Later, the United  
92 States of America updated its strategy for particle physics [2]. Latin America completed its first strategy  
93 for research infrastructures for high energy physics, cosmology and astrophysics [3].

94 Participation in activities to develop or update a physics strategy is voluntary; it is a non-legal collaboration  
95 by physicists to work and develop a scientific plan or vision. However, the development of a strategy  
96 ought to be mandated by an authority recognized by the physics community. In the USA, the Division  
97 of Particles and Fields (DPF) of the American Physical Society is the mandating authority of the USA  
98 particle physics strategy. The final report of the DPF strategy serves as an input to P5 (Particle Physics  
99 Project Prioritization Panel), an authoritative body that develops “a strategic plan for U.S. particle physics,  
100 plan that can be executed over a 10 year timescale, in the context of a 20-year global vision for the field.”  
101 In Europe, the mandating body of the European strategy for particle physics is the CERN Council. The  
102 Latin American strategy was mandated by the Council of Latin American Science Ministers. Similar to  
103 the case of the USA, ASFAP was mandated by—and developed in consultation with—the African Physical  
104 Society (AfPS). Furthermore, ASFAP received support from many institutes, the logos of which are shown  
105 Figure 0-1.

106 The final report of ASFAP will be submitted to the mandating body (AfPS), the international Advisory  
107 Committee and the supporting institutes. When the strategy report is submitted, the work of the physics



- 124 2. The groups solicited of community inputs through surveys, short documents—Letters of Interest  
 125 (LOI)—and discussions; The groups analyzed of the inputs received from the community and cat-  
 126 egorized these inputs into a few major physics topics of importance to Africa;
- 127 3. The groups studied the topics that emerged from the community inputs and consultations, to develop  
 128 scientific narratives—white papers—that form the basis of the strategy report;
- 129 4. The group summaries contain the major strategic directions extracted from analyzing the white papers.

130 The aforementioned steps required efforts within physics working groups, to reach out to the community at  
 131 large and draw more volunteer physicists, encourage physics communities to contribute LOI, and encourage  
 132 folks with similar interest to self-organize into white paper study groups. Each physics working group  
 133 within ASFAP has 3-5 group conveners to organize the activities within the group, encourage progress and  
 134 ultimately deliver a report of their working group. The working groups were designs along the major physics  
 135 areas of interest to Africa, as defined by AfPS:

- 136 • Particles and related applications: nuclear physics, particle physics, medical physics, (particle)astrophysics  
 137 & cosmology, fluid & plasma physics, complex systems;
- 138 • Light sources and their applications: light sources, condensed matter & materials physics, atomic &  
 139 molecular physics, optics & photonics, earth science;
- 140 • Cross-cutting fields: accelerator physics, computing, instrumentation & detectors.

141 Topics in quantum computing & quantum information and machine learning & artificial intelligence were  
 142 also on the agenda. Furthermore, ASFAP included the fields of societal engagements, namely: topics related  
 143 to physics education, community engagement, women in physics and early career physicists. The timeline  
 144 of the activities is shown in Figure 0-3.

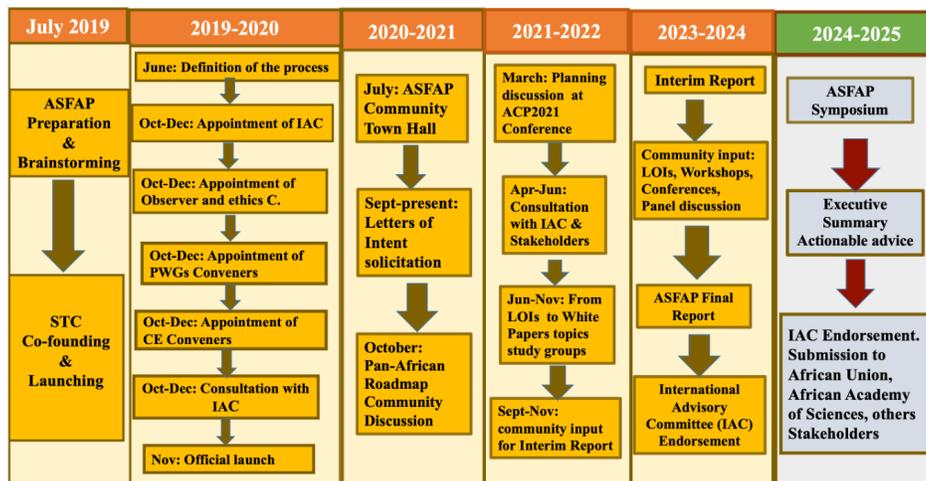


Figure 0-3: ASFAP roadmap timeline.

145 The final report will be presented to the international community in a dedicated symposium, planned  
 146 in October 2025 in connection with the fourth African Conference on Fundamental and Applied Physics,  
 147 ACP2025, at the University of Lome, Togo. The report will contain the summaries of each working group

148 with their recommendations and actionable items. Through the symposium, we will collect final feedback  
149 from the international community. After the symposium, the community feedback will be integrated to  
150 prepare the final version of the report. For effective impact, we will need travel coverage so that many of the  
151 working group conveners would attend the symposium in person. The report will benefit from professional  
152 editing and formatting help, towards publication. We will also need help to disseminate the report to  
153 interested parties that may be interested in its recommendations and actionable items.

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# Ethics in Physics

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## 450 1.1 Introduction

451 Ethical behavior within the African Strategy on Fundamental and Applied Physics (ASFAP) has been  
452 governed by a code of conduct (COC) [1], which is a set of core principles and community guidelines to which  
453 members of the ASFAP community must adhere. Registration to any working group implies that the member  
454 has read and accepted the ASFAP COC. The COC was drafted by the ASFAP steering committee but it  
455 subsequently fell under the responsibilities of a four-member ethics committee, which had been established  
456 to review and act as custodians of this document. It has been the task of the ethics committee to amend  
457 this document whenever necessary, while ensuring that ASFAP remains a community where everyone feels  
458 welcome and respected. In addition, members of the ethics committee have been mandated to serve as  
459 ombudspersons if need arises. We're pleased to report that, so far, we have not received any reports of  
460 conflicts within the ASFAP community requiring our intervention. Therefore, this report only outlines  
461 amendments we have made to the COC to date.

## 462 1.2 Amendments to the code of conduct

463 Between June 2021 and March 2022, we held several meetings to review contents of the COC and made  
464 adjustments and addendums in addition to some general textual editing. We also incorporated a few  
465 suggestions received from the steering committee. The current version of the COC was implemented in  
466 March 2022. Highlighted below are some of the “major” edits/addendums to the document.

### 467 1.2.1 Authorship

468 Very often there are ethical questions raised around large authorship papers in terms of each author's  
469 contribution to the body of work that has been published. In some cases, names are included as authors  
470 ‘only because it was always done’. Therefore, the ethics committee decided that this matter needed to be  
471 covered in the COC. The following text was thus added to section 3(d) of the COC [1].

472 “Authorship offers credit for an individual’s contributions to a study. It also holds the author accountable  
473 for the content in a published paper. All individuals who carried out the work are responsible for the decision  
474 on who should be listed as an author when that work is published. Any individual who makes a significant  
475 contribution to the work (as agreed by everyone contributing to the paper) should be listed as an author.  
476 Any other individual or organization should be acknowledged accordingly. In case of conflict, working group  
477 conveners should be contacted in order to help resolve the conflict. If the conveners and the contributors are  
478 unable to reach a consensus, the ethics committee should be contacted.”

### 479 1.2.2 Email Communication

480 For a community involving hundreds of people, poor use of email communication could be problematic if not  
481 addressed. For example, one member could send a personal email to another member (e.g to congratulate  
482 them on an important achievement) but adding a larger email group in cc. This may be an issue if several  
483 other members reply to this email with everyone in copy. The ethics committee felt that this borders on the  
484 “unethical use of email communication”. Hence, the text below was added to the COC as a bullet point in  
485 section 3(c).

486 **“Ethical use of email communication:** If your email concerns an individual person or a closed group of  
487 individuals, do not write to or reply to everyone in a general list. In addition, email communication should  
488 be done in a respectable manner, respecting the rest of this document’s guidelines. Be also conscious of the  
489 fact that members of the ASFAP community are in different time zones. Therefore, prompt responses should  
490 not always be expected.”

### 491 1.2.3 Guidelines on Virtual Meetings

492 Given that ASFAP meetings were mostly virtual and a number of them were held during the covid-19  
493 pandemic, the steering committee advised the ethics committee to add a section on guidelines for such  
494 meetings to the COC. The text below was thus added to section 3(e).

495 “As members of ASFAP are located in various places across the globe, virtual meetings are inevitable. In  
496 addition, due to the ongoing pandemic, virtual or hybrid conferences/workshops may also be inevitable. To  
497 facilitate the smooth running of such meetings, members of the ASFAP community and invited guests should  
498 adhere to the guidelines listed below:

- 499 • Meeting times should accommodate participants from all time zones. Meeting minutes and/or record-  
500 ings should also be made available on the meeting web page.
- 501 • Meeting hosts should ensure that only the speaker’s microphone is ON at any given time.
- 502 • Participants should use the raise hand feature found in online meeting solutions (e.g. Zoom), or type  
503 their comments/questions in the chat box. Otherwise, participants should wait for an appropriate  
504 opportunity to comment or ask questions without interrupting other participants.
- 505 • Conveners should ensure that each participant receives an equal opportunity to participate in the  
506 discussion.

- 507       • Given that many individuals are currently working remotely, conveners should ensure that the meeting  
508       durations are respected. Virtual meetings tend to go overtime, but participants’ time zones and  
509       personal lives should be respected.”

510 Even though we have now gone past the pandemic, many individuals have continued to work from home for  
511 various reasons. Therefore, we believe that the last bullet point above still applies, and we have decided to  
512 keep it in the COC.

#### 513 1.2.4 General Edits

- 514       • In section 5(b), we replaced “moderator/host/code of conduct committee” by “convener/host/observer/ethics  
515       committee” because we believe that members of the observers committee should also be able to speak  
516       up in case of violation.
- 517       • Throughout the COC document, we removed parts that mention contacting an individual’s institution  
518       if the individual violates the COC. We believe this is unnecessary as in many cases, members of ASFAP  
519       are by no means representing their institutes

### 520 1.3 Conclusion

521 We have highlighted the major addendums and edits that we have made to the COC document since our  
522 engagement as its custodians. To date, no violations to the COC that needed our intervention have come  
523 to our attention. We believe that we would have done our job very well if there are zero complaints that  
524 come to us. Therefore, rather than being passive about these matters, our plan was to implement a way  
525 to constantly educate the community about these issues in a smart and non-intrusive manner. This could,  
526 for example, be a five minute slot at every meeting with conveners to remind them of the COC and its  
527 importance. However, we have not been able to enforce this during this strategy and we hope that future  
528 custodians of ASFAP’s COC will keep these ideas alive and discussed in the public domain from time to  
529 time.

## 530 Bibliography

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# Observers Committee Report

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## 537 2.1 Introduction

538 The Observers Committee is an intermediate body providing an additional link between the working groups  
539 and fora, and the Steering Committee. Members of this committee are people with experience in long term  
540 planning but also an outstanding involvement with projects in and with Africa. Members participate in  
541 WG discussions, they help to review papers, attend meetings and participate in the editing of the reports  
542 together with the WGs they are assigned to follow. The job of the Observers Committee during the first  
543 stage is to help the working groups get running efficiently and smoothly. At a later, the committee can help  
544 to review LOIs and White Papers, and with the editing of the Group Reports [1].

## 545 2.2 Hands-on

546 The interaction between the Observers Committee and the WGs was highly reduced. This has to do with  
547 the commitment of the committee members (together with an agenda that often did not fit the schedules)  
548 but also to a lack of visibility in the importance of an Observers Committee in such a major initiative.

549 In some specific cases, especially in the beginning of the ASFAP process, members of the Observer Committee  
550 facilitated initial contacts between the WG convenors and senior colleagues in their respective communities.  
551 This was arguably the most tangible benefit from the scheme, as at least perceived by individual Observers.

## 552 2.3 Next stage

553 At this stage of the initiative, the Observers Committee is expected to bring its know-how to the project  
554 through the reviewing of the different documents that have been produced by the Working Groups for the  
555 final report. This role has been implemented and was useful at least in some WGs.

## 556 2.4 Comments

557 The concept of inviting independent Observers with a broad background in science strategies is a very  
558 interesting approach. However, its effectiveness remained rather short of the initial expectations, and it  
559 has to be rethought for future strategy exercises, The Observers did in fact not interact formally among  
560 themselves, so no common actions were developed, nor was there any internal motivation generated that  
561 could have been useful. The Observer Committee actions remained with the initiatives of its individual  
562 members, both with respect to their assigned WGs as well as with the Steering Committee. Nevertheless,  
563 given the willingness of individual Observers to enhance the ASFAP process, one may still underline some  
564 positive contributions overall.

565 Committee email: ASFAP-Observers@cern.ch

## 566 Bibliography

- 567 [1] African Strategy Town Hall - Observers Committee Talk - CA Lee,  
568 [https://indico.cern.ch/event/1039315/contributions/4365534/attachments/2282501/3878422/African%20Strategy%20T  
569 %20Observers%20Committee%20Talk%20-%20CA%20Lee%20v2.pdf](https://indico.cern.ch/event/1039315/contributions/4365534/attachments/2282501/3878422/African%20Strategy%20T%20Observers%20Committee%20Talk%20-%20CA%20Lee%20v2.pdf)



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# Accelerators Working Group

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## 3.1 Introduction and Motivation

Accelerator physics is the study of the design, operation, and applications of particle accelerators, which are devices that use electromagnetic fields to accelerate and manipulate charged particles. Particle accelerators have many uses in science, medicine, industry, and security, such as producing beams of high-energy photons, electrons, protons, or ions for nuclear physics, nuclear medicine, materials science, radiation therapy, and nuclear security. This field holds the key to transformative advancements in various scientific and technological domains. While this discipline has made significant strides globally, the landscape of accelerator physics in Africa presents a unique set of challenges and opportunities.

In recent years, accelerator facilities have become indispensable tools for fundamental research, material science, medical applications, and industrial processes. However, despite the increasing importance of accelerator-based technologies, Africa faces distinctive hurdles in establishing and maintaining state-of-the-art accelerator facilities. The demand for accelerator physics expertise in Africa is experiencing remarkable growth, fueled by the continent's ambitious pursuit of scientific and technological advancements. However, this progress is met with considerable challenges that arise from limited resources, infrastructure, and research funding. Despite these barriers, notable strides are being made in accelerator science across the continent. With over 578 accelerator facilities that support scientific research and offer some analytical or irradiation services to diverse community of users, distributed in 59 countries around the world, several accelerator facilities have been established in Africa, showcasing a commitment to advancing nuclear and particle physics research [1]. In particular, Algeria hosts one electrostatic accelerator at the Center de Recherche Nucleaire d'Alger [2], while Tunisia operates an Accelerator-Based Neutron Source at the Centre National de Sciences et Technologies Nucleaires [17]. In Egypt, the Atomic Energy Authority oversees one Electrostatic Accelerator, and Zagazig University houses an Accelerator-Based Neutron Source [18]. Ghana boasts an Electrostatic Accelerator at the Accelerator Research Centre, while Nigeria is equipped with an Electrostatic Accelerator at the Centre for Energy Research and Development [19]. South Africa leads the continent with six accelerator facilities, including three Accelerator-Based Neutron Sources at Nesca and iThemba, and three Electrostatic Accelerators at the University of Pretoria, iThemba Labs in Johannesburg, and iThemba Labs in Cape Town. These installations stand as beacons of scientific progress, contributing to the broader landscape of accelerator physics in Africa (see Fig. 3-1).

The field of accelerator physics in Africa has also experienced a steady increase in research output over recent decades. Fig. 3-2 shows a review of publication trends from 1967 to 2024 reveals minimal activity during

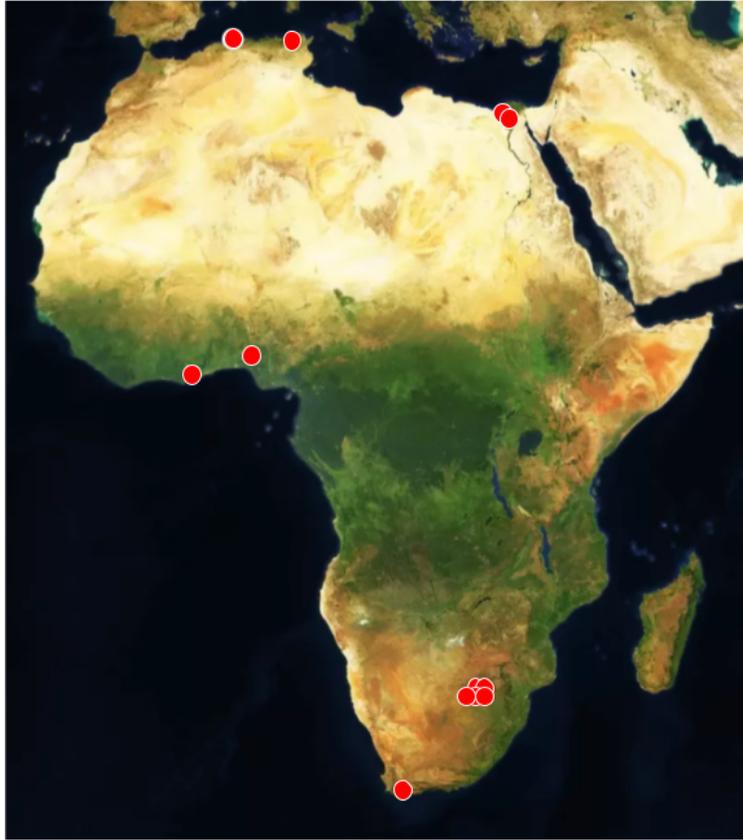


Figure 3-1: IAEA Physics Section’s Developed and Maintained Interactive Map Showcasing Accelerators Across Africa [1]

602 the early years, with significant growth beginning in the late 1990s. The 2012s marked a peak in publication  
603 activity, reflecting the impact of international collaborations, regional initiatives, and the establishment of  
604 new facilities. Although fluctuations are evident, particularly after 2020 due to factors like the COVID-19  
605 pandemic, recent years show a strong upward trajectory, underscoring the continent’s expanding role in  
606 the global accelerator-physics community. This growing body of research demonstrates Africa’s potential to  
607 contribute to fundamental and applied science, despite the challenges of limited infrastructure and funding.

608 Collaborative efforts among African nations and international partnerships have further accelerated progress,  
609 fostering the establishment of facilities aimed at addressing both local and global challenges. From funda-  
610 mental research in nuclear and particle physics to applications in medical diagnostics and materials science,  
611 African scientists are actively involved in pioneering initiatives that will pave the way for transformative  
612 advancements in science and technology.

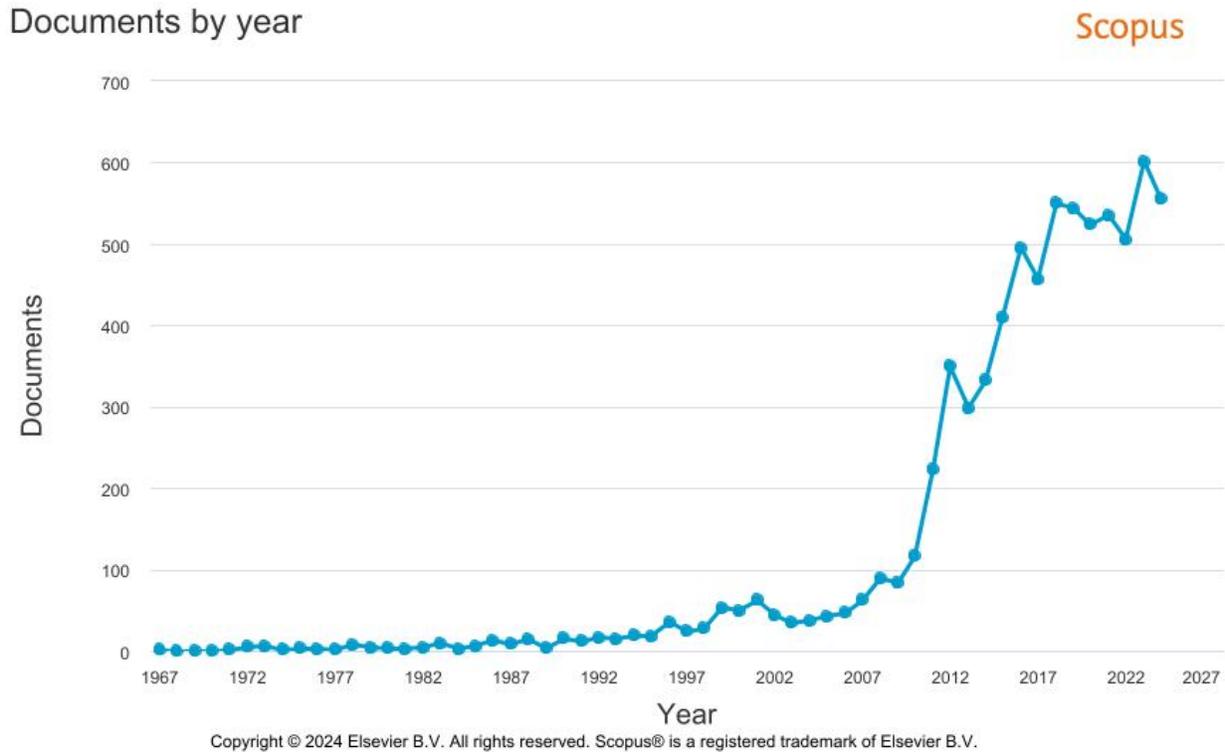


Figure 3-2: Annual Research Output in Particle Accelerator Physics in Africa (1967–2024) (Source: Scopus [6])

## 3.2 Accelerator Physics Capacity in Africa

Within the realm of accelerator physics in Africa, a spectrum of scientific activities unfolds, reflecting a diverse range of research endeavors. Countries such as South Africa, Nigeria, and Egypt, among others, have emerged as focal points for accelerator-based investigations. These endeavors encompass fundamental studies in nuclear and particle physics, exploring the fundamental building blocks of matter, and unraveling the mysteries of the universe.

One notable example is the iThemba LABS facility in South Africa, a prominent accelerator center that serves as a hub for nuclear and particle physics research. Researchers at iThemba LABS are engaged in investigations spanning nuclear structure, astrophysics, and materials science, contributing valuable insights to both fundamental science and applied technologies.

Collaborative efforts are a hallmark of the accelerator physics landscape in Africa. Initiatives like the African School of Fundamental Physics and Applications (ASP) bring together physicists from across the continent to share expertise, foster collaborations, and train the next generation of scientists. ASP not only facilitates knowledge exchange but also strengthens the scientific network within Africa, positioning the continent as an active participant in the global scientific community. Moreover, accelerator applications extend beyond theoretical explorations to practical solutions for societal challenges. Medical physics research, utilizing accelerators for cancer treatment and diagnostic imaging, is gaining momentum in several African countries.

630 These initiatives aim to enhance healthcare infrastructure and address pressing medical needs, showcasing  
631 the tangible impact of accelerator physics on improving lives.

632 In energy research, accelerator-driven systems are explored as potential solutions for sustainable power  
633 generation. African researchers are actively involved in studying accelerator-driven subcritical systems for  
634 nuclear energy applications, contributing to the quest for cleaner and more efficient energy sources.

635 As we delve into the scientific activities of accelerator physics in Africa, this section will provide a compre-  
636 hensive overview of key projects, collaborative initiatives, and advancements that underscore the vibrant  
637 and dynamic landscape of accelerator research on the continent.

### 638 3.2.1 The iThemba LABS

639 The main facility for accelerator physics research and facilities in Africa is iThemba Laboratories for  
640 Accelerator Based Sciences (LABS), which is a business unit of the National Research Foundation (NRF)  
641 in South Africa. iThemba LABS operates one of the most significant and advanced cyclotron facilities in  
642 the African continent and the separated sector cyclotron is the largest accelerator facility in the Southern  
643 Hemisphere. The k-200 separated sector cyclotron can accelerate protons to energies of 200 MeV, and heavier  
644 particles to much higher energies. iThemba LABS provides access to state-of-the-art research infrastructure,  
645 both locally and globally, to facilitate activities that probe the nature, structure and properties of matter  
646 and materials, and to produce radioisotopes that can be used for diagnostics, imaging and therapy in nuclear  
647 medicine applications.

648 iThemba LABS has embarked on a recapitalization program, the overall objective of which is to safeguard  
649 the long-term sustainability of Africa's most unique Accelerator Based research facility. The first pillar of  
650 this program is the South African Isotope Facility (SAIF) [22], which is dedicated to research infrastructure  
651 renewal whose accomplishment is geared to achieve the twin objectives of increase in radioisotope production  
652 and research on the one hand, and the freeing up (on the other hand) of beamtime from the 200 MeV  
653 Separated Sector Cyclotron which will be dedicated for sub-atomic physics research and applications [8].  
654 The first phase of SAIF is centred around the acquisition of a 70 MeV Cyclotron to enhance research and  
655 production of radioisotopes for nuclear medicine. In addition, iThemba LABS has two laboratories dedicated  
656 to research at the atomic scale using particle beams from a 3-MV Tandetron and a 6-MV Tandem accelerator  
657 [10]. These laboratories offer various techniques for ion beam analysis, ion implantation, subatomic physics,  
658 and environmental isotopes. iThemba LABS also collaborates with other international facilities and networks,  
659 such as the African light Source (AfLS), which is an initiative to build a synchrotron light source on the  
660 African continent [9, 11].

### 661 3.2.2 CERD Nigeria

662 The Particle Accelerator Facility located at the Centre for Energy Research and Development (CERD)  
663 within Obafemi Awolowo University, Ile-Ife, Nigeria, was inaugurated on September 28, 2008, primarily for  
664 Ion Beam experiments utilizing a single beam line [12, 13]. The establishment of this facility was made  
665 possible through the collaborative efforts of the Federal Government of Nigeria and the International Atomic  
666 Energy Agency Technical Cooperation (IAEA TC) Project NIR 1010. The accelerator itself is a NEC  
667 5SDH 1.7MV Pelletron Accelerator, a product of the National Electrostatics Corporation (NEC) based in  
668 Middleton, WI, USA. Notably, in 2016, a significant enhancement was made to the facility by introducing

669 a second beam line, complete with an NEC RC43 end-station, thus further augmenting its capabilities and  
670 research potential.

671 The Ion Beam Analysis (IBA) facility at CERD revolves around the utilization of a NEC 5SDH 1.7 MV  
672 Pelletron Accelerator, incorporating an RF charge exchange ion source capable of generating both proton  
673 and helium beams [4]. Although the accelerator can accommodate up to five beam lines, our current  
674 configuration focuses on maintaining two operational beam lines. One of these lines is furnished with a  
675 versatile End Station designed for four distinct analytical techniques: Particle Induced X-ray Emission  
676 (PIXE), Rutherford Backscattering (RBS), Elastic Recoil Detection Analysis (ERDA), and Particle Induced  
677 Gamma-ray Emission (PIGE). Meanwhile, the second beam line houses an NEC RC 43 End Station, similarly  
678 equipped with these four techniques, with added capabilities for conducting grazing experiments on thin  
679 samples, thereby enhancing our capacity for material studies. The application spectrum of our facility spans  
680 across a multitude of fields, encompassing mineralogy, geological analysis, agricultural assessments of soil  
681 and plant samples (including leaves, fruits, and seeds), biomedical and biological research, environmental  
682 pollution monitoring, air quality assessments, materials science investigations, thin film studies, as well as  
683 archaeological and cultural heritage analyses.

### 684 3.2.3 PELLETRON Accelerator in GHANA

685 The Ghana National Accelerator Project, initiated in 2008, aimed to acquire and install a 1.7MV Pelletron  
686 Accelerator in Ghana, facilitated through cost-sharing with the International Atomic Energy Agency (IAEA)  
687 [14, 15, 16]. This endeavor saw the generous donation of the accelerator, complete with Ion Source and high-  
688 energy end components, from the Government of the Netherlands. The refurbishment of the accelerator  
689 and the procurement of a complete beamline, as well as its subsequent installation, were financed by the  
690 IAEA. In turn, Ghana contributed by providing essential local infrastructure, including the construction  
691 of the facility building, electrical installations, air conditioning, and water and compressed air systems.  
692 Furthermore, the project prioritized human capacity building, with support from the IAEA. This included  
693 sponsorship for staff training in accelerator technology and applications, such as through the IAEA sandwich  
694 PhD program in advanced accelerator laboratories. Additionally, technicians received specialized training  
695 in accelerator systems maintenance, fostering local expertise in maintaining and operating the facility. Staff  
696 members also actively participated in the refurbishment of the accelerator in Groningen and were involved in  
697 the installation process alongside NEC Technicians, culminating in an Acceptance Test conducted by IAEA  
698 experts. This concerted effort not only realized the establishment of the Pelletron Accelerator in Ghana but  
699 also empowered local personnel with the necessary skills and knowledge to effectively utilize and maintain  
700 this advanced scientific infrastructure.

701 The accelerator was commissioned on March 2016, while its performance since its installation has been  
702 generally satisfactory, there have been some challenges and breakdowns encountered along the way. However,  
703 most of these issues have been successfully resolved, in some cases with or without the assistance from the  
704 NEC supporting Team. This collective effort not only ensured the establishment of advanced scientific  
705 infrastructure in Ghana but also facilitated the development of local expertise in accelerator technology  
706 and operations. Through continuous maintenance and improvement efforts, the accelerator continues to  
707 contribute significantly to scientific research and educational initiatives in the region, further solidifying  
708 Ghana's position in the field of accelerator physics and related disciplines.

### 3.3 Instrumentation and Control Systems Capacity in Africa

South Africa leads the continent in instrumentation and control systems with several institutions and initiatives driving advancements in this field. iThemba LABS, SARA0 (South African Radio Astronomy Observatory), SKA (Square Kilometer Array), Necsa (Nuclear Energy Corporation of South Africa), and St. James Software are key players, each contributing expertise and infrastructure to various scientific endeavors. iThemba LABS, for instance, not only houses advanced accelerators but also excels in instrumentation and control systems crucial for monitoring and managing these facilities. It has advanced control systems for its cyclotrons and Tandetron accelerators, employing frameworks like EPICS (Experimental Physics and Industrial Control System). Recent developments include integrating EtherCAT-based hardware for distributed control and developing advanced user interfaces using tools like CS-Studio and React Automation Studio. These systems ensure real-time monitoring and high-performance operation across its facilities. SARA0 and SKA are at the forefront of radio astronomy, deploying cutting-edge instrumentation and control systems to operate telescopes and process vast amounts of astronomical data [31]. Necsa, South Africa's Nuclear Energy Corporation, focuses on instrumentation and control systems for nuclear applications, ensuring safety and efficiency in nuclear facilities and research. Moreover, entities like St. James Software provide innovative solutions such as the JlogBook e-log-book, enhancing data management and collaboration across scientific disciplines. Furthermore, African countries actively participate in international collaborations like CERN, where they engage in technology transfer, operations, upgrades, and instrumentation development, using advancements in areas such as artificial intelligence to drive scientific progress and innovation both locally and globally. These efforts collectively demonstrate Africa's growing expertise and capacity in instrumentation and control systems, essential for driving scientific research and technological innovation across various disciplines.

### 3.4 Diverse Applications of Accelerator Physics Across Various Fields

More than 50,000 accelerators are used in a wide range of applications that span various scientific disciplines and industrial sectors [21, 23, 24]. From fundamental research in nuclear physics to practical applications in medicine, materials science, and beyond, accelerator-based techniques play a pivotal role in the advancement of scientific knowledge, technological innovation, and social progress. In this section, we explore the diverse array of applications enabled by accelerator physics.

- **Nuclear Physics:** Nuclear physics research facilities often have multiple accelerators for various purposes, including particle physics experiments and nuclear research. Large research institutions like iThemba LABS in South Africa [20, 10], CERN in Switzerland, Fermilab in the United States, and KEK in Japan host numerous accelerators, including cyclotrons, synchrotrons, and linear accelerators. The number of accelerators dedicated specifically to nuclear physics worldwide is estimated to be from 500 to 1000. The Egyptian Atomic Energy Authority (EAEA) operates several facilities equipped with accelerators for nuclear physics research [25]. These facilities include cyclotrons and linear accelerators used for nuclear research, medical isotope production, and radiopharmaceutical development. EAEA also collaborates with international institutions on nuclear research projects.
- **Medical Physics:** Accelerators in the medical field are primarily used for radiation therapy in cancer treatment. Thousands of medical linear accelerators (LINACs) are installed in hospitals and clinics worldwide for delivering external beam radiation therapy. More details about the ones in Africa can

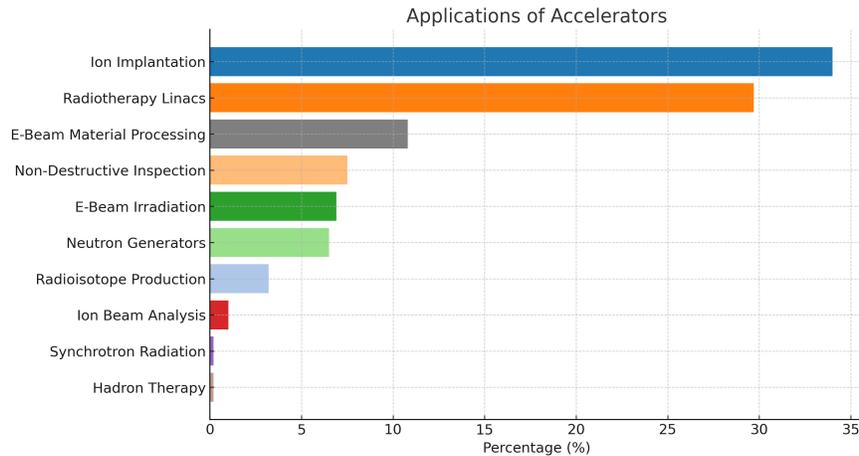


Figure 3-3: Distribution of accelerators worldwide by common applications. Data sourced from [21]

be found in Section 3.8. In addition to LINACs, advanced treatment techniques such as hadron therapy, which utilizes protons or heavier ions, are being increasingly adopted to target tumors with greater precision, though it currently represents a smaller share of applications. iThemba LABS uses its accelerators for proton therapy which makes it one of the few centers in Africa offering advanced radiation therapy using proton beams, in addition to its standard radiotherapy treatments.

- Materials Science:** Synchrotron radiation facilities are widely used for materials science research. Major synchrotron facilities, such as the Advanced Photon Source (APS) in the United States, the European Synchrotron Radiation Facility (ESRF) in France, and the Diamond Light Source in the United Kingdom, host thousands of researchers annually conducting experiments on materials properties, crystallography, and structural biology. Moreover, ion implantation, which accounts for 34% of accelerator use, is a crucial technique in the semiconductor industry for doping materials, essential for manufacturing integrated circuits. Researchers use the accelerators at iThemba LABS to modify and analyze materials at the atomic level, contributing to the development of new materials and the improvement of existing ones.
- Energy:** Accelerators are utilized in environmental and energy research for various purposes, including nuclear waste management, environmental monitoring, and alternative energy research. Facilities such as the European Spallation Source (ESS) in Sweden, which is under construction, aim to advance research in areas like nuclear energy, materials for energy storage, and environmental science. Beyond research, accelerators are used in non-destructive inspection (7.5%) and neutron generation (6.5%), critical in energy applications for ensuring the integrity and safety of materials and systems. The EAEA in Egypt operates several research centers that use accelerators for energy research. Their work includes studying materials for nuclear reactors, improving the efficiency of energy production from nuclear sources, and exploring alternative energy solutions. The EAEA also focuses on research to advance nuclear energy technology and its applications in Egypt and the broader region. NCERD in Nigeria also focuses on energy research [26]. The center conducts studies on nuclear energy, including the development of nuclear reactors and the application of nuclear techniques in energy production. NCERD's work is essential for advancing nuclear energy technology in Nigeria and supporting the country's energy needs.

778 Accelerators are versatile tools with applications extending beyond these traditional areas (see Fig. 3-3). For  
779 example, ion beam analysis (1.0%) and E-beam material processing (10.8 %) play important roles in quality  
780 control and material modification in various industries. Radioisotope production (3.2%) supports medical  
781 diagnostics and treatments, contributing to advancements in nuclear medicine, while synchrotron radiation  
782 (0.2 %) continues to drive forward cutting-edge research in structural biology and materials science. These  
783 diverse applications highlight the critical role accelerators play in both industrial and medical advancements.

### 784 3.5 Building a Pan-African Accelerator Network: Bridging Inno- 785 vation, Collaboration, and Scientific Growth

786 The motivation for establishing dedicated accelerator divisions across African countries stems from the  
787 transformative potential these facilities hold for science, technology, and sustainable development. A pan-  
788 African vision for accelerator technology would involve strategic placement of accelerator divisions in different  
789 regions, bolstering local capacity and fostering regional collaboration. This network would not only elevate  
790 Africa's research capabilities but also create a platform for shared expertise, enabling scientists from across  
791 the continent to collaborate and push forward high-impact projects like the development of African light  
792 sources.

793 Morocco's strategic geographic position offers significant advantages for establishing an accelerator division  
794 that could lead to deeper collaboration with European research centers like ALBA (Spanish 3rd generation  
795 synchrotron light source) in Spain [36] and the STAR (Southern European Thomson back-scattering source  
796 for Applied Research) facility in southern Italy [35]. The proximity to these centers allows for easier exchange  
797 of expertise, joint projects, and access to advanced infrastructure. Such collaboration would contribute  
798 to a robust ecosystem where Moroccan researchers can engage in international partnerships, leveraging  
799 the experience of these established projects to develop new capabilities in accelerator technology and light  
800 sources. The broader context includes existing strong trade and scientific ties between Morocco, Spain, and  
801 Italy, as shown by Morocco's position as a significant partner in EU trade and research agreements. This  
802 mutual relationship underlines the potential for beneficial scientific exchanges and infrastructure projects in  
803 fields such as accelerator physics and light source development. Collaborative efforts would help establish  
804 the foundations for a comprehensive Pan-African network of research facilities, reversing the brain drain by  
805 providing African scientists with the necessary tools and resources at home. Such initiatives could pave the  
806 way for the future development of larger, more advanced light source projects across Africa, including in  
807 South Africa and Morocco, building on initial steps with compact light sources.

808 Currently, South Africa's iThemba LABS stands as a strong research facility in the field of nuclear physics  
809 and accelerator-based sciences. However, creating a specialized accelerator division within iThemba LABS  
810 and replicating similar divisions in north countries like Morocco and other African nations would significantly  
811 strengthen the continent's research infrastructure. Such divisions would serve as hubs for training, innovation,  
812 and collaborative research in accelerator physics and related disciplines.

813 The establishment of multiple accelerator divisions would accelerate the continent's progress toward building  
814 compact light sources. These sources are feasible starting points due to their relative simplicity and lower  
815 costs compared to large-scale synchrotrons or colliders. Compact light sources can still deliver impactful  
816 results in applications ranging from medical imaging and materials analysis to cultural heritage conservation  
817 and environmental studies. This vision aligns with reversing the brain drain that has historically affected  
818 Africa's scientific community. By providing advanced research facilities and opportunities, African accelerator  
819 physicists and engineers who work abroad could be motivated to return, bringing their skills and experiences  
820 to bolster the development of domestic research ecosystems. Such initiatives could lead to the eventual

821 establishment of full-scale light source facilities—potentially one in South Africa and another in North  
822 Africa, such as Morocco. These facilities would create a robust research network that promotes scientific  
823 excellence and positions Africa as a leader in the global research landscape.

824 Furthermore, the creation of accelerator divisions supports economic development, as it attracts investments  
825 and partnerships with international research organizations. By investing in accelerator technology, African  
826 countries can foster local innovation, build highly skilled workforces, and strengthen regional and interna-  
827 tional scientific collaborations, laying the groundwork for long-term development and scientific leadership.

## 828 3.6 High-priority future needs

829 • **Infrastructure Development:** Accelerator physics in Africa faces a crucial need for the development  
830 and enhancement of research infrastructure. Investing in state-of-the-art accelerator facilities, upgrad-  
831 ing existing ones, and establishing new centers will be pivotal for conducting cutting-edge experiments  
832 and staying at the forefront of global scientific advancements.

833 • **Human Capital Development:** The shortage of skilled personnel poses a significant challenge. Ini-  
834 tiatives for training and capacity building in accelerator physics are essential. Collaborative programs,  
835 workshops, and educational partnerships can play a vital role in nurturing the next generation of  
836 African physicists, engineers, and technicians.

837 • **International Collaboration:** Strengthening collaboration with international partners is a high-  
838 priority need. This involves fostering partnerships with established accelerator centers worldwide, partic-  
839 ipating in joint research projects, and facilitating knowledge exchange. International collaborations  
840 with organizations like CERN, Fermilab, and SESAME (in Jordan) can accelerate progress, including  
841 funding Support from governments, private sector, and international agencies that should invest in  
842 accelerator research for African scientists to contribute meaningfully to global scientific endeavors.

843 • **Outreach Programs** Increasing outreach programs to introduce accelerator physics to students is  
844 critical for fostering interest and cultivating talent in this field. Organizing workshops, seminars, and  
845 summer schools targeted at high school and undergraduate students can raise awareness about accel-  
846 erator physics and its applications. Additionally, mentorship programs and internships at accelerator  
847 facilities can provide hands-on experience and inspire students to pursue careers in this specialized area  
848 of science. As an exemplar, the ASP Outreach Program, which took place in Marrakech, Morocco,  
849 from April 15th to 19th, 2024. This initiative was meticulously designed to ignite and sustain learners'  
850 interests in Physics and its diverse applications. A significant segment of the program was exclusively  
851 dedicated to Accelerator Physics, aimed at acquainting students with its fundamental principles and  
852 cutting-edge technologies. Under the guidance of esteemed experts, Dr. Sanae Samsam from INFN  
853 (Istituto Nazionale di Fisica Nucleare) and Dr. Christine Darve from ESS (European Spallation  
854 Source), the program unfolded with a blend of comprehensive lectures and engaging practical sessions.  
855 These sessions were meticulously curated to provide participants with a holistic understanding of  
856 accelerator physics, ranging from its theoretical underpinnings to its real-world applications. Through  
857 interactive discussions and hands-on activities, students were not only introduced to the intricacies of  
858 particle acceleration but were also inspired to explore its interdisciplinary connections and potential  
859 for scientific innovation. The report which resume all the activity can be found in this Ref. [7].

860 In summary, Africa has immense potential to develop accelerator physics for scientific research, medical  
861 applications, and socioeconomic growth. By investing in education, infrastructure, and collaborations,  
862 African nations can contribute significantly to this field.

### 3.7 Synergies with neighbouring fields

Accelerator technologies play a pivotal role in medical physics and healthcare, contributing to cancer treatment through radiation therapy and medical imaging. Moreover, accelerator-based techniques in materials science and nanotechnology significantly impact research and development, offering powerful tools for ion-beam analysis and materials characterization. Environmental science and geophysics benefit from accelerator applications, particularly in studies related to archaeology, climate change, and geological processes. The intersection of accelerator physics with nuclear physics and astrophysics is evident in research exploring nuclear structure, reactions, and astrophysical phenomena. Accelerator technologies also drive technological innovation and industry applications, influencing semiconductor manufacturing, ion implantation, and non-destructive testing. Furthermore, accelerator initiatives contribute to education and capacity building, offering training programs and workshops that empower the next generation of scientists and technologists. Collaborations with international research institutions underscore Africa's role in global scientific endeavors, fostering knowledge exchange and joint projects. Through these synergies, accelerator physics emerges as a catalyst for holistic scientific progress, bridging diverse fields and expanding the frontiers of knowledge in the African context.

### 3.8 Clinical Linacs Driving Cancer Treatment Across Africa

Clinical Linacs, short for Clinical Linear Accelerators, are sophisticated medical devices primarily used in the treatment of cancer through a process called radiation therapy. These machines generate high-energy X-rays or electrons, which are directed towards the patient's tumor to destroy cancerous cells while minimizing damage to surrounding healthy tissues.

The proliferation of clinical Linacs across Africa marks a significant advancement in the region's capacity to provide essential cancer treatment services. According to the IAEA DIRAC (Directory of Radiotherapy Centres), there are approximately 432 Linacs dedicated to MV Therapy spread across the continent [5]. Notably, North Africa boasts the largest share with 237 Linacs, followed by 107 in the southern region and 88 in the central part of the continent (see Fig. 3-4).

This distribution underscores the commitment of African nations to improve access to radiotherapy services, addressing the pressing healthcare needs of their populations. With Linac technology widely available in different regions of Africa, more patients can receive timely and effective treatment, contributing to better cancer outcomes and improved healthcare infrastructure throughout the continent.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Algeria	16	37	0	0	13
Egypt	75	124	0	1	23
Libya	5	8	0	0	0
Morocco	30	48	0	0	10
Tunisia	15	27	0	1	4

Table 3-1: Clinical Linacs in North Africa

Tab. 3-1 provides an overview of the distribution of clinical linear accelerators across North Africa, highlighting the infrastructure for cancer treatment in the region. Egypt emerges as a leader in this regard,

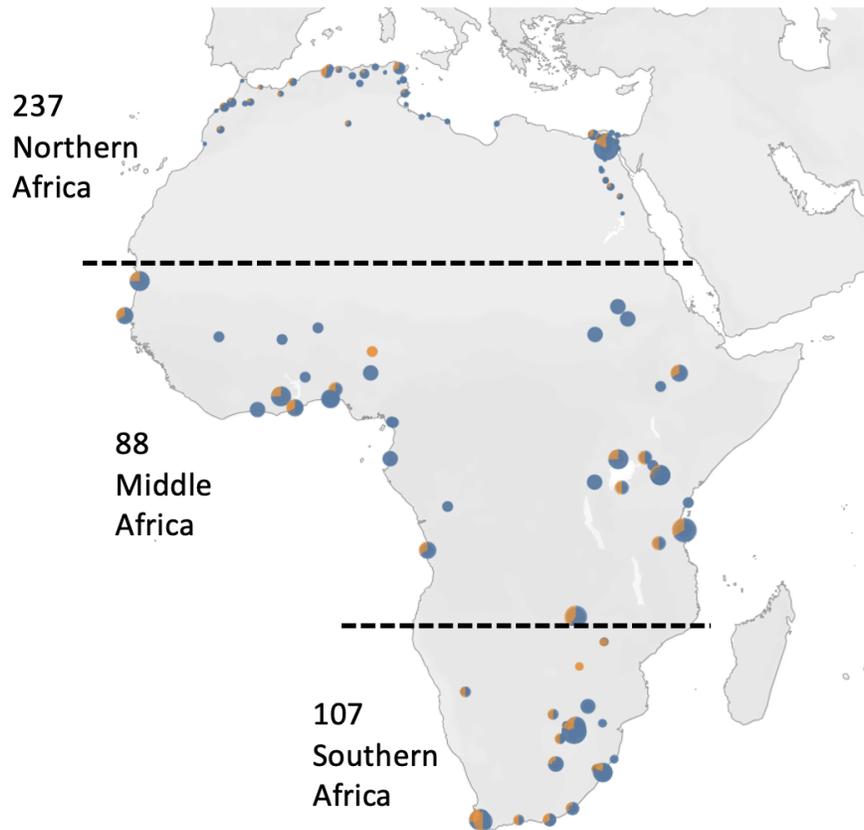


Figure 3-4: Status of Radiation Therapy Equipment in Africa

894 boasting the highest number of Linac centers (75) and offering the most diverse range of treatment modalities,  
 895 including megavoltage (MV) therapy and kilovoltage (kV) therapy. Additionally, Egypt stands out as the  
 896 sole provider of light ion therapy among the countries surveyed, indicating a more advanced level of radiation  
 897 oncology infrastructure.

898 Following Egypt, Morocco demonstrates a significant presence in Linac facilities with 30 centers, although its  
 899 range of treatment modalities is slightly more limited compared to Egypt. Algeria and Tunisia also exhibit  
 900 substantial Linac infrastructure, albeit with fewer centers. Algeria notably has a considerable number of  
 901 brachytherapy facilities (13), indicating a focus on this targeted treatment method.

902 Conversely, Libya appears to have the most limited infrastructure among the surveyed countries, with only  
 903 five Linac centers and minimal representation in other treatment modalities.

904 In Middle Africa (see Tab. 3-2), several countries demonstrate modest but emerging capabilities in cancer  
 905 care. Kenya is distinguished with a notable presence of 10 Linac centers, indicative of its commitment to  
 906 expand the accessibility to cancer treatment. Nigeria follows closely with seven Linac centers, reinforcing its  
 907 position as a regional hub for healthcare services.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Angola	2	3	0	0	1
Burkina Faso	1	2	0	0	0
Cote D'Ivoire	1	2	0	0	0
Cameroon	3	2	0	0	0
Congo	1	1	0	0	0
Ethiopia	3	3	0	0	1
Gabon	1	2	0	0	0
Ghana	3	6	0	0	3
Kenya	10	16	0	0	5
Madagascar	2	3	0	0	1
Mali	1	1	0	0	0
Mozambique	1	1	0	0	0
Mauritania	1	4	0	0	1
Mauritius	1	3	0	0	1
Malawi	1	1	0	0	0
Niger	1	1	0	0	0
Nigeria	7	9	0	0	2
Reunion (France)	1	5	0	0	0
Rwanda	1	2	0	0	0
Sudan	4	6	0	0	0
Senegal	4	4	0	0	1
Togo	1	1	0	0	0
Tanzania	4	8	0	0	4
Uganda	1	3	0	0	1
Zambia	1	3	0	0	2

Table 3-2: Clinical Linacs in Middle Africa

908 Ghana, Tanzania, Sudan, and Senegal also show significant progress in Linac installations, reflecting efforts  
 909 to enhance cancer treatment capacities. These countries not only possess multiple Linac centers but also  
 910 offer various treatment modalities, including megavoltage (MV) therapy and brachytherapy.

911 In contrast, several countries in the region have limited Linac infrastructure, with only one or a few centers.  
 912 Despite this, there is potential for growth and collaboration to address the gaps in cancer care accessibility.

913 In South Africa, as shown in Tab.3-3, South Africa emerges as a prominent player in cancer care, boasting  
 914 a substantial number of Linac centers (62) and offering a wide range of treatment modalities. With more  
 915 than 100 units of MV therapy and significant representation in brachytherapy.

916 Botswana and Namibia show promising developments in cancer treatment infrastructure, with two Linac  
 917 centers each. These countries also provide brachytherapy services, indicating efforts to diversify treatment

options. Zimbabwe, while having a more limited number of Linac centers, still contributes to the regional landscape of cancer care with three facilities. The presence of brachytherapy services underscores efforts to provide holistic cancer treatment approaches.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Botswana	2	2	0	0	1
Namibia	2	2	0	0	1
South Africa	62	102	0	8	23
Zimbabwe	3	1	0	0	2

Table 3-3: Clinical Linacs in Southern Africa

The distribution of clinical Linacs facilities in Africa reveals varying levels of cancer treatment infrastructure. While Egypt leads in North Africa and South Africa in the south with substantial Linac centers and diverse treatment modalities, Kenya emerges as a notable player in Middle Africa. These findings underscore the imperative for continued investment and collaboration to strengthen cancer care infrastructure across the continent and ensure equitable access to quality treatment options.

Overall, the data underscores the need for continued investment and collaboration to strengthen cancer treatment infrastructure across Middle Africa, ensuring that all individuals have access to quality care regardless of geographic location.

### 3.9 Cyclotrons Capacities for Medical and Reserach applications

#### 3.9.1 Current Landscape of Cyclotron Facilities in Africa

While accelerators are primarily known for their large-scale applications in research facilities like iThemba LABS, cyclotrons play an essential role in various sectors across Africa, particularly in nuclear medicine and medical isotope production. Several African countries (as shown in Fig.3-5), including Egypt, Morocco, Algeria, South Africa, Kenya and Tunisia, host cyclotron facilities, which are pivotal for the local production of medical isotopes used in diagnostics, imaging, and radiation therapy [27, 28]. These isotopes, such as fluorine-18 used in PET scans, are critical for early disease detection and treatment planning.

In addition to their medical uses, cyclotrons in Africa are also utilized for fundamental research. iThemba LABS, in South Africa, operates one of the largest cyclotron facilities on the continent, producing isotopes for medical and industrial applications. The facility’s separated sector cyclotron, which accelerates protons to energies of up to 200 MeV, serves as a cornerstone for both regional research and medical applications. Other countries, such as Egypt and Tunisia, utilize their cyclotrons for nuclear physics research, where they contribute to scientific advancements in areas such as material science and radiation physics.

These smaller, standalone cyclotrons are not only crucial for local healthcare advancements but also represent a growing infrastructure that supports collaborative scientific efforts across the continent. Their expansion in Africa reflects the increasing importance of accelerator-based technologies in improving public health, advancing scientific research, and contributing to technological innovation.

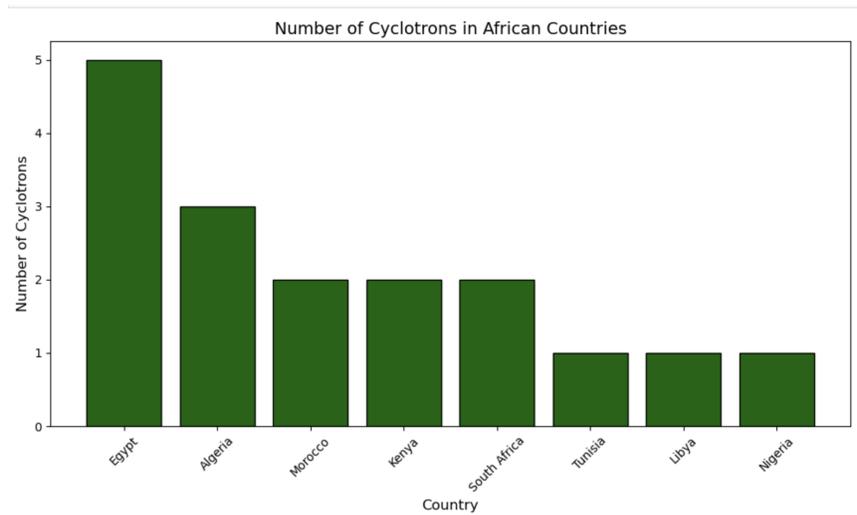


Figure 3-5: Database of the Cyclotrons used for radionuclide production in Africa[28]

### 947 3.9.2 Challenges in Cyclotron Access and Usage

948 Despite their importance, many African nations still face challenges in expanding their cyclotron facilities.  
949 Key barriers include:

- 950 • High initial costs: The infrastructure for cyclotron facilities is expensive, and many countries lack the  
951 financial resources or investment mechanisms to develop them.
- 952 • Limited technical expertise: Cyclotron operation and maintenance require highly specialized technical  
953 skills. There is a need for training programs and capacity-building efforts in this area.
- 954 • Geographic concentration: Cyclotron facilities are currently concentrated in a few countries, creating  
955 disparities in access to these critical technologies across the continent.

### 956 3.9.3 Strategic Recommendations for Enhancing Cyclotron Use in Africa

957 To address these challenges and expand the role of cyclotrons in Africa, the following strategies are recom-  
958 mended:

- 959 • Establishing Collaborative Networks: Strengthening regional collaboration between countries with  
960 existing cyclotron facilities (such as South Africa, Egypt, and Tunisia) can help share knowledge,  
961 resources, and best practices. Regional hubs could be developed to provide services to neighboring  
962 countries with limited access to such facilities.
- 963 • Increasing Investment in Cyclotron Infrastructure: Governments and international organizations should  
964 consider allocating more funds to the establishment of cyclotron facilities in countries that do not yet

965 have them. Public-private partnerships could be explored to reduce the financial burden on national  
966 governments.

967 • Building Local Expertise and Training Programs: Developing specialized training programs in accel-  
968 erator physics, cyclotron operation, and medical isotope production is critical. This could involve  
969 collaborations with existing facilities like iThemba LABS, as well as international training programs  
970 offered by institutions such as the IAEA.

971 • Expanding Medical Applications: There is an opportunity to scale up the production of medical  
972 isotopes for both domestic use and export. This would involve improving the production capabilities  
973 of existing cyclotron facilities and expanding their medical isotope portfolios to include isotopes for  
974 cancer therapy, diagnostic imaging, and radiopharmaceuticals.

975 • Promoting Research and Development: Encouraging the use of cyclotrons for both medical and  
976 scientific research in Africa is essential for advancing fields such as nuclear physics, materials science,  
977 and environmental research. Collaborative international research projects could boost the scientific  
978 capabilities of African cyclotron facilities, making them more attractive for global research initiatives.

## 979 3.10 Energy Recovery Linacs: A Pathway for Sustainable Particle 980 Accelerators in Africa

### 981 3.10.1 Introduction and Motivation

982 Energy Recovery Linacs (ERLs) represent a transformative technology in the field of accelerator science,  
983 offering unparalleled energy efficiency, high beam quality, and the potential for sustainable operation.  
984 Globally, ERLs have demonstrated their ability to address diverse challenges in particle physics, materials  
985 science, and medical applications [29]. However, their adoption remains limited in regions lacking the  
986 infrastructure and expertise needed to develop advanced accelerator facilities.

987 Africa, despite its growing contributions to global science, faces significant barriers to building a robust  
988 accelerator science ecosystem. The absence of dedicated accelerator divisions and research facilities has  
989 hindered the development of cutting-edge technologies such as ERLs. Yet, this challenge presents an  
990 opportunity: by leveraging international collaborations and focusing on sustainable technologies like ERLs,  
991 Africa can lay the foundation for a future of self-sufficient and impactful accelerator research.

992 This section explores the motivation for pursuing ERL technologies in Africa. It highlights their potential to  
993 address pressing regional needs such as advancing healthcare diagnostics, supporting industrial innovation,  
994 and fostering scientific collaboration while providing a pathway for building capacity and expertise in  
995 accelerator science. By integrating ERLs into Africa’s scientific roadmap, the region can align with global  
996 trends, contributing to and benefiting from advancements in accelerator technology.

### 997 3.10.2 History

998 The concept of an energy-recovery linac (ERL) was first proposed by Maury Tigner in 1965 , as a way to  
999 enhance the current in a collider for high-energy physics [30]. Traditional methods, where two beams are  
1000 accelerated, collided, and then discarded, were highly inefficient. Tigner suggested recovering the energy

1001 of the beams using the same cavities that accelerated them, significantly improving machine efficiency and  
1002 simplifying the design of the beam dump. However, implementing this idea required the development of  
1003 reliable superconducting RF (SRF) accelerating cavities, which advanced over the following decade. The  
1004 first major application of SRF cavities occurred at the High Energy Physics Lab at Stanford University,  
1005 where researchers introduced a recirculation loop capable of varying the path length. This allowed electrons to  
1006 either be accelerated or decelerated during a second pass through the cavities both processes were successfully  
1007 demonstrated [32]. This marked the first ERL with SRF cavities , referred to as "same-cell energy recovery".  
1008 Although the beam was neither used for experiments nor operated in continuous mode, energy recovery was  
1009 clearly observed in the RF power requirements during the beam pulses.

### 1010 3.10.3 The Role of ERLs in Africa's Research Landscape

1011 Energy Recovery Linacs (ERLs) offer a transformative opportunity to address Africa's research challenges  
1012 by providing energy-efficient, compact accelerator systems suited for diverse applications. These systems  
1013 can drive advancements in synchrotron-based research for materials science, drug development, and energy  
1014 technologies, while also enabling medical imaging and nondestructive testing in industrial applications. The  
1015 sustainability and cost-efficiency of ERLs make them a practical choice for regions with limited resources, of-  
1016 fering a pathway to align with global trends in environmentally conscious scientific infrastructure. Moreover,  
1017 integrating ERLs into Africa's research landscape can foster capacity-building through training programs  
1018 and collaborations with global institutions, such as CERN or Cornell University, creating a new generation  
1019 of accelerator physicists and engineers. This development can bridge the gap between fundamental and  
1020 applied sciences, enabling Africa to contribute to global accelerator projects and establish a leadership role  
1021 in sustainable accelerator technology. By prioritizing ERLs, Africa can simultaneously address pressing  
1022 regional needs and lay the groundwork for a self-sufficient and impactful research ecosystem.

### 1023 3.10.4 Challenges and Opportunities in Adopting ERLs

1024 The adoption of Energy Recovery Linacs (ERLs) in Africa presents both significant challenges and exciting  
1025 opportunities. One of the primary challenges is the lack of existing infrastructure and technical expertise in  
1026 accelerator science. Building ERL facilities requires specialized knowledge in superconducting technology,  
1027 high-gradient RF structures, and beam dynamics, which are currently limited in many African countries.  
1028 Additionally, the high initial costs of setting up such advanced technologies, along with the need for  
1029 ongoing operational support, pose financial barriers. Moreover, there is a need for specialized facilities  
1030 and laboratories, which require substantial investment in research and development (R&D), as well as in  
1031 training personnel capable of designing, operating, and maintaining ERL systems.

1032 However, these challenges also create significant opportunities for Africa. The development of ERLs offers  
1033 the potential for leapfrogging traditional accelerator technologies, providing a more energy-efficient and cost-  
1034 effective solution for scientific research and applications. By starting with compact ERL systems, Africa can  
1035 focus on smaller, more manageable projects that can serve as a foundation for future growth. The long-  
1036 term benefits of adopting ERLs include reduced energy consumption, the ability to support a wide range of  
1037 scientific applications, and the creation of high-tech job opportunities in accelerator physics and engineering.  
1038 Furthermore, international collaboration with established ERL research centers could facilitate technology  
1039 transfer and knowledge sharing, helping to overcome the resource and expertise gaps. As the global demand  
1040 for sustainable accelerator technologies increases, Africa's involvement in ERL development could position

1041 the continent as a key player in the future of accelerator science, with the potential for both local impact  
1042 and global collaboration.

### 1043 **3.10.5 R&D Objectives and Capacity Building**

1044 To successfully adopt Energy Recovery Linac (ERL) technology in Africa, focused research and development  
1045 (R&D) objectives must be established alongside capacity-building initiatives. The primary R&D objectives  
1046 for ERL adoption include developing cost-effective, energy-efficient accelerator systems tailored to Africa's  
1047 specific scientific and technological needs. These systems should prioritize sustainability, with a focus on  
1048 reducing operational energy consumption and integrating renewable energy sources, making ERLs ideal for  
1049 the continent's infrastructure challenges. Additionally, advancing key areas such as high-gradient RF struc-  
1050 tures, superconducting materials, and beam dynamics will be critical to ensuring the long-term performance  
1051 and reliability of ERLs in diverse applications.

1052 Simultaneously, capacity building must be at the core of ERL adoption in Africa. This includes training  
1053 the next generation of accelerator physicists and engineers through specialized programs, workshops, and  
1054 collaborations with established global ERL research centers. Building local expertise will not only support  
1055 the development and operation of ERLs but also foster innovation in accelerator science. Partnerships  
1056 with institutions like CERN, Jefferson Lab, and Cornell University could play a vital role in facilitating  
1057 knowledge transfer, providing hands-on training, and supporting the establishment of research hubs in  
1058 Africa. Furthermore, creating educational pathways, such as graduate programs and internships focused on  
1059 accelerator physics, will be essential in developing a skilled workforce capable of supporting ERL projects.  
1060 The R&D efforts should also involve collaborative projects with industry to ensure that the technologies  
1061 developed are commercially viable and can be scaled to meet local needs. Through these initiatives, Africa  
1062 can create a robust scientific and technical foundation for the successful integration of ERLs, driving both  
1063 regional and global advancements in accelerator technology.

### 1064 **3.10.6 Potential Applications of ERLs in Africa**

1065 Energy Recovery Linacs (ERLs) offer a wide range of potential applications that could significantly impact  
1066 various sectors in Africa, driving both scientific progress and socio-economic development. One of the  
1067 most promising applications is in medical imaging and radiotherapy. ERLs can provide high-quality electron  
1068 beams for advanced imaging techniques such as X-ray and CT scans, potentially improving healthcare access  
1069 and diagnostics in underserved regions. The high beam quality of ERLs also makes them ideal for precise  
1070 cancer treatments, offering a non-invasive, highly effective method for radiation therapy, which could enhance  
1071 medical capabilities across Africa's growing healthcare sector.

1072 In materials science, ERLs could enable the development of advanced synchrotron light sources. These light  
1073 sources are crucial for the analysis of materials at the atomic level, supporting innovations in industries  
1074 such as energy storage, nanotechnology, and environmental science. By establishing regional synchrotron  
1075 facilities powered by ERLs, African researchers could contribute to the global effort to develop more efficient  
1076 batteries, renewable energy technologies, and environmentally friendly materials, fostering economic growth  
1077 and technological independence.

1078 ERLs could also play a significant role in industrial applications, such as non-destructive testing of materials,  
1079 which is essential for sectors like mining, construction, and manufacturing. The precision of ERL-driven

1080 electron beams can be used to detect structural weaknesses and improve quality control without damaging  
1081 the materials. This application is particularly valuable in Africa, where industries such as mining and in-  
1082 frastructure development are rapidly growing, and where cost-effective, reliable testing methods are essential  
1083 for ensuring safety and durability.

1084 Finally, ERLs could serve as a foundation for training and education in accelerator physics, enabling the  
1085 development of a highly skilled workforce. Establishing ERL facilities could serve as a hub for knowledge  
1086 exchange, attracting students and researchers from across Africa and beyond. These facilities would not only  
1087 enhance scientific capacity but also create opportunities for international collaboration, positioning Africa  
1088 as a key player in the global accelerator science community. Through these diverse applications, ERLs can  
1089 drive innovation, improve public health, and support sustainable economic development across the continent.

### 1090 3.10.7 Collaboration and Implementation Roadmap

1091 The successful adoption and implementation of Energy Recovery Linacs (ERLs) in Africa will require a  
1092 coordinated approach that integrates local, regional, and international efforts. A robust collaboration  
1093 framework is essential to overcome the challenges of limited infrastructure and expertise, while also ensuring  
1094 that the benefits of ERL technology are realized across multiple sectors. This roadmap outlines key steps for  
1095 fostering partnerships, guiding the phased implementation of ERL projects, and ensuring sustainable growth  
1096 in Africa's accelerator research landscape.

- 1097 • **Building International Partnerships:** Collaboration with established global ERL research centers,  
1098 such as CERN, the Thomas Jefferson National Accelerator Facility (TJNAF), and Cornell University,  
1099 will be pivotal for technology transfer and knowledge sharing. These institutions can offer both  
1100 technical expertise and training programs, facilitating the development of local competencies in ac-  
1101 celerator science. International partnerships will also enable access to shared resources, joint research  
1102 projects, and participation in global accelerator initiatives. Strategic alliances with countries that  
1103 have successfully developed ERLs will provide critical insights and guidance, ensuring that Africa can  
1104 leapfrog some of the early-stage challenges faced by other regions.
- 1105 • **Developing Local Collaborations:** Collaboration among African nations will be key to maximizing  
1106 the impact of ERL technology. The establishment of regional research consortia, involving universities,  
1107 national laboratories, and industrial partners, will allow for pooling of resources, talent, and expertise.  
1108 These consortia can spearhead the design, development, and operation of small-scale ERL demonstra-  
1109 tors, serving as training hubs and pilot projects for larger facilities in the future. Additionally, local  
1110 industries and stakeholders, such as those in the healthcare, energy, and materials sectors, should be  
1111 engaged early in the process to identify specific applications for ERL technology and ensure that the  
1112 resulting infrastructure meets regional needs.
- 1113 • **Phased Implementation Approach:** The roadmap for ERL implementation in Africa should follow  
1114 a phased approach, starting with the establishment of small-scale ERL prototypes and progressing  
1115 towards larger, more complex facilities. In the initial phase, the focus should be on building the tech-  
1116 nical capacity needed to design and operate ERLs, including the development of laboratory space, the  
1117 acquisition of key components, and the training of local staff. This phase could also involve establishing  
1118 collaborations with international partners to create a knowledge-sharing platform, such as workshops  
1119 and joint research projects, aimed at building a sustainable ERL ecosystem in Africa. The next phase  
1120 should focus on scaling up to pilot facilities capable of supporting applications in materials science,  
1121 medical imaging, and industrial testing. These facilities would serve as a demonstration of ERL's

1122 potential impact and would help attract further investment and collaboration. The final phase would  
1123 involve the establishment of full-scale ERL-based research centers with broader applications, including  
1124 synchrotron light sources, particle physics research, and advanced medical facilities. These centers  
1125 would be integrated into the global scientific community, contributing to collaborative international  
1126 research and ensuring long-term sustainability.

- 1127 • **Resource Mobilization and Funding:** Securing adequate funding for the development and oper-  
1128 ation of ERL facilities will require a combination of national, regional, and international investment.  
1129 Governments should recognize the long-term value of ERL technology for scientific and economic  
1130 development, and prioritize funding for accelerator research as part of broader science and technology  
1131 initiatives. International funding agencies, such as the African Union, the United Nations, and the  
1132 European Union, can play an important role in supporting the establishment of ERL infrastructure  
1133 through collaborative research grants and joint programs. Additionally, private sector involvement,  
1134 particularly from industries that would benefit from ERL technology, should be explored to ensure a  
1135 diverse and sustainable funding base.

1136 Through strategic collaboration, phased implementation, and resource mobilization, Africa can overcome  
1137 existing barriers and lay the groundwork for a thriving accelerator research ecosystem powered by ERLs.  
1138 This roadmap will enable the continent to not only benefit from the global advancements in accelerator  
1139 technology but also contribute meaningfully to the future of sustainable science and technology.

#### 1140 3.10.8 Towards a Sustainable Future

1141 The development and adoption of Energy Recovery Linacs (ERLs) in Africa represents a significant step  
1142 toward building a sustainable and self-sufficient research infrastructure. As the global scientific community  
1143 increasingly prioritizes sustainability, ERLs offer a promising pathway for Africa to address its unique  
1144 challenges while contributing to international efforts to reduce the environmental impact of large-scale  
1145 research facilities. By leveraging the inherent energy efficiency of ERLs, Africa can establish accelerator-  
1146 based technologies that not only drive scientific progress but also align with global sustainability goals.

1147 ERLs are particularly well-suited for Africa's needs due to their energy-efficient design, which recycles the  
1148 energy from electron beams, significantly reducing operational energy consumption compared to traditional  
1149 linear accelerators. This characteristic makes ERLs an ideal technology for regions with limited energy  
1150 resources or those seeking to minimize the environmental footprint of scientific infrastructure. By integrating  
1151 renewable energy sources into ERL operations, such as solar or wind power, Africa can further enhance the  
1152 sustainability of these systems, making them resilient to energy supply challenges.

1153 In addition to their energy efficiency, ERLs can contribute to Africa's sustainable development by supporting  
1154 applications that address critical regional needs. For example, ERL-driven synchrotron light sources can aid  
1155 in the development of cleaner energy technologies, such as more efficient solar cells or advanced materials  
1156 for energy storage, directly contributing to Africa's transition to renewable energy. Similarly, ERLs used  
1157 in medical imaging and radiation therapy can improve healthcare outcomes across the continent, providing  
1158 access to state-of-the-art technologies without the high operational costs typically associated with traditional  
1159 accelerators.

1160 The sustainable impact of ERLs in Africa will also extend beyond energy and health. By fostering local  
1161 expertise in accelerator technology and creating a skilled workforce, ERL projects will generate long-  
1162 term educational and economic opportunities, helping to build a knowledge-based economy. International

1163 collaborations, knowledge-sharing platforms, and the establishment of regional research hubs will ensure that  
1164 ERLs serve as a catalyst for broader innovation and scientific advancement across the continent.

1165 Ultimately, the adoption of ERLs in Africa has the potential to create a sustainable and forward-looking  
1166 accelerator science ecosystem that addresses both local and global challenges. By embracing this technology,  
1167 Africa can contribute to the global pursuit of sustainable, energy-efficient research infrastructure while  
1168 building a foundation for scientific and technological leadership in the 21<sup>st</sup> century.

### 1169 3.11 Recommendations

1170 To ensure sustainable progress in accelerator physics in Africa, we propose the following key recommenda-  
1171 tions:

- 1172 • **Strengthening Research Networks and Consortia:** It is crucial to establish pan-African research  
1173 consortia dedicated to accelerator physics (see Section 3.5). These networks should facilitate collabora-  
1174 tion between African institutions, pooling resources, expertise, and infrastructure. Such consortia  
1175 can also act as a platform for engaging with global partners, securing funding, and coordinating large-  
1176 scale research initiatives. By including Africa’s needs in international conferences, we can amplify  
1177 the importance of developing accelerator physics on the continent. For instance, during the recent  
1178 EuPRAXiA PP Annual Meeting in Italy, the mission of the African School of Physics was presented,  
1179 followed by a roundtable discussion pointing out that the number of accelerator physicists in Africa is  
1180 critically low, stressing the urgent need to train more in order to benefit from their expertise in the  
1181 future [33]. The mission had also been presented earlier in April 2024 during the 3rd Accelerator Days  
1182 (TERZA Giornata Acceleratori) at the Frascati National Labs of INFN [34], which inspired the idea  
1183 of including more outreach activities in conferences like EuPRAXiA and inviting members of the IOC  
1184 to strengthen the relationship between INFN and ASP.
- 1185 • **Creating Structured Training Programs:** Governments, universities, and research centers should  
1186 prioritize the creation of structured educational programs like Ph.D positions focused on accelerator  
1187 physics. This includes developing graduate programs, certification courses, and specialized training  
1188 sessions. Additionally, expanding opportunities for African students and professionals to receive  
1189 training abroad, through scholarships and exchange programs, will help in skill-building and knowledge  
1190 transfer.
- 1191 • **Expanding Public and Private Sector Funding:** A strong push for increasing financial support  
1192 from both the public and private sectors is needed. Governments should recognize the strategic  
1193 importance of accelerator physics in driving scientific and technological innovation, and allocate more  
1194 resources to research and development in this field. Partnerships with industry could also be leveraged  
1195 to attract private investments in accelerator-related technologies, particularly those with commercial  
1196 potential, such as medical accelerators or renewable energy applications.
- 1197 • **Enhancing Digital Infrastructure and Access to Computational Tools:** With many accelerator  
1198 physics experiments requiring advanced simulation software and computational tools, it is important  
1199 to ensure that African institutions have access to the necessary digital infrastructure. This includes  
1200 high-performance computing facilities and access to software platforms such as CAIN, WHIZARD, and  
1201 others. Support for training researchers in using these tools effectively should also be prioritized.
- 1202 • **Encouraging Knowledge Dissemination and Scientific Publications:** It is essential to promote  
1203 knowledge sharing within the African accelerator physics community and beyond. Initiatives should

be developed to encourage researchers to publish their work in peer-reviewed journals, participate in international conferences, and contribute to open-access platforms. Creating an African accelerator physics journal or repository could further enhance visibility and collaboration in this field.

- **Long-term Strategic Planning:** Governments and research institutions should formulate long-term strategic plans to guide the growth of accelerator physics in Africa. This could include roadmaps for infrastructure development, timelines for achieving specific research goals, and frameworks for integrating accelerator technologies into national priorities, such as healthcare, energy, and education.
- **Encourage Policy Support for Accelerator Research:** Policy frameworks that support the growth of accelerator science and technology in Africa should be established at the national and regional levels. Governments should create policies that promote investment in R&D, facilitate international partnerships, and provide incentives for private sector involvement. By recognizing the strategic importance of accelerators in advancing science and technology, policymakers can create an enabling environment for innovation and ensure the long-term success of ERL projects. Furthermore, policies that encourage the use of ERLs in various sectors, including healthcare, materials science, and industrial applications, will ensure that the technology has a broad and lasting impact.
- **Promote Sustainability in ERL Design and Operation:** Given Africa's unique environmental and energy challenges, sustainability should be a central consideration in the design and operation of ERL facilities. The integration of renewable energy sources, such as solar and wind, should be explored to power ERL operations, reducing their environmental footprint and enhancing their resilience to energy shortages. Additionally, energy-efficient technologies, including those for cooling, power supply, and waste heat recovery, should be prioritized in the development of ERL systems. By focusing on sustainability, Africa can position itself as a leader in environmentally responsible accelerator technology and contribute to global efforts to reduce the carbon footprint of scientific infrastructure.

By following these recommendations, African nations can build the necessary infrastructure, expertise, and partnerships to harness the full potential of an accelerator division, advancing not only scientific research but also economic and social development. With careful planning, international collaboration, and a focus on sustainability, ERLs can become a cornerstone of Africa's future in science and technology.

## 3.12 Preliminary Results of the ASFAP Survey on Accelerator Physics

### 3.12.1 Educational Background and Awareness

The survey revealed significant gaps in the educational exposure of African students and researchers to accelerator physics. In Fig.3-6, only 46.3% of respondents had accelerator physics or technology included in their academic curriculum, and 53.7% were unfamiliar with fundamental accelerator concepts. These results highlight the urgent need for integrating accelerator-related topics into undergraduate and graduate programs across Africa.

Moreover, 57.1% of respondents were unaware of existing accelerator facilities in Africa. Among those familiar, 69% cited iThemba LABS in South Africa, indicating the limited recognition of existing resources. These findings point to the need for awareness campaigns to showcase the relevance of accelerators and their applications in various fields.

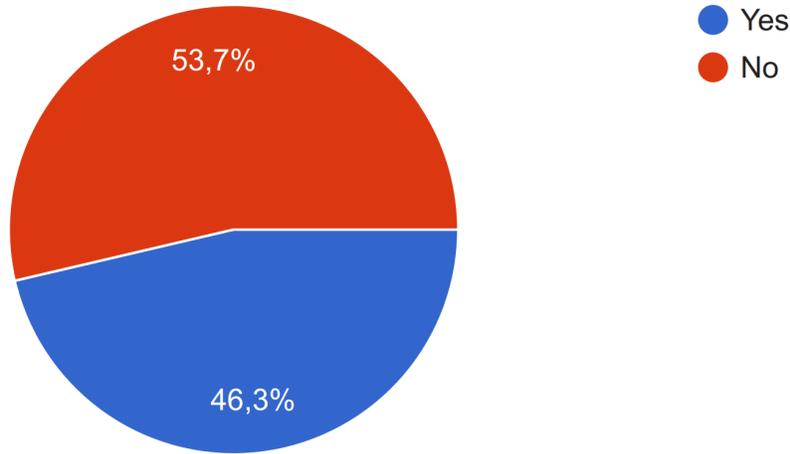


Figure 3-6: Inclusion of Accelerator Physics or Technology in Academic Curricula

### 1243 3.12.2 Aspirations for Accelerator Physics Development

1244 The survey highlighted widespread support for developing accelerator divisions in Africa, with 88.1% of  
1245 respondents expressing the belief that such divisions are necessary (see Fig. 3-7). Furthermore, Fig. 3-8  
1246 shows that 77.4% strongly agreed that the establishment of accelerator facilities would significantly enhance  
1247 research opportunities on the continent.

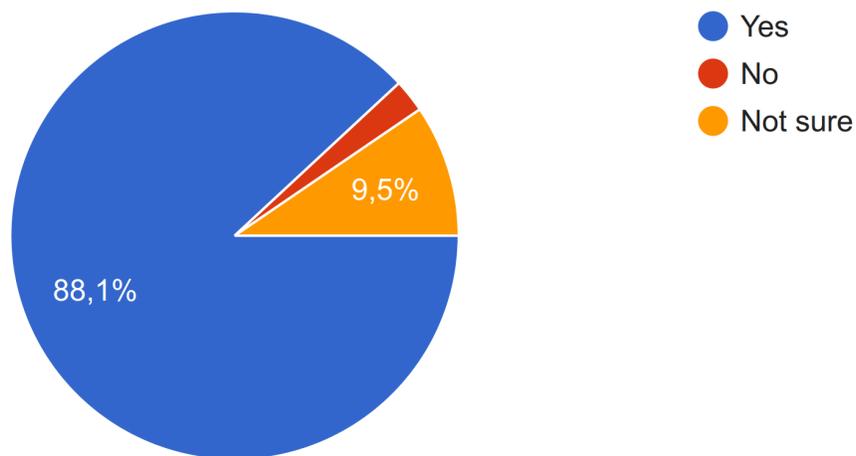


Figure 3-7: Perception of the Need for Accelerator Divisions in Africa

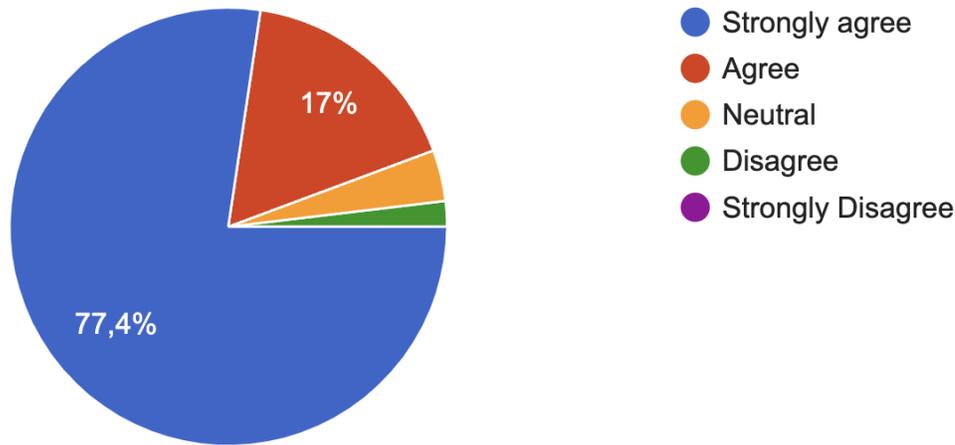


Figure 3-8: Impact of Accelerator Facilities on Scientific Research Opportunities in Africa

1248 Respondents also identified compact accelerator technologies as a promising starting point for Africa. 92.3%  
 1249 viewed compact accelerators favorably, emphasizing their cost-effectiveness and accessibility compared to  
 1250 larger facilities. These preliminary results suggest a clear interest and readiness within the African scientific  
 1251 community to embrace accelerator technology.

### 1252 3.12.3 Barriers to Progress

1253 Respondents identified several key challenges to establishing accelerator divisions in Africa:

- 1254 • Lack of funding: Identified by 64.3%, this was the most significant barrier.
- 1255 • Insufficient expertise: Highlighted by 57.1%, this reflects the need for more trained professionals.
- 1256 • Limited education and training opportunities: Reported by 57.1% of participants.
- 1257 • Political and logistical obstacles: A lack of political will and infrastructural support further compounds  
 1258 the difficulty of establishing such facilities.

1259 These barriers underscore the need for focused strategies to address funding, skills development, and infras-  
 1260 tructure deficits.

### 1261 3.12.4 Potential Solutions and Strategies

1262 Participants proposed several actionable strategies to overcome these challenges:

- 1263 • Increasing funding through international partnerships: Supported by 78.6% of the respondents.
- 1264 • Strengthening regional and global collaborations: Highlighted by 57.1%.
- 1265 • Developing smaller, cost-effective facilities (e.g., compact light sources (CLS): Suggested by 54.8% as  
1266 a practical entry point for Africa.

1267 Respondents also emphasized the importance of capacity building through training programs and the in-  
1268 volvement of the African diaspora. In particular, 57.5% expressed willingness to return to Africa to work  
1269 in accelerator divisions if opportunities arise, providing a strong basis for diaspora participation initiatives.

### 1270 3.13 Conclusion and perspectives

1271 Although accelerator physics in Africa may not be as developed as in some other regions, there is a growing  
1272 recognition of its importance for scientific research and technological advancement, leading to increased  
1273 investment and collaboration in this field across the continent. Africa's accelerating interest stems from a  
1274 collective understanding of the transformative potential that accelerator-based facilities offer across diverse  
1275 scientific domains. This burgeoning acknowledgment has spurred a notable uptick in investment and  
1276 collaboration within the accelerator physics realm throughout Africa.

1277 This momentum is not merely confined to the establishment of accelerator facilities but encompasses a  
1278 broader spectrum of initiatives aimed at nurturing indigenous expertise, fostering collaborative networks, and  
1279 leveraging international partnerships. Through strategic capacity-building programs, educational outreach  
1280 endeavors, and knowledge exchange platforms, African countries are actively cultivating a skilled workforce  
1281 capable of driving accelerator-based research forward.

1282 Moreover, the increasing integration of accelerator physics into national scientific agendas reflects a broader  
1283 commitment to harnessing science and technology for sustainable development objectives. By leveraging  
1284 accelerator-based tools, such as synchrotron radiation facilities and particle accelerators, African nations are  
1285 poised to address pressing societal challenges, ranging from healthcare and materials science to environmental  
1286 conservation and renewable energy.

1287 In essence, while accelerator physics in Africa may currently be in a nascent stage compared to its counter-  
1288 parts in more developed regions, the trajectory is undeniably upward. As investment and collaboration  
1289 continue to amplify, Africa's accelerator physics community is poised to make increasingly substantial  
1290 contributions to global scientific discourse, innovation, and societal well-being, solidifying its place on the  
1291 international stage of scientific endeavor.

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## 1378 4.1 Abstract

1379 This report summarises the current status, challenges, recommendations, and future needs of Astronomy in  
1380 Africa, developed within the framework of the Astrophysics and Cosmology Working Group (WG) of the  
1381 African Strategy for Fundamental and Applied Physics (ASFAP). It provides a brief introduction to the  
1382 developments in astronomy in Africa over the past ten years, showing that astronomy is one of the emerging  
1383 fields of science on the continent, and the importance of astronomy for socio-economic and environmental  
1384 development, in line with the United Nations Sustainable Development Goals (SDGs). It provides a list of  
1385 challenges facing the professional community and a list of recommendations for policy and decision-makers.  
1386 Finally, it describes the highest priority future needs and plans in line with the Letters of Interest received  
1387 and general activities.

## 1388 4.2 Introduction and motivation

1389 Astronomy is currently one of the emerging scientific fields in Africa. This can be seen through  
1390 different activities, from institutional development, strong infrastructure development with new observatories  
1391 and site testing, human capacity building through new postgraduate programmes and training, research and

1392 publications, the creation of professional societies and networks, to the growth of outreach activities, amateur  
 1393 astronomical societies, and increased political engagement. Moreover, astronomy is an important tool for  
 1394 socio-economic and environmental development and, as such, can be used to combat poverty in Africa and  
 1395 globally and to reduce inequalities between countries.

#### 1396 4.2.1 Current status of astronomy in Africa: brief summary

1397 The last ten to twenty years have seen a strong institutional development in astronomy, with the  
 1398 creation of numerous space agencies, research centres, and astronomy departments within universities.  
 1399 Some examples include, among others: Algeria with the launch of the Algerian Space Agency (ASAL)  
 1400 in 2002, Angola with the establishment of the National Space Programme Management Office (GGPEN) in  
 1401 2010, Botswana with the establishment of astronomy research and infrastructure under the new Botswana  
 1402 International University of Science and Technology (BIUST) in 2006, Egypt with the establishment of  
 1403 the Egyptian Space Agency (EgSA) in 2018 and the strengthening of the National Research Institute for  
 1404 Astronomy and Geophysics (NRIAG), Ethiopia with the establishment of the former Ethiopian Space Science  
 1405 and Technology Institute (ESSTI) in 2016, now the Space Science and Geospatial Institute (SSGI), and the  
 1406 Entoto Observatory (see below), Gabon with the Agency for Space Studies and Observation (AGEOS) since  
 1407 2010, Ghana with the launch of the Ghana Space Science and Technology Institute (GSSTI) in 2012 and  
 1408 the Ghana Radio Observatory (see below), Kenya with the launch of the Kenya Space Agency (KSA) in  
 1409 2017, Morocco with the strong development of the Oukaimeden Observatory (see below) since 2007, Nigeria  
 1410 with the strengthening of the Centre for Basic Space Sciences (CBSS) and the strong development of the  
 1411 National Space Research and Development Agency (NASRDA) since 1999, Rwanda with the launch of the  
 1412 Rwandan Space Agency (RSA) in 2020, South Africa with multiple strong institutional developments, such  
 1413 as the South African Radio Astronomical Observatory (SARAO, see below), the South African Astronomical  
 1414 Observatory (SAAO, see below) and the South African National Space Agency (SANSA) since 2010, Sudan  
 1415 with the launch of the Institute for Space and Aerospace Research (ISRA) in 2013, Zimbabwe with the  
 1416 launch of the Zimbabwe National Geospatial and Space Agency (ZINGSA) in 2019, etc. [8]. In the African  
 1417 Union (AU) Science, Technology and Innovation (STI) strategy and the Common African Position (CAP) on  
 1418 the Post-2015 Development Agenda, astronomy and space science have been selected as some of the priority  
 1419 fields for achieving the goals of the development agenda. Taking into account the importance of astronomy  
 1420 and space science, the AU established in 2018 the first African Space Agency based in Egypt and developed  
 1421 the first African Space Strategy [1].  
 1422

1423 The development of infrastructure with new observatories and the construction of new telescopes,  
 1424 including site testing, has also been remarkable, growing from small to some of the largest telescopes in the  
 1425 world. Figure 4-1 (central map) shows some of the existing and future telescopes and observatories in radio,  
 1426 optical and gamma-rays.

1427 In radio astronomy, the Square Kilometre Array (SKA)<sup>1</sup>, one of the most ambitious scientific projects  
 1428 of the 21st century that aims to reproduce the entire radio universe since the Big Bang, together with the  
 1429 African Very Long Baseline Interferometry (VLBI) Network (AVN)<sup>2</sup> are some of the major initiatives in  
 1430 Africa, with South Africa being the main host of the SKA in partnership with Botswana, Ghana, Kenya,  
 1431 Madagascar, Mauritius, Mozambique, Namibia and Zambia. All these countries signed a memorandum of  
 1432 understanding in 2019 to work together to develop SKA and radio astronomy. As part of this collaboration,  
 1433 Ghana was the first country to convert the former telecommunication dish antenna into a radio telescope and

<sup>1</sup><https://www.skatelescope.org/africa/>

<sup>2</sup><https://www.sarao.ac.za/science/avn>

1434 established Ghana's first Radio Observatory at Kuntunse in 2017. The MeerKAT<sup>3</sup> radio interferometer, the  
1435 precursor to the African SKA, with 64 dishes located in South Africa in the Karoo Desert, became operational  
1436 in 2018 and is currently producing some of the best and most detailed radio data in the Universe. With  
1437 participation in the SKA, the South African SKA and the HartRAO Observatory joined forces in creating  
1438 SARAO. In addition, South Africa is working on the Hydrogen Intensity and Real-time Analysis eXperiment  
1439 (HIRAX)<sup>4</sup> radio interferometer. Namibia is currently building the African Millimetre Telescope (AMT [2, 3]),  
1440 the first millimetre-wave radio telescope on the African continent, as part of the European Research Council  
1441 (ERC) Synergy Grant named 'BlackHolic' obtained in collaboration with Finland, the Netherlands and  
1442 the United Kingdom. Once completed, the AMT will join the global telescope network of the Event Horizon  
1443 Telescope (EHT) project, which aims to observe and study supermassive black holes at the centres of galaxies  
1444 [5, 6]. Other countries are developing radio astronomy infrastructures, such as Nigeria, and/or testing sites,  
1445 such as Tanzania, to establish small dishes in the near future and join some of the international networks,  
1446 such as the EHT. All the radio telescopes mentioned are part of large international collaborations.

1447 In optical astronomy, South Africa hosts the 11 m South African Large Telescope (SALT)<sup>5</sup> and more  
1448 than 15 smaller optical telescopes at the South African Astronomical Observatory (SAAO)<sup>6</sup> in collaboration  
1449 with different countries. SALT is currently the largest optical telescope in the world, offering the possibility  
1450 to obtain various types of photometric, spectroscopic and polarimetric data, including near-infrared (NIR)  
1451 and optical integral field spectroscopy with the two newly developed instruments. Morocco also established  
1452 through different international collaborations several small telescopes at the Oukaïmeden Observatory<sup>7</sup> that  
1453 are effectively used for observations of small bodies, extrasolar planets, stars, nearby galaxies, and space  
1454 debris [4]. This includes the TRAPPIST-North 60cm telescope that is actively used in the detection of  
1455 extrasolar planets. Small optical telescopes (approx. up to 2 m) have also been installed in several other  
1456 countries and/or are in the process of being established soon, such as in Algeria with the old Bouzaréah  
1457 Observatory, Burkina Faso with intentions to install the 1m Marly optical telescope (a project that has been  
1458 affected by political instability and conflict), Egypt with the Kottamia Astronomical Observatory (KAO),  
1459 Ethiopia with the twin 1 m telescopes at the Entoto Observatory (see [8] for more information), and Namibia  
1460 with the re-establishment of the ROTSE telescope. All these facilities in optical, aim to create in the future  
1461 a network of connected robotic observatories called the African Integrated Observing System (AIOS), to  
1462 strengthen continental and international collaborations and research in optical astronomy and make better  
1463 use of small telescopes. In addition, several countries are conducting site testing to build optical telescopes  
1464 in the future. These include Algeria, in collaboration with the European Virgo consortia, Egypt, to establish  
1465 the 4-6 m Egyptian Large Optical Telescope, Ethiopia, to establish a 3-4 m telescope, and Kenya, to build a  
1466 small telescope in collaboration with the United Kingdom.

1467 Finally, in gamma-rays, Namibia hosts, in collaboration with Germany, the High Energy Stereoscopic  
1468 System (H.E.S.S.)<sup>8</sup> Cherenkov telescope for the study of cosmic gamma rays, and there are also research  
1469 groups (in particular in South Africa and Namibia) involved in the development of the next-generation  
1470 Cherenkov Telescope Array (CTA).  
1471

1472 New postgraduate programmes (masters and PhD) in astronomy and astrophysics increased across  
1473 the continent in the last 10-15 years, as well as the number of professional astronomers (e.g., in Algeria,  
1474 Botswana, Burkina Faso, Cote d'Ivoire, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Mauritius,  
1475 Morocco, Namibia, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tunisia, Uganda, Zambia, Zimbabwe,  
1476 etc.). This brought a strong development in astronomy research across the continent (e.g., the number

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<sup>3</sup><https://www.sarao.ac.za/science/meerkat/>

<sup>4</sup><https://hirax.ukzn.ac.za>

<sup>5</sup><https://www.salt.ac.za/>

<sup>6</sup><https://www.saa.ac.za/>

<sup>7</sup><http://moss-observatory.org/>

<sup>8</sup><https://www.mpi-hd.mpg.de/hfm/HESS>

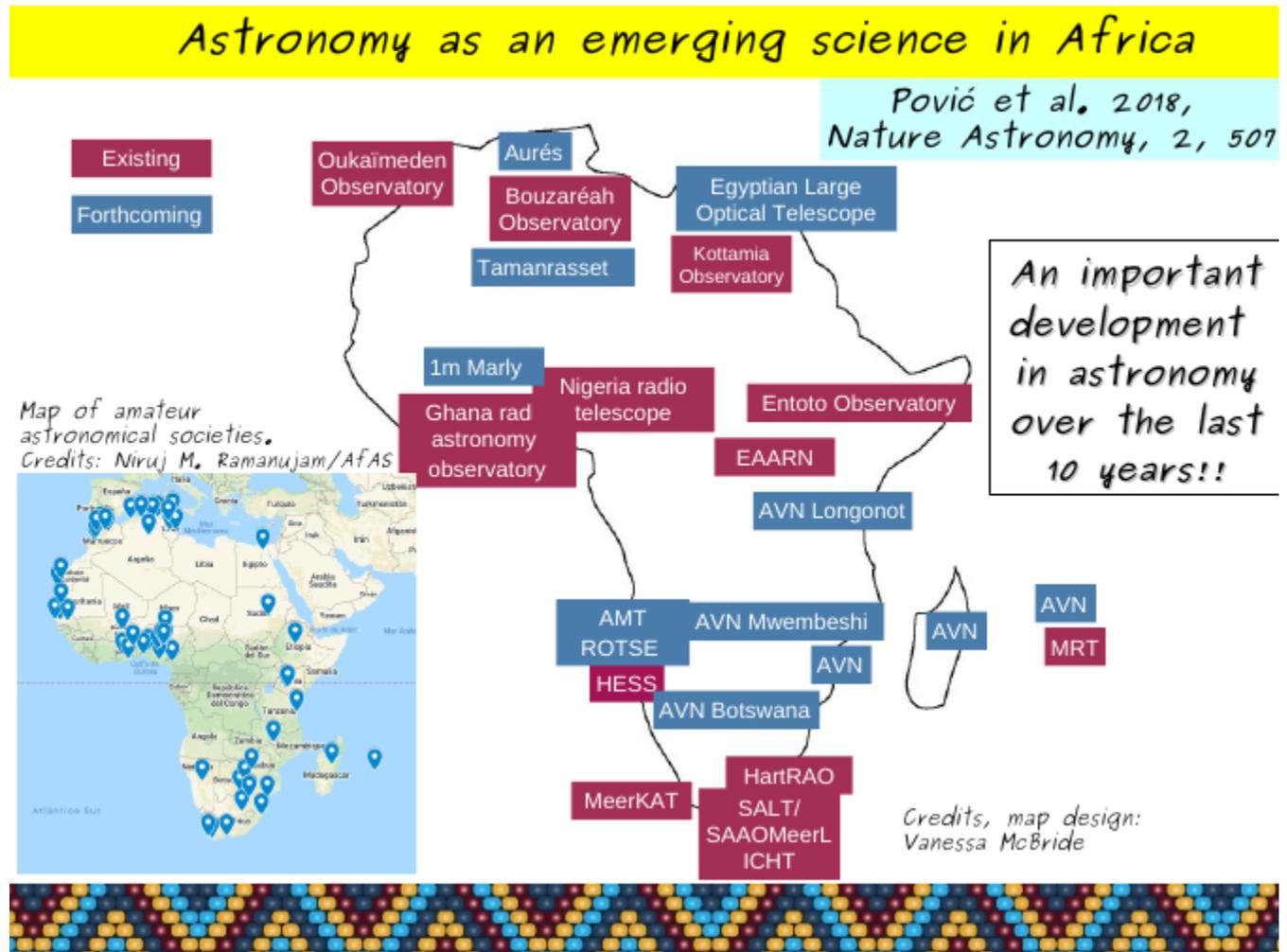


Figure 4-1: Central map: Existing and forthcoming telescopes and observatories in optical, radio, and gamma-rays, produced by Vanessa McBride using the data from Ref. [8]. Left bottom map: Amateur astronomical societies in Africa produced by the Niruj M. Ramanujam, under the African Astronomical Society (AfAS).

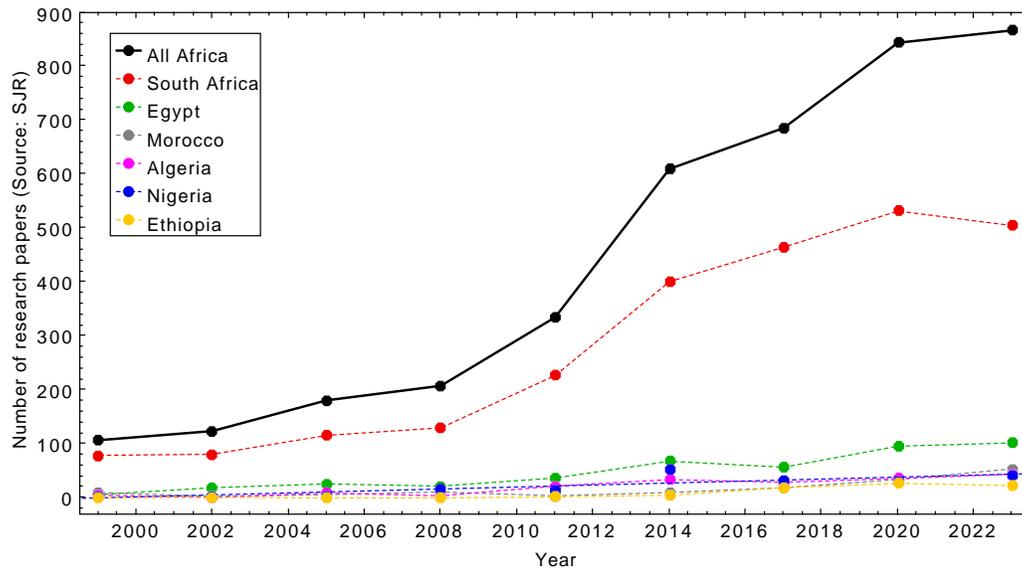


Figure 4-2: Number of publications in astronomy and astrophysics in the last 25 years in all African countries (black), and in six countries with the highest number of published research papers. These are South Africa (red), Egypt (green), Morocco (grey), Algeria (pink), Nigeria (blue) and Ethiopia (yellow). The data were obtained from the Scimago Journal Country Rank (SJR).

1477 of published research papers tripled from 2011 to 2021; source SRJ-Scimago Journal and Country Rank).  
 1478 Figure 4-2 shows the increase in the number of refereed publications in astronomy and astrophysics in Africa  
 1479 (in black) over the last 25 years and the six countries with the highest number of published research papers.  
 1480 South Africa is the leading contributor to astronomy and astrophysics research, followed by Egypt. In  
 1481 all cases, it can be seen that there has been a strong development in research since 2010. Currently, all  
 1482 fields of astronomy research are present on the continent. This can also be seen in Figure 4-3, which was  
 1483 obtained as a result of a survey conducted within the ASFAP Astrophysics and Cosmology WG with 130  
 1484 professional astronomers from 20 countries in Africa, who expressed their professional interests in different  
 1485 fields of astronomy. It can be seen that the majority of the participants (> 60%) are interested in the use of  
 1486 astronomy for the development of our society. Astronomical methods and data are the second most popular  
 1487 interest, followed by cosmology and gravitational astronomy, and galactic and extragalactic astronomy.  
 1488 Figure 4-3 also outlines which fields of astronomy are less developed in Africa and have fewer experts, such  
 1489 as solar physics, transients and pulsars, or ethno-archaeoastronomy (cultural astronomy) and the history  
 1490 of astronomy. Increased research activities brought strong international collaborations, including long-term  
 1491 initiatives such as the Development in Africa with Radio Astronomy (DARA)<sup>9</sup>, the Africa Initiative for  
 1492 Planetary and Space Sciences (AFIPS)<sup>10</sup>, the Europlanet Society<sup>11</sup>, and mobility programs in research  
 1493 such as the Pan-Africa Planetary and Space Science Network (PAPSSN)<sup>12</sup>. Finally, taking into account all  
 1494 aspects of professional development, such as research, institutional development, infrastructure development  
 1495 and site testing, and human capacity building (with masters and PhD programmes), most African countries  
 1496 are conducting activities in professional astronomy, as shown in Figure 4-4.

<sup>9</sup><https://www.dara-project.org/>

<sup>10</sup><https://africapss.org/>

<sup>11</sup><https://www.europlanet-society.org>

<sup>12</sup><https://www.papssnmobility.org/>

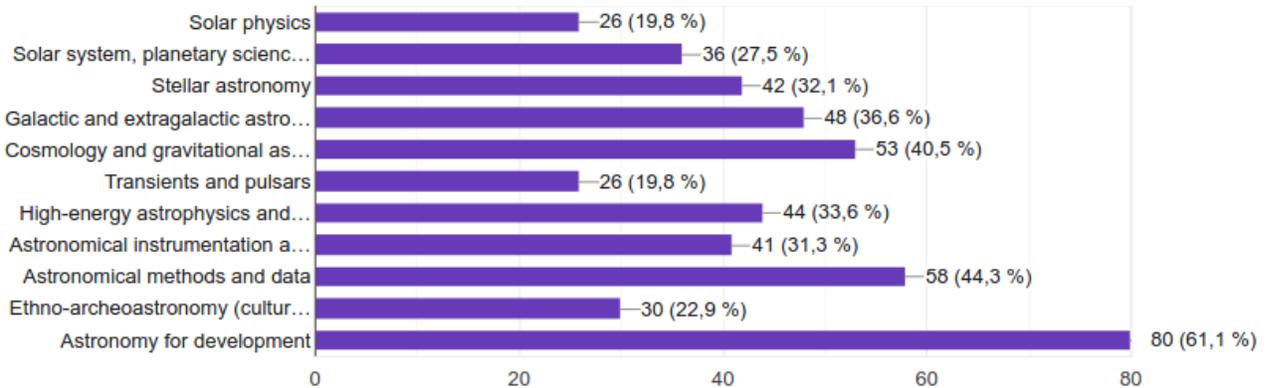


Figure 4-3: Interest in different fields of astronomy among the professional community in Africa. This figure was derived from the feedback of 130 professional astronomers in Africa.

1497 The number of astronomy schools, workshops and training, as well as professional conferences and  
 1498 meetings, has increased considerably. This includes the organisation of regular astronomy schools, such as  
 1499 the Pan-African School for Emerging Astronomers (PASEA), some of the first International Astronomical  
 1500 Union (IAU) symposia, such as IAU 356 and IAU 386 held in Ethiopia, the 3rd and 4th symposia organised in  
 1501 Africa in the last 100 years of the IAU, and the organisation of the 1st IAU General Assembly (GA) in Africa,  
 1502 held in August 2024 in Cape Town, South Africa. This first GA, organised in line with Vision 2024<sup>13</sup>, was a  
 1503 truly unique and historic event that will have a long-term legacy in terms of improved research, infrastructure  
 1504 development, education, outreach and stronger collaborations around the world, and particularly in Africa.

1505 Consequently, with the support of the South African Department of Science and Innovation (DSI),  
 1506 the African Astronomical Society (AfAS)<sup>14</sup> was re-established in 2019 with the aim of becoming the voice  
 1507 of astronomy development in Africa. AfAS is now a vibrant and active professional society, with more than  
 1508 350 members, and different established committees, including the Science Committee and the Education  
 1509 and Outreach Committee, which lead a number of initiatives, including the annual research conference  
 1510 and awards and prizes for postgraduate students and early-career researchers. In close collaboration with  
 1511 AfAS, and with support from DSI, other initiatives such as the African Planetarium Association (APA)<sup>15</sup>,  
 1512 the African Network of Women in Astronomy (AfNWA)<sup>16</sup>, the African Science Stars (ASSAP)<sup>17</sup> and the  
 1513 Africa-Europe Science Innovation and Collaboration Platform (AERAP)<sup>18</sup> have emerged. In addition, AfAS  
 1514 established strong connections and initiated long-term collaborations with several professional societies and  
 1515 organisations such as the European Astronomical Society (EAS), the American Astronomical Society (AAS),  
 1516 the Square Kilometre Array Observatory (SKAO), the Breakthrough Listen initiative, etc. Africa also hosts  
 1517 the Office of Astronomy for Development (OAD)<sup>19</sup> of the IAU, which includes the main Office in South  
 1518 Africa and three OAD Regional Offices in Ethiopia, Nigeria and Zambia. Finally, public awareness and  
 1519 outreach activities have increased exponentially across Africa in the last ten years, including the creation of  
 1520 more than 70 amateur astronomical societies, as can be seen in Figure 4-1 (bottom left map).

<sup>13</sup><https://astronomy2024.org/vision-2024/>

<sup>14</sup><https://www.africanastronomicalsociety.org/>

<sup>15</sup><https://africanplanetarium.org/>

<sup>16</sup><https://afnwa.org/>

<sup>17</sup><https://assap.co.za/>

<sup>18</sup><https://aerapscience.org/>

<sup>19</sup><https://www.astro4dev.org/>



Figure 4-4: African countries with professional astronomy present, including research, human capacity building, institutional development, infrastructure development with new observatories and telescopes, and site testing.

## 4.2.2 Astronomy for development

The impressive advances in astronomy in Africa described above now increase the possibility of achieving the United Nations (UN) Sustainable Development Goals (SDGs) through astronomy, which has proven to be an important tool for socio-economic and environmental development (e.g., [10, 7, 9]). Indeed, never before has it been more possible to use astronomy for development than now. Astronomy is one of the most multidisciplinary sciences, and has proven to be a powerful tool to promote education and inspire young people and children (including girls) to do science through the beauty of the Universe, contributing directly to SDG4 (Quality education) and SDG5 (Gender Equality) (e.g., see OAD annual reports). Astronomy is one of the leading sciences in bringing highly skilled people into the sector through fundamental research and instrument and data development, in line with SDG8 (Decent work and economic growth), and technological development and innovation through the continued construction of next-generation telescopes and instruments, in line with SDG9 (Industry, innovation and infrastructure). Astronomy helps advance medical diagnostic techniques (e.g., X-ray imaging, magnetic resonance, thermal sensors, etc.) contributing directly to SDG3 (Good health and well-being). Astronomy is a major contributor to the development of renewable and green energies, through fundamental research in solar physics and the development of ground- and space-based missions, in line with SDG7 (Affordable and clean energy) and SDG13 (Climate action). Astronomy can be used to promote diplomacy and peace, through the message that ‘We all live under the same sky’, in line with SDG16 (Peace, justice and strong institutions). Astronomy is also one of the scientific fields that contribute significantly to long-term international collaborations through fundamental research, data sharing, and the building of next-generation telescopes and instruments, in support of SDG17 (Partnerships for the goals). Many of the high- and middle-income countries have benefited significantly from their dark skies and investment in astronomical research and infrastructure, and it is time for African countries to use astronomy as one of the tools to achieve the UN SDGs. Finally, empowering Africa through astronomy and other fields of science will in the long term reduce inequalities between countries, in line with SDG10, and help to combat poverty (SDG1).

### 4.3 High-priority current and future initiatives

Until the date of this report, we received 13 LoI (out of 68, 20%) with Astrophysics and Cosmology being indicated as the primary physics WG. The received LoI cover radio astronomy, gamma-rays and optical observational astronomy, cosmology, and astronomy for development. Most of them, describe the initiatives/projects that are already running, but there are also several LoI with new proposed developments. In continuation, we are providing a summary of the received LoI and their suggestions:

- African Radio Astronomy Network (James Chibueze, UNISA/South Africa), suggests building a network of small and cheap radio telescopes, with an aim to provide training in radio astronomy across Africa and to undertake research with the ultimate aim of getting African astronomers to participate in the SKA science.
- Astro-particle and cosmology potential in the underground of Africa (Fairouz Malek, CNRS/France, and Yasmine Sara Amhis, IJCLab/France), addresses the opportunity for African countries to contribute to the enhancement of the knowledge and understanding of the fundamental aspects of the Universe by building and leading underground experiments similar to IceCube, ANTARES, Kamioka neutrino observatory, SNOLAB, etc.
- Continued gamma-ray observations with H.E.S.S (Michael Backes, UNAM/Namibia), addresses the importance of H.E.S.S telescopes for the current gamma-ray observations, and for the development of the future CTA telescope.
- Development in Africa with Radio Astronomy (Melvin Hoare, University of Leeds/UK), describes the DARA project that has provided basic training in radio astronomy to over 300 young graduates across eight African countries, and scholarships to 26 MSc and 9 PhD African students, with perspectives to continue with the work in future. Recently, DARA started the 3rd phase of its development and human capacity building in radio astronomy and data science in Africa.
- Furthering the sustainable development goals in Africa by exposing young children to the beauty, excitement and perspective of astrophysics (George Miley, Leiden University/The Netherlands), suggests that ASFAP incorporates into its strategy the use of physics in the education of very young children (4 - 10 years old), particularly those in underprivileged communities.
- Gamma-ray astronomy in the context of multi-wavelength astronomy and multi-messenger astrophysics (Markus Boettcher, NWU/South Africa), summarises opportunities for Africa to take on a driving role in the field of multi-wavelength and multi-messenger astrophysics.
- Low-frequency (< 1GHz) radio interferometric arrays and radio astronomy/cosmology (Patrice Okouma, Rhodes University/South Africa), suggests the development in space science and low-frequency (< 1.2 GHz) radio astronomy and cosmology.
- Observational astronomy in North Africa (Fairouz Malek, CNRS/France, and Mourad Telmini, University of Tunis El Manar/Tunisia), addresses the opportunity for North African countries to unite in contributing to build and lead a series of local observatories and/or one large facility.
- The first millimetre-wave radio telescope in Africa: the Africa Millimetre Telescope (Michael Backes, UNAM/Namibia), introduces the AMT and its impact on human capacity development in Namibia and Africa.
- The importance of the financial and technical support for the improvement of cosmology in Cameroon and in Africa (Ragil Ndongmo, University of Yaoundé I/ Cameroon), addresses the current difficulties

1587 in Cameroon regarding the studies in cosmology and brings some suggestions on how to overcome the  
1588 existing challenges.

- 1589 • The Lofar global citizenship radio array “GLORAY” (George Miley, Leiden University/The Nether-  
1590 lands), summarises a proposal to be submitted to ASTRON and to the International LOFAR Telescope  
1591 Board to carry out a design study for a project that would transform LOFAR into a multidisciplinary  
1592 facility that would span 3 continents, including Africa (in particular North Africa).
- 1593 • The South African Radio Astronomy Observatory (SARAO) (Rob Adam, SARAO/South Africa),  
1594 describes SARAO’s vision, mission, objectives, and research infrastructure for radio astronomy devel-  
1595 opments in South Africa and Africa, particularly through the SKA.
- 1596 • Using Astronomy for Development in Africa (Kevin Govender, OAD-IAU/South Africa), summarises  
1597 the activities, vision, and strategy behind the OAD, and suggests to ensure the growth of astronomy in  
1598 Africa and to use the experience of the OAD to ensure that developmental impacts are fully realised.

1599 These received LoI present some of the high-priority initiatives, and provide the starting point for the  
1600 development of White Papers in the future. A number of additional initiatives and projects are listed  
1601 in section 4.2.1, with the main priorities focusing on institutional development, human capacity building  
1602 through master and PhD programs and general trainings, and infrastructure development in particular in  
1603 optical astronomy and radio astronomy.

## 1604 4.4 Major challenges and needs

1605 Despite the strong development of astronomy in Africa, there are still many challenges and needs  
1606 to be addressed. In the framework of the AfAS Scientific Committee, a survey was conducted among 60  
1607 experienced researchers from 21 countries with professional astronomy. Most of the researchers who filled in  
1608 the survey are high-level experts who know very well the state of development of astronomy in their country.  
1609 In addition, the Vision 2024<sup>20</sup> online document has been developed by the community in line with the 2024  
1610 IAU GA in South Africa. The following difficulties and challenges have been identified (in no particular  
1611 order) to be considered for future improvement and to be taken into account in the development of future  
1612 policies and strategies:

- 1613 • Most countries are starting from scratch in the development of astronomy, so they need considerable  
1614 support in all aspects.
- 1615 • There is a limited number of human resources, in addition to the limited skilled sector to carry out all  
1616 activities and satisfy all needs.
- 1617 • In many countries, the lack of astronomy master and PhD fellowships and job vacancies forces people  
1618 to look abroad for opportunities, leading to a severe brain drain and the loss of talent and qualified  
1619 people.
- 1620 • Supporting infrastructures for astronomy and scientific development, in general, are often lacking, often  
1621 including access to basic tools such as adequate computers, external disks, etc.
- 1622 • There is a lack of funding, especially secured long-term funding, and a lack of support from local  
1623 governments. This includes a lack of funding to hire master and PhD students, or postdocs, to set up  
1624 research groups and for various facilities, including computers.

<sup>20</sup><https://astronomy2024.org/vision-2024/>

- 1625 • Many researchers face daily difficulties in carrying out their work due to a lack of uninterrupted power  
1626 supply and poor internet connection.
- 1627 • Astronomy in Africa is still not accessible to everyone, as can be seen above and in particular in  
1628 Figures 4-1 and 4-4.
- 1629 • Work overload is common among African astronomers due to the still small number of experts in most  
1630 countries compared to the needs, including teaching and lack of time for research. In addition, the  
1631 administration of higher institutions has grown exponentially in many countries in the last decade,  
1632 taking much time away from research and teaching.
- 1633 • Attracting new students is not an easy task, particularly attracting well-prepared students.
- 1634 • Many researchers face great uncertainty due to non-permanent positions.
- 1635 • Telescope time available for African researchers at the larger telescopes is limited.
- 1636 • Mobility of African researchers is a major problem, due to funding problems, but also visa problems,  
1637 even when funding is secured.
- 1638 • Many African astronomers live far from their home country (in Africa, especially in South Africa),  
1639 which often puts additional stress on them, especially if funding is limited and they cannot travel  
1640 home frequently.
- 1641 • Low salaries have been identified as a major problem and the reason why people leave the field and/or  
1642 the country.
- 1643 • Publication fees for prestigious international journals are high, as are subscription fees.
- 1644 • There is a need for more awareness to be done among the general public, policy- and decision-makers  
1645 regarding the importance of astronomy and science for African growth and socio-economical and  
1646 environmental development [7].
- 1647 • Political instability, conflicts, and wars pose a serious problem for the development of astronomy and  
1648 science and all other aspects of a society's well-being.

1649 Considering all of the above, ASFAP is timely, to address the enormous developments in astronomy in Africa,  
1650 but also to highlight the current challenges and needs.

## 1651 4.5 Systemic inequalities and recommendations

1652 The main challenges listed above can be grouped into systemic inequalities that exist in current scientific  
1653 practices in astronomy and cosmology in Africa and the world. This section lists some of the main systemic  
1654 inequalities and recommendations to be considered in the future developments in astronomy and cosmology  
1655 at the policy level to foster a more equitable science system.

- 1656 • **Global perception of importance of astronomy for development and for achieving the**  
1657 **UN SDGs.** There is lack of awareness how different science fields are perceived when we speak about  
1658 development and SDGs. Astronomy and cosmology are in particular exposed to such lack of awareness,  
1659 being cutting-edge sciences. This leads then to conscious and/or unconscious bias towards investment  
1660 in astronomy and cosmology in Africa that leads to systemic inequalities in science development and

1661 its impact on socio-economic and environmental development in short- and long-term.

1662 **Recommendation.** Develop the methods that will efficiently bring awareness at all levels, from  
1663 decision makers to general public, that investing in astronomy, cosmology, and science in general, is  
1664 not a question of luxury but a fundamental need if we want to bring more equal opportunities to  
1665 everyone. The future science, technology, and innovation (STI) policies should raise better the impact  
1666 and importance of different science fields, including astronomy/cosmology for development in short-  
1667 but also long-term.

- 1668 • **Systemic funding inequalities** in astronomy at all levels between Africa and other continents, and  
1669 more generally between the global south and north. This includes systemic inequalities in access to  
1670 national (internal) but also external funding. Moreover, if funding is not available, we cannot talk about  
1671 advances in astronomy and cosmology and their use for STI and for achieving the SDGs. Furthermore,  
1672 access to external funding often comes with conditions that follow the agenda of donors, and not  
1673 necessarily the needs of African countries. This leads to systematic inequalities between countries in  
1674 terms of progress in astronomy and STI in general.

1675 **Recommendation.** There is a need to secure increased funding at the national levels across Africa for  
1676 all aspects of astronomy and cosmology development (from research, through human capacity building,  
1677 institutional development, to infrastructure development and communication of astronomy and science  
1678 to the public). External funding structures/modalities need to be designed at the global level to be  
1679 more flexible, more inclusive (in all aspects), broad (considering all fields of science and that can  
1680 be easily adapted to the needs of each country), to consider not only current challenges/needs and  
1681 short-term benefits in line with rapid economic growth, but also long-term impact on society and more  
1682 sustainable development.

- 1683 • **Systemic inequalities in human resources and number of qualified experts in the fields**  
1684 **of astronomy and cosmology** between most African countries (except possibly South Africa)  
1685 and countries in other continents, or between the global south and north, with significantly more  
1686 limited human resources in low-income countries. This leads to a number of problems, such as the  
1687 overburdening of senior researchers (between research, teaching, leadership/management activities,  
1688 administration, etc.), on the cost of research, and the strong brain drain of younger researchers due to  
1689 lack of opportunities.

1690 **Recommendation.** Design models to strengthen postgraduate programs and recruitment in the  
1691 fields of astronomy and cosmology at master's, PhD and post-doctoral level. The generation of  
1692 more permanent positions in astronomy and cosmology (in universities, research centers) and the  
1693 creation of more research opportunities are required to avoid/minimize the brain drain. This should  
1694 be accompanied by funding modalities for the creation of new research groups. Develop modalities  
1695 to strengthen human capacity building through international collaborations (e.g., through mobility  
1696 programs in astronomy research, joint supervision of students, organization of scientific meetings in  
1697 Africa, etc.).

- 1698 • Because of the points raised above, there are **systemic inequalities in the quality of the activities**  
1699 **carried out** in the fields of astronomy and cosmology, and thus in their efficiency and impact on the  
1700 SDGs. In addition, there are also **systemic inequalities in metrics** and in how the quality of work  
1701 done in astronomy and cosmology is measured between Africa and the rest of the world, and between  
1702 different African countries.

1703 **Recommendation.** The last two recommendations above will have a direct impact on improving the  
1704 quality of research and other activities carried out in the fields of astronomy and cosmology. More  
1705 diverse and inclusive metrics need to be developed in the near future to assess advances in astronomy  
1706 and cosmology and their impact on our society across Africa.

- 1707 • **Inequalities in the means of communicating astronomy** and presenting quality work to others,  
 1708 e.g., through publication. Publication fees in Q1 impact factor journals are high and most African  
 1709 researchers cannot afford them.  
 1710 **Recommendation.** Implementation of open science policies are necessary for authors, not just readers  
 1711 in astronomy and cosmology in Africa.
- 1712 • **Systemic inequalities in access to basic infrastructure**, such as electricity (power cuts are  
 1713 common in many African countries), internet connectivity (which remains poor in many countries,  
 1714 particularly in landlocked countries), computers (this remains a major challenge for many African  
 1715 researchers), other computing facilities (e.g. supercomputers, grids, clusters), etc.  
 1716 **Recommendation.** Develop strategies to ensure access to power and internet connectivity to all  
 1717 academic centers in the future, and improve access to personal computers and computing infrastructure.  
 1718 Improve access to shared computing infrastructures through national and international collaborations.
- 1719 • **Systemic inequalities in access to world-class infrastructure and data in astronomy and**  
 1720 **cosmology**, including new generation telescopes and instruments. This improved with open science  
 1721 policies, at least in terms of access to public data, but significant inequalities remain between African  
 1722 countries and the rest of the world in access to high-quality data.  
 1723 **Recommendation.** Strengthen open access policies in astronomy and cosmology, and give more visi-  
 1724 bility to already available resources, strengthen international collaborations around infrastructure and  
 1725 available astronomical data. Include more African researchers in the large international collaborations  
 1726 developed around the latest and next generation telescopes and instruments.
- 1727 • All of the above, particularly affects **under-represented groups** such as women, minorities and the  
 1728 astronomical community in conflict- and crisis-affected areas.  
 1729 **Recommendation.** Special attention shall be given to each of the above (funding, recruitment,  
 1730 capacity building, leadership development, etc.) when dealing with under-represented groups and at-  
 1731 risk scientists to ensure equity. This should be taken into account in all astronomy-related policies and  
 1732 in the overall development of STI in Africa.

## 1733 4.6 Conclusions

1734 Astronomy has developed in Africa at an astonishing pace in the last 10-15 years, including research,  
 1735 human resources, infrastructure, etc. Africa needs to participate in international projects together with  
 1736 international partners, to ensure that it is not left behind. Such involvement should be in projects that  
 1737 include scientific discovery, technological development and innovation, as well as projects involving training,  
 1738 including for women and minorities. There are still important systemic inequalities when comparing the  
 1739 status of astronomy in Africa and in other continents. These include the perception of astronomy for  
 1740 African development, funding, human resources, the quality and metrics used to measure it, the means to  
 1741 communicate astronomical research, access to basic infrastructure, access to the latest and next-generation  
 1742 telescopes and instruments, and the challenges faced by under-represented groups. The STI policies will  
 1743 need to develop particular strategies to address all these systemic inequalities in the future for the benefit  
 1744 of all.

## 1746 *Acknowledgements*

1747 *We acknowledge the hard work and efforts of all colleagues and students who in one way or another*  
1748 *contributed to the development of education, science and technology in Africa through astronomy, and all*  
1749 *those who will continue to do so in the future.*

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# Atomic & Molecular Physics Working Group

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## 5.1 Foreword

Recent advances in experimental and theoretical scanning probing methods at the atomic scale have led to tremendous applications in biology, medicine, electronics, quantum technologies, spintronics or heterogeneous catalysis. For example, insight into the structure of living cells, the single molecule transistor, the minute working of catalytic reactions allowing the rational design of catalysts and improvement of properties, just to cite a few. However, probing matter at the nanoscale on the African continent is still challenging, both theoretically and experimentally. This stems from the various limitations in research facilities.

Despite the population of about 1.3 billion, which are mainly youth, the research and development output of Africa is quite low in virtually all areas of physics. To quantitatively understand this abysmal performance, we analyse the amount of research articles published by African scientists (based in African institutions) from 2000 – 2021, see Figure 5-1. Over the last two decades, the total research output from Africa stands shy of 70,000 articles with about 6,000 per year in recent times. It will be interesting to know that these are comparable to the Brazil scientific research output over the same period. However, the dramatic rise of India over the same period clearly shows the need for understanding the problem facing African scientists. This graphical illustration could readily be linked to the poor economic performance of the Africa continent, the world's poorest inhabited continent according to the World Bank. This is basically demonstrated by the difficulty to access energy for community services (health, education and so on) as well as the lack/inadequate information and communication technologies among others [1]. Moreover, only Egypt and South Africa made it in the Top 40 of the world's research and development index in 2021 [2]. However, Africa Union Agenda 2063 has identified Physics – fundamental and applied as a key solution to address the developmental problems facing the continent [3].

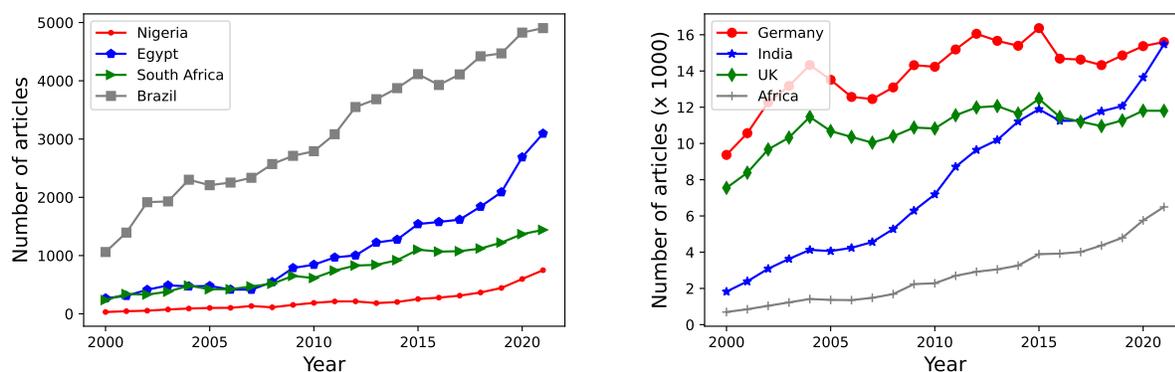


Figure 5-1: Research output per year from 2000 – 2021 for search keywords: atoms, atomic, molecular, molecules, or ions. **Left panel** – The number of articles published by some African countries (Egypt, Nigeria, South Africa) compared to the Brazil. **Right panel** – The total articles published by African scientists (Algeria, Cameroon, Congo, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, South Africa, Tunisia) compared western countries (Germany and UK) and India. Source: Scopus – accessed October 8, 2022.[6]

## 5.2 Challenges facing African scientists/physicists

1794

1795 On a theoretical point of view, electrical power instability in many countries does not allow sustain-  
 1796 able computing and computational facilities are scarce, see Ref.[4] for more discussion. Most sub-saharan  
 1797 countries barely have supercomputers available for research. The few available facilities on the continent  
 1798 are concentrated in Northern Africa and South Africa. Researchers rely on the latter and on external  
 1799 partners such as the Abdus Salam International Centre for Theoretical Physics, Italy. A dependence  
 1800 that limits the productivity but also the size of the system to study simple molecules. Experimentally,  
 1801 resources are also scarce. For example, it is only recently that central Africa got its first operational AFM  
 1802 apparatus in what is likely the first nanotechnology laboratory in the Republic of Congo. Besides, the  
 1803 light source community is still to build the first synchrotron on the continent and relies on external sources  
 1804 and networks like the Synchrotron-Light for Experimental Science and Applications in the Middle East  
 1805 (SESAME) and the free and open-source software such as Large-scale Atomic/Molecular Massively Parallel  
 1806 Simulator (LAAMPS). Unfortunately, for Africa, international organizations often support research of their  
 1807 interest and are compounded by the government's ill-advised policies towards education.

## 5.3 Current support towards enhance research output

1808

1809 During the last decades, various research groups and networks have been active on the continent, thanks to  
 1810 some foreign collaborations/donors. These include Physics Department, Marien Ngouabi University (Braz-  
 1811 zaville, Congo), CEPAMOQ (Douala, Cameroon), Lasers Atoms Laboratory, Cheikh Anta Diop University  
 1812 (Dakar, Senegal), Atomic Molecular Spectroscopy and Applications Laboratory, University of Tunis El Manar  
 1813 (Tunisia), Medical University of Southern Africa (South Africa), African Laser Atomic Molecular and Optical  
 1814 Science Network. In addition, there is growth in the study of materials sciences in Africa through the African  
 1815 School for Electronic Structure Methods and Applications (ASESMA).

1816 As an extension of these efforts, African physicists from a variety of specializations are developing an African  
1817 strategy for basic and applied physics, see <https://africanphysicsstrategy.org/> [5]. Organized into several  
1818 working groups, committees, and forums, they are working to produce a report to inform the African  
1819 and broader community of strategic directions that can positively impact physics education and research  
1820 over the next decade [7, 8]. The report is intended to help African policy makers, educators, researchers,  
1821 communities, and international partners prioritize resources and activities for physics education and research  
1822 at the national, regional, and pan-African levels. As part of this group of African physicists, we have the  
1823 task of coordinating the activities of the Atomic and Molecular Physics working group.

## 1824 5.4 Atomic and molecular physics working group – journey so far 1825 and way forward

1826 In the spirit of the ASFAP, the Atomic and Molecular Physics (AMP) working group aims at reporting on  
1827 the state of research and knowledge transfer of these groups and their derivatives on the continental level  
1828 but also on the various research carried by African scientists in AMP performed all over the world and that  
1829 align to sustainable development goals. From the above-mentioned research groups and networks, we have  
1830 identified and have traced the various African scientists still active in the field, their research interests and  
1831 compiled their various achievements.

1832 As part of this, we have successfully organised meetings and had an online workshop on Atomic and  
1833 Molecular Physics in January 2022 during which the discussion is cantered on identifying challenges facing  
1834 different research groups across the continent among others. These efforts, in conjunction with other ASFAP  
1835 working group, have resulted in some letter of intents (LOIs) submitted for the strategies. In addition, after  
1836 deliberation with the ASFAP Steering committee members and the Photonics and Optics working group  
1837 during the second African Conference of Fundamental and Applied Physics ACP2021, there is a unilateral  
1838 decision to merge the two working groups – *Atomic, Molecular and Optical Physics*. We believe that this  
1839 will synergise interdisciplinary activities towards industrial and technological advancements.

1840 To conclude, we advocate for physics-based policies in the various country, region and the continent at  
1841 large. These will be geared towards development of human capital as well as engaging the private sectors  
1842 for support. Finally, with the support of international collaborations, qualitative increase in the research  
1843 output of Atomic, Molecular and Optical Physics in Africa will become a fruition.

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# Biophysics Working Group

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## 1863 Abstract

1864 This report is a serious call to scientists, innovators, investors, and policymakers to invest in the development  
1865 of biophysics in Africa. The complex problems of our day demand multidisciplinary approaches, and  
1866 biophysics offers training in much-needed multi- and cross-disciplinary thinking. Biophysics is a research  
1867 field at the forefront of modern science because it provides a powerful scientific platform that addresses  
1868 many of the critical challenges humanity faces today and in the future. It is a vital source of innovation  
1869 for any country interested in developing a high-tech economy. However, there is woefully little biophysics  
1870 educational and research activity in Africa, representing a critical gap that must be addressed with urgency.  
1871 This report suggests key research areas that African biophysicists should focus on, identifies major challenges  
1872 to growing biophysics in Africa, and underscores the high-priority needs that must be addressed.

## 1873 6.1 Introduction and Motivation

1874 Since the COVID-19 pandemic, many governments have expressed the need for Africa to be able to make  
1875 its own therapeutics and vaccines. The first step for that to happen is investing in the basic and applied  
1876 sciences and engineering research, and that especially means biophysics.

1877 Why biophysics? This unique interdisciplinary field brings our understanding of biological processes to an  
1878 unprecedentedly detailed level. Only when we understand nature's processes at a sufficiently deep level can we  
1879 make reliable predictions and obtain sustainable technological solutions.

1880 This is realised by numerous pharmaceutical companies, where biophysics forms an indispensable component  
1881 of drug discovery [1]. Dr. Martin Friede from the World Health Organization's Initiative for Vaccine Research  
1882 took it a step further by stating, "It is impossible to develop the next generation of vaccines without  
1883 biophysics" [2]. Consider Structural Biology, a subdomain of biophysics that aims to resolve and study the  
1884 structure and dynamics of biological macromolecules such as proteins — the molecular machines of biological  
1885 cells. Knowing the protein structure at the atomic level has enormous commercial potential in areas such as  
1886 industrial enzymology and drug discovery. A fully resolved protein structure enables us to engineer proteins  
1887 that can make new chemicals and to design molecules that interfere with the life-giving reactions of harmful

1888 pathogens or pests (i.e., drugs and pesticides). Structural Biology is, therefore, an important step to the  
1889 global economic success of a country. It is particularly telling that over 80 Nobel Prizes have thus far been  
1890 awarded in the field of Structural Biology: 70 prizes for scientific discoveries and 11 prizes for experimental  
1891 methods that enabled these discoveries [3].

1892 Biophysics is not only concerned with scientific research. An integral component of scientific discovery in  
1893 biophysics involves technological development. Innovative experimental and computational methods pave  
1894 the way for new scientific discoveries and provide practical solutions across the broad domain of biological  
1895 sciences. Therefore, biophysics is more than a basic science that feeds innovation, because innovation is an  
1896 integral part of research in biophysics.

1897 Biophysics revolutionised medical research and technology in the 20th century. It provided both the tools  
1898 and the understanding for treating various diseases. These developments are accelerating in the 21st century.  
1899 Biophysics addresses not only human health challenges but also plant and animal health. By understanding  
1900 the minutiae of photosynthesis through decades of scientific research, rice, and soy plants were recently  
1901 engineered with 20–30% enhanced crop yield [4, 5, 6].

1902 Biophysics research features in various aspects of the global effort to combat climate change. An important  
1903 area of research and technological development in this regard is biomimetics, which originates from biophysics  
1904 [7]. The design of environmentally friendly materials such as biodegradable plastics is one example. Another  
1905 example is how biomimetics offers a useful perspective in addressing food security and sustainable energy,  
1906 two of the great challenges of our time: we can gain inspiration from the efficacy and adaptability of  
1907 photosynthetic organisms to produce food or fuel from sunlight using materials that are very abundant in  
1908 nature (i.e., inexpensive and scalable) [8]. In addition, meeting food, water, and energy demands is not  
1909 limited to mankind, but it is a basic need of essentially every cell of every living organism. It is therefore  
1910 prudent to investigate how other living organisms meet these demands at various levels.

1911 Quantum Biology is a new, emerging research field with enormous potential for science and technology. This  
1912 field of research investigates how biological organisms use the principles of quantum mechanics to gain a  
1913 physiological advantage in executing their physiological functions [9, 10]. Through quantum sensing, quantum  
1914 computing, and quantum-inspired algorithms, this field has the potential to revolutionise our understanding  
1915 of biological processes and lead to new technological innovations. During the past few years, several research  
1916 programmes focussing on Quantum Biology have been launched across the world [11]. It is important that  
1917 Africa actively contributes to the development of this promising field of research. Applications of Quantum  
1918 Biology could impact many technologies, such as energy, environment, health, sensing, and information  
1919 technologies [9, 10, 12]. Learning from life will not only lead to new technologies but also to new fundamental  
1920 insights in physics, chemistry, and biology. For example, in the medical field, it is known that light enhances  
1921 wound healing and effectively treats different types of cancer, and when applied to the brain it can have  
1922 a range of physiological effects such as improved attention, memory, executive function, and rule-based  
1923 learning [12]. Identifying how quantum effects might play out in the brain could offer a completely new way  
1924 of imagining medical intervention beyond the purely chemical.

1925 The term “century of biology” was coined for the 21st century in the context of biotechnological development  
1926 [13] to address several critical global challenges. Biophysics plays an indispensable role both in establishing  
1927 the crucial scientific basis and in bridging the gap between science and technology.

1928 A strong and diverse biophysics research and commercial sector is essential for the success of the African  
1929 economy. The importance of the bioeconomy has been recognised by numerous countries. For example, the  
1930 UK [14], EU [15], USA [16] as well as South Africa [17] have formulated strategies to move away from the  
1931 traditional industrial base and instead develop a strong bioeconomy. Notably, biophysics is an indispensable  
1932 component of these bioeconomy strategies.

## 6.2 Biophysics and the UN SDGs

Biophysics research and education have the potential to make significant contributions towards achieving several of the United Nations' Sustainable Development Goals (SDGs). The most direct connections are with SDG 2: Zero Hunger and SDG 3: Good Health and Wellbeing. Furthermore, biophysics also indirectly supports other SDGs, such as SDG 1: No Poverty, SDG 8: Decent Work and Economic Growth, SDG 9: Industry, Innovation and Infrastructure, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action, SDG 14: Life Below Water, and SDG 15: Life on Land. Additionally, the development of biophysics in Africa requires a strong commitment to SDG 4: Quality Education.

### SDG 2: Zero Hunger

Biophysics research in agribusiness and food security plays a crucial role in addressing SDG 2: Zero Hunger. Key areas of biophysics research that contribute to this goal include:

- Understanding the complex process of photosynthesis to engineer crops with enhanced yield [4, 5, 6];
- Developing innovative biosensing technologies to detect and prevent plant diseases;
- Exploring alternative, less toxic treatments for plant pests and diseases to ensure sustainable agriculture.

By advancing our scientific understanding of plant biology and developing practical technological solutions, biophysics can help improve food production, nutrition, and security across the African continent.

### SDG 3: Good Health and Wellbeing

Biophysics research in the medical field is essential for achieving SDG 3: Good Health and Wellbeing. Relevant areas of biophysics research include:

- Structural biology to understand disease mechanisms and guide the rational design of new drugs and vaccines [1, 2, 3];
- Biosensing and quantum biology for sensitive disease diagnostics [9, 10, 11, 12];
- Biophotonics for light-based therapies and diagnostics;
- Computational approaches to complement experimental work and deepen our understanding of diseases.

Addressing the significant health challenges faced by Africa, such as poverty-related diseases, neglected tropical diseases, malaria, and cancer, requires innovative biophysics-driven solutions.

### SDG 4: Quality Education

Underpinning the development of biophysics in Africa is the need for a strong commitment to SDG 4: Quality Education. Investing in biophysics education, training, and research opportunities is crucial to build the necessary human capacity and expertise to drive innovation in this field. By aligning biophysics research priorities with the UN SDGs, Africa can leverage this powerful scientific discipline to address some of the continent's most pressing challenges and contribute to a more sustainable and prosperous future.

### 1967 Indirect Contributions to Other SDGs

1968 In addition to the direct links to SDG 2, SDG3, and SDG 4, biophysics research also indirectly supports  
1969 several other SDGs:

- 1970 • SDG 1 (No Poverty): Improved food security and access to affordable healthcare can help alleviate  
1971 poverty.
- 1972 • SDG 8 (Decent Work and Economic Growth): Biophysics-driven innovations can foster economic  
1973 development and create new job opportunities.
- 1974 • SDG 9 (Industry, Innovation and Infrastructure): Biophysics research is essential for building a strong  
1975 bioeconomy and developing new technologies.
- 1976 • SDG 12 (Responsible Consumption and Production): Biophysics-inspired solutions, such as biomimetic  
1977 materials, can promote sustainable production.
- 1978 • SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land): Biophysics research  
1979 can contribute to understanding and addressing environmental challenges.

## 1980 6.3 Key Research Areas Requiring Biophysicists

1981 Biophysics research in Africa should focus on several key areas that address the continent's most press-  
1982 ing challenges. These areas are crucial for advancing the field and ensuring that biophysics contributes  
1983 meaningfully to the development of Africa.

### 1984 6.3.1 Medicine

1985 We wish to focus specifically on diseases that constitute the most significant health, social, and economic  
1986 burden to the African continent. These include (i) poverty-related diseases such as HIV/AIDS and tuber-  
1987 culosis, which kill millions of people annually, (ii) neglected tropical diseases that affect in the order of 400  
1988 million people on the continent according to the World Health Organization, (iii) malaria with an annual  
1989 mortality rate of about half a million African people, and (iv) cancer, for which the mortality rate increases  
1990 every year and is predicted to reach ca. 1.4 million annual deaths in Africa by 2040 [18].

1991 Most of these mortality cases can be linked to the patient having limited access to treatment or the inability to  
1992 afford the treatment. African countries, therefore, have a desperate need for robust, cost-effective diagnostics  
1993 and low-cost innovations to address local needs — and biophysics plays a crucial role in the development of  
1994 these technologies.

1995 Another key area of research is the development of drugs and vaccines for which research in Structural  
1996 Biology is indispensable. By resolving molecular structures of macromolecules, Structural Biology provides  
1997 the tools to understand the molecular basis of diseases, which guides the rational design of new drugs and  
1998 the optimisation of existing medicines. Tangible areas in which biophysicists can contribute include the  
1999 following:

#### 2000 Disease Diagnosis and Treatment

- 2001 • Biosensing: Developing sensitive diagnostic tools for diseases prevalent in Africa, such as malaria,  
2002 tuberculosis, and HIV/AIDS.
- 2003 • Biophotonics: Applying biophotonics to enhance light-based therapies and diagnostics for various  
2004 diseases, including cancer and neurological disorders.
- 2005 • Quantum Biology of Disease Mechanisms: Investigating how quantum effects contribute to disease  
2006 mechanisms and developing new therapeutic approaches.
- 2007 • Computational Approaches: Using computational methods to complement experimental work and  
2008 deepen our understanding of diseases, enabling more effective treatments.

### 2009 **Drug Discovery and Development**

- 2010 • Structural Biology: Understanding the molecular mechanisms of diseases through structural biology  
2011 to guide the rational design of new drugs and vaccines.
- 2012 • Microfluidics: The capability to miniaturise and automate biophysical experiments enables high through-  
2013 put screening, which can be further enhanced using artificial intelligence.

## 2014 **6.3.2 Agribusiness and Food Security**

2015 Biophysics can also contribute significantly to agribusiness in several ways, in particular by scientific and  
2016 technological solutions to improve plant health. Growing food insecurity and sustained malnutrition are  
2017 a major concern in the developing world. The rapidly growing food demand is due to the combination  
2018 of a growing African population and a reduction in fertile farmland. This requires drastic agricultural  
2019 intensification, which means that plant health becomes an increasingly important demand every year.

2020 Currently, at least half of agricultural loss occurs due to biotic or abiotic stressors. Biotic stressors are stress  
2021 factors of a biological origin, for example, pathogens, insects, fungi, parasites, worms, and weeds. Abiotic  
2022 stressors are non-biological factors such as non-optimal soil salinity, nutrient deficiency, drought, extreme  
2023 temperature, and excess light.

### 2024 **Early Disease Detection**

2025 Early plant disease detection is an emerging area of research, constituting non-invasive methods — typically  
2026 remote sensing technologies — that enable early, pre-symptomatic diagnosis of plant stress [7, 20]. These  
2027 methods enable the farmer to treat diseases or optimise abiotic factors at the earliest stages, which can be  
2028 several days before the plants would show symptoms that are observable by the eye. Early treatment curbs  
2029 the spread of diseases, increases the chances of successful treatment, and reduces the resources required for  
2030 treatment. The non-invasiveness of these methods also enables precision agriculture and plant phenotyping  
2031 for resistance breeding [21, 22]. Remote sensing includes numerous promising spectroscopy-based methods,  
2032 such as hyper- and multispectral imaging and pulse-amplitude-modulation fluorometry. Owing to their deep  
2033 understanding of spectroscopy, modelling, and device development, biophysicists are apt to enhance the  
2034 sensitivity of these technologies, devise ways to relate spectroscopic changes to particular stress factors,  
2035 and translate the detected signals between different environments (e.g., from indoor to outdoor) and across  
2036 different scales (e.g., from the leaf to the canopy level). This is a largely unexplored area of research, but  
2037 crucial for maintaining crop productivity and food security.

2038 In summary, biophysicists can contribute specifically to the following research area:

- 2039       • Biosensing: Developing innovative and inexpensive biosensing technologies to detect and prevent plant  
2040       diseases, ensuring sustainable agricultural practices.

### 2041 **Sustainable Agriculture and Pest Management**

2042 Another promising area of biophysics research is to provide a basis for finding alternative treatments for  
2043 plant diseases. Reducing chemical use for pest management is an urgent need in Africa for cost, food safety,  
2044 and environmental sustainability. Key problems of using pesticides and fungicides are the growing resistance  
2045 of pests and fungi, and their toxicity to humans, animals, and the environment. We therefore urgently need  
2046 to develop alternative ways to enable more accurate use of fungicides in the short term and explore less toxic  
2047 alternatives in the long term. An example is to control spore dispersal from fungi, which can only be done  
2048 when understanding the mechanics of fungal dispersal [23]. Again, biophysicists are needed to provide such  
2049 a mechanistic understanding. This is one of numerous underexplored areas of research.

2050 Biophysics is also paramount to obtaining a deep understanding of the complex photosynthetic process.  
2051 The onset of biotic and abiotic stressors triggers a series of photoprotective mechanisms. It has been  
2052 demonstrated that the genetic modification of some of these mechanisms can significantly improve crop  
2053 yields [4, 5, 6]. Biophysics contributes to sustainable agriculture and pest management in various ways,  
2054 including the following:

- 2055       • Photosynthesis and Plant Biology: Understanding the complex process of photosynthesis to engineer  
2056       crops with enhanced yields and improved nutritional content.
- 2057       • Biomimetics: Designing environmentally friendly materials and technologies inspired by nature to  
2058       reduce chemical use and promote sustainable agriculture practices.
- 2059       • Biophysics of Plant-Microbe Interactions: Understanding the interactions between plants and microor-  
2060       ganisms to develop more effective and sustainable pest-management strategies.
- 2061       • Quantum Biology of Plant Processes: Investigating how quantum effects influence plant processes and  
2062       developing more efficient agricultural practices.

### 2063 **Climate Change and Sustainability**

2064 Climate change is one of the most pressing global challenges of our time. Rising temperatures, melting ice  
2065 caps, and extreme weather events are all symptoms of a planet in distress. Biophysics plays a crucial role in  
2066 addressing this crisis by providing innovative solutions that can mitigate the effects of climate change and  
2067 promote sustainability.

2068 Biophysicists can contribute to the following specific areas:

- 2069       • Biodegradable Materials: Developing biodegradable plastics and other materials inspired by nature to  
2070       reduce waste and promote sustainable practices.
- 2071       • Quantum Biology and Energy: Investigating how biological organisms use quantum physics to gain  
2072       physiological advantages in energy production and storage.
- 2073       • Biophysics of Environmental Processes: Understanding the biophysical processes that govern environ-  
2074       mental systems to develop more effective strategies for sustainability.

## 6.4 Major Challenges to Growing Biophysics in Africa

The best way to grow and establish biophysics on the continent is to create adequate opportunities for state-of-the-art research on home soil. The major challenges to this goal are discussed here. It is important to note that these challenges feed one another. In other words, addressing one requires addressing them all.

### 6.4.1 Vastly Inadequate Infrastructure and Resources

All research and development require appropriate infrastructure and resources. This is even more so for biophysics research operating at the forefront of science and technology. There are a handful of research centres scattered across Africa that house relevant infrastructure [24]. This is a good start but undoubtedly markedly insufficient. Most African countries do not have even basic equipment for biophysics research, while the equipment hosted by the rest of the countries is vastly inadequate [24]. The severe lack of equipment is a very demotivating factor for aspiring biophysicists on the continent.

Acquisition of equipment is only one side of the coin. Equally important is the need to maintain technical infrastructure by equipping our own people and providing sufficient funds. It has happened too often that state-of-the-art specialised equipment gets wasted because of inadequate resources to sustain it — due to a lack of expertise or funds for maintenance or both.

Consider as an example the infrastructure required for Structural Biology. Determining the structure of biological macromolecules requires the establishment of a workflow that includes the ability to prepare the material, test its functionality, obtain the data necessary for structure determination, process this data, and interpret the outcome. Both X-ray crystallography and cryo-electron microscopy lead to directly interpretable, near-atomic-resolution visualisations of biomolecular structures and are currently the most widely used structure determination techniques. The value of structural insights is recognised internationally to the extent that industries as well as governments abroad have invested billions in building and staffing shared, large-scale, centralised infrastructure for Structural Biology. In comparison, due to the high cost of the technology and the critically scarce skills required to operate such equipment, only limited structural investigations are possible at select sites in Africa, all of which are currently in South Africa. The technology and thus critical insights remain elusive to both local industry and academic researchers. Where resources have been committed, appropriate equipment and skills have been spread over many sites, and this has meant that a productive critical mass that could lead to development and innovation has never been established. Trained students have in general not been retained, and many have found employment in the field abroad, where they have been highly successful.

It is also important that one or more of the societal activities in which structural biology is needed must exist in a country interested in developing this field of research. For example, there should be companies researching novel agrochemicals, medicines, or industrial enzymes for which protein structural information is a *sine qua non*. Given the poor state of development of the discipline in Africa, it is unlikely that entrepreneurs will invest without substantial government intervention.

From the above, the two main key points are:

- **Equipment and Facilities:** Biophysics research requires state-of-the-art equipment and facilities. However, most African countries lack the necessary infrastructure and resources to support biophysics research. This includes basic and advanced experimental equipment, as well as high-performance computers for theoretical investigations.

- Maintenance and Sustainability: Even if equipment is acquired, it is crucial to ensure that it is properly maintained and sustained. This requires a steady supply of funds and technical expertise, which is often lacking in Africa.

## 6.4.2 Very Low Critical Mass

### Awareness and Funding

The present state of affairs is that very few students and research scientists in Africa venture into biophysics. One major reason is a lack of awareness of the importance of this field of research. This leads to limited funding opportunities supporting biophysics research and development, which, in turn, discourages scientific work in this area.

### Exodus of Skilled Scientists

Another major reason for Africa's low critical mass in biophysics is the exodus of skilled scientists. Most Africans interested in biophysics study abroad and do not return to Africa, while most of those who returned to their home countries have remained in biophysics for short periods. The primary reason for this is the severe shortage of infrastructure and resources for biophysics research. These scientists have the necessary knowledge and skills, but they lack the capacity to execute the research. Opportunities are urgently needed to support and help these scientists to excel in their research.

### Limited Educational, Training, and Mentorship Opportunities in Africa

Going hand-in-hand with the previous two challenges is the need to educate, train, and mentor our current and aspiring biophysicists in Africa. Only a few African universities offer biophysics courses, and even fewer offer biophysics degrees. In addition, general and specialised biophysics schools and workshops in Africa are organised too infrequently.

Mentorship is crucial for encouraging and nurturing aspiring and established biophysicists on the continent. However, this is often lacking due to the limited number of experienced biophysicists in Africa.

## 6.5 High-Priority Future Needs

### 6.5.1 Capacity Building

An earnest investment in educational opportunities is a low-hanging fruit for the growth of critical mass and knowledge in biophysics. This must be done through the development of biophysics curricula and the hosting of general and specialised biophysics schools, workshops, seminars, and expert lectures. Biophysics programmes and degrees would need to be established as a pipeline in developing curricula along both academic and vocational lines. Both Africans and non-Africans can help significantly to address these needs. In this regard, the International Union for Pure and Applied Biophysics (IUPAB) and the Biophysical Society (BPS) have ample resources that can be tapped into.

The development of biophysics research should be a natural outflow of biophysics education and training. Again, support from IUPAB and BPS as well as numerous other international societies would be of immense help, for example, to bring international experts to Africa through the organisation of workshops and

2150 conferences. Collaboration with well-established biophysicists in other continents through multinational  
2151 research programmes and consortia is an excellent way to boost research quality and opportunities. This  
2152 becomes a realistic opportunity when African researchers strive for excellence.

2153 Lastly, the severe lack of awareness of biophysics on the continent must additionally be addressed through  
2154 public awareness activities such as popular science literature, news reports, science festivals, roadshows, and  
2155 school visits and demonstrations. In general, the profile of scientists must be raised in the public eye. They  
2156 are the people expending great effort in training the next generation of leaders and developing innovative  
2157 technological solutions. If scientists — and biophysicists in particular — could be elevated to the same level  
2158 as sports stars, this would immediately attract significant attention from the public and governments. In  
2159 addition, if scientists do not actively define their role in society, their relevance will be determined by society  
2160 — and this will be a vastly underappreciated role.

2161 From the above, the key points are:

- 2162 • **Education and Training:** Establish biophysics curricula and degrees at African universities. Host  
2163 general and specialised biophysics schools, workshops, seminars, and expert lectures to educate and  
2164 train aspiring biophysicists.
- 2165 • **Mentorship:** Provide mentorship opportunities for aspiring and established biophysicists. This includes  
2166 pairing experienced biophysicists with younger researchers and encouraging collaboration between  
2167 African and international biophysicists.
- 2168 • **Public Awareness:** Organise public awareness activities such as popular-science literature, news reports,  
2169 science festivals, roadshows, and school visits and demonstrations to elevate the profile of biophysicists  
2170 and the importance of biophysics research.

### 2171 6.5.2 Investment in Infrastructure and Equipment

2172 As motivated above, the acquisition and maintenance of modern infrastructure and equipment is key to the  
2173 development of biophysics research and innovation. Funding for this requires governmental support, which  
2174 should grow through policy development and high-level discussions with governments convincing them of the  
2175 need to support the work of African biophysicists, build the necessary infrastructure, and encourage African  
2176 industries to invest in the bioeconomy strategy.

2177 Governing bodies and investors must make adequate funding available for the procurement of necessary  
2178 facilities for biophysics research. Funding incentives should also be provided to researchers to establish  
2179 and develop biophysics research in important areas. To this end, governments may develop multiple-  
2180 department initiatives to support the work of biophysicists. They should incentivise our universities to build  
2181 infrastructure in all the fields that support biophysics and make funding available for basic and advanced  
2182 equipment.

2183 African home countries need to invest in their own research. Currently, the weakest link is the fact that we  
2184 get most funding from outside Africa and no or very limited buy-in from our own continent. Africans must  
2185 be convinced that their support is indispensable.

2186 Investment in infrastructure and human capacity development must be seen for what it is: an investment  
2187 — not for a limited number of elite persons but for the country and ultimately for the whole continent! A  
2188 growing body of expertise will attract industrial development, which, in time, will inevitably lead to direct

2189 foreign investment and the development of intellectual property and products. Consider as an example the  
2190 study of protein structure. Proper investment in the development of infrastructure and scientists to do  
2191 cutting-edge Structural Biology research will enable the development of local industries concerned with drug  
2192 discovery and development, advanced agrochemicals, and fourth-generation industrial biotechnology.

2193 Biophysics research depends on a very broad spectrum of experimental techniques, and it is therefore  
2194 impossible to house all the necessary equipment on the African continent. But it is also unnecessary to  
2195 try and collect all types of equipment. Firstly, we must be selective in our focus, specifically addressing the  
2196 key research areas stated above. Secondly, we must follow the example of European countries that similarly  
2197 do not house all the necessary equipment but, instead, form consortia to share expensive equipment, which  
2198 can also be accessed by scientists from non-member countries.

2199 In summary, we recommend:

- 2200 • Acquisition and Maintenance: Acquire and maintain modern infrastructure and equipment for bio-  
2201 physics research.
- 2202 • Funding: Secure funding for the procurement and maintenance of necessary facilities for biophysics  
2203 research. This includes government support and incentives for researchers to establish and develop  
2204 biophysics research in important areas.
- 2205 • Collaboration: Collaborate with international organisations and experts to access shared, large-scale,  
2206 centralised infrastructure for biophysics research.

### 2207 6.5.3 Low-Cost Innovations to Address Local Needs

2208 Although the importance of acquiring and maintaining expensive equipment for state-of-the-art biophysics  
2209 research and development cannot be understated, a particularly pressing need for Africa is to find inexpensive  
2210 technologies for the vast majority of its people who cannot afford expensive solutions. In this regard, it is  
2211 important to note that for most applications, only a dedicated technology is needed, not a versatile one.  
2212 This requirement may significantly decrease the price of the technology. Connected with this is the need  
2213 to develop methods that are specific to particular contexts. Such affordable solutions require innovative  
2214 thinking.

2215 Consider as an example a quantum light imaging device to improve the resolution of medical images for people  
2216 living in remote areas. This technology is out of place for its target group because, firstly, such equipment  
2217 is very expensive; secondly, it requires a well-isolated (vibration-free) environment and reliable electricity  
2218 supply; and, thirdly, it requires highly skilled staff to operate and maintain. Instead, a significantly cheaper  
2219 instrument can be used to acquire an image at a lower resolution, after which machine-learning techniques  
2220 can be employed to optimise the image resolution.

2221 Another example of an inexpensive innovative instrument is a homebuilt multispectral camera, which can be  
2222 a few orders of magnitude cheaper than state-of-the-art commercial ones. Such a camera can be built using  
2223 a 3D printer and Raspberry Pi kit, the latter of which is then used to control inexpensive camera sensors and  
2224 filters. Running the output through a machine-learning algorithm can again improve the image and spectral  
2225 resolution. The cost of this instrument can be cut further when dedicated to a specific application. Possible  
2226 applications are diverse and may include the sensing of particular stressors in plants, drug sorting, detection  
2227 of tainted drugs, diagnosis of traditional medicines, food diagnosis to determine its safety for consumption  
2228 (e.g., detection of pesticides, rot, or diseases), or investigation or detection of plastics.

2229 These examples highlight the importance of translating scientific work from the laboratory to society by  
2230 finding inexpensive, dedicated solutions. This is in line with the World Health Organization's set of  
2231 criteria for ideal diagnostic test development based on the acronym REASSURED, which refers to **R**eal-time  
2232 connectivity, **E**ase of specimen collection, **A**ffordable, **S**ensitive, **S**pecific, **U**ser-friendly, **R**apid and robust,  
2233 **E**quipment-free or simple, and **D**eliverable to end-users.

2234 In summary, we recommend:

- 2235 • Affordable Solutions: Develop inexpensive technologies for the vast majority of Africans who cannot  
2236 afford expensive solutions. This includes dedicated technologies for specific applications and innovative  
2237 thinking to find affordable solutions.
- 2238 • Artificial Intelligence: Utilise artificial intelligence such as machine learning and techniques to optimise  
2239 and enhance biophysics research and applications.

## 2240 6.6 Synergies With Neighbouring Fields and Multinational Re- 2241 search Programmes

2242 The broad scope of biophysics demands a broad range of experimental and modelling approaches. Even  
2243 within a focused area of biophysics, numerous experimental and modelling approaches are often used to  
2244 obtain a holistic picture and a deep understanding of the complex system at hand. Therefore, biophysics has  
2245 synergy with many other fields of physics. ASFAP subgroups with which there is significant overlap include  
2246 Accelerators, Atomic & Molecular Physics, Computing & 4IR, Instrumentation & Detectors, Light Sources,  
2247 Condensed Matter & Materials Physics, Medical Physics, Optics and Photonics, and Complex Systems. In  
2248 addition, some research areas within biophysics have synergy with the ASFAP subgroups Earth Science,  
2249 Energy, and Fluid and Plasma.

2250 Adopting a broad definition of biophysics here, biophysics has a strong overlap with many other disciplines  
2251 such as biochemistry, bio-computing, bio-mathematics, biomedical engineering, biotechnology, botany, chem-  
2252 istry, crystallography, genetics, genomics, molecular biology, neuroscience, oceanography, pharmacology,  
2253 physiology, structural biology, synthetic biology, systems biology. Professional African Societies for many of  
2254 these disciplines already exist, and biophysics initiatives must cooperate with these societies [24].

2255 Cross-pollination of biophysics with the various sub-disciplines of physics and the other related scientific  
2256 disciplines is strongly recommended because this encourages lateral, cross-disciplinary thinking.

2257 In summary, we recommend:

- 2258 • Interdisciplinary Approaches: Encourage interdisciplinary approaches by collaborating with other fields  
2259 of physics and related scientific disciplines.
- 2260 • Professional Societies: Cooperate with professional societies for various disciplines to leverage synergies  
2261 and cross-pollination of ideas.
- 2262 • Establish Initiatives: Establish multinational research programmes and consortia to share expensive  
2263 equipment and expertise.
- 2264 • Training Events: Organise training events and workshops to enhance research quality and opportuni-  
2265 ties.

## 6.7 Conclusion and Perspectives

Biophysics offers a powerful scientific platform that addresses many of the critical challenges humanity faces today and in the future. It is a vital source of innovation for any country interested in developing a high-tech economy. However, there is woefully little biophysics educational and research activity in Africa, representing a critical gap that must be addressed with urgency.

This report identifies key research areas that African biophysicists should focus on, including medicine, agribusiness, and climate change. It also discusses major challenges to growing biophysics in Africa, including inadequate infrastructure and resources, low critical mass, and limited educational, training, and mentorship opportunities.

To address these challenges, the report recommends capacity building through education and training programs, investment in infrastructure and equipment, and public awareness activities. It also emphasizes the need for multinational research programs and consortia to leverage synergies and cross-pollination of ideas.

By addressing the challenges and leveraging the opportunities for biophysics research and development in Africa, the continent can build a strong foundation for biophysics research and innovation, ultimately contributing to the continent's economic and social development.

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# Computing Working Group

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## 2359 7.1 Introduction and Motivation

2360 Research nowadays needs strong computing services to analyze big data, extract results, make discoveries,  
2361 and improve the lives of citizens.

2362 What we define as a computing service is comprised of many layers, ranging from the underlying hardware  
2363 including network resources, computer systems, and storage, to the applications and software implemented  
2364 on the hardware. For decades, we have observed the advent of new computing fields such as Artificial  
2365 Intelligence and Deep Learning that have revolutionized data processing.

2366 Even though computing is itself a science and a field of research and technology, we consider here the  
2367 application of informatics to other science research fields. We should also not forget Quantum Computing,  
2368 which will give a major advantage to countries and organizations that master this field.

2369 A large fraction of the information collected in this report is based on a survey launched in March 2022,  
2370 including ASFAP participants and attendees of the 2nd African Conference of Fundamental and Applied  
2371 Physics ACP2021 [1] held in March 2022 in Casablanca, Morocco. More details can be found in ref. [19]. This  
2372 survey was launched to evaluate the status of computing resources in the field of African Physics Research.  
2373 The panel was mainly composed of participants working and living in Africa (more than 82% ); the rest  
2374 being largely what we call Africans from the diaspora. 26 countries were represented in the panel.

## 7.2 Computing Challenges for Scientific Activities in Africa

Scientific fields that rely on data processing to extract knowledge are numerous. They span various fields including Physics, Astrophysics, Biomedical and Environmental research, etc. The survey cited above has gathered participants belonging to more than 30 different fields. Most of them highlighted the scarcity of computing infrastructure and often the lack of stakeholder understanding about the extent of the need for computing in their field.

In recent decades, the importance of providing robust computing resources and services has become increasingly evident. For instance, the discovery of the Higgs Boson at the Large Hadron Collider (LHC) at CERN [4, 5] would not have been possible without such resources. To put this in perspective, the CRAY X-MP/48 computer, used at CERN around 1985, would take approximately 3.5 million years to process just one year's worth of data from the LHC today. Even the high-performance computing infrastructure from around 1995 would still require 11,000 years to achieve the same task [6].

The sheer size and complexity of the LHC's data, the stringent selection process required to find the "needle in a haystack," and the necessity of generating billions of simulated events to compare against theoretical models required an unprecedented level of computing power. This example underscores the need for computing resources that are not only vast, but also shared, distributed, and interoperable across a global community of scientists.

Another computational challenge is the need to simulate increasingly more complex physical phenomena that require different heterogeneous architectures and a level of coding that allows better exploitation of new architectures such as GPUs (Graphical Processing Units). Active research, in particular using Deep Learning, Natural Language Processing, Graphical Networks and other AI-related techniques is ongoing to produce code that would be optimized for specific infrastructures. Simulations require substantial processing power for computational physics, and other research applications in Physics involving large datasets require high computational power to produce precise and timely results (Navaux, et al.,2023 [8]). To process large datasets and perform complex calculations, researchers can use High Performance Computing (HPC) resources. The main challenge in Africa is the limited availability of HPC facilities for researchers, hindering research in the African region.

Not all fields demand such a large amount of computing resources; but as modest as the data sample may be, it may need complex processing that cannot anymore be done by hand.

If we focus on the Africa region, lack of commitment from African governments toward advancing scientific and technological innovation is also a key challenge to the scientific research in the region. The ASFAP community report (2020-2024) reveals that African countries have been spending less than 1% of their gross domestic product (GDP) on research despite the increase in the number of scientists in the past five years. South Africa and Egypt allocate the highest budgets for scientific research which are respectively 0.83% and 0.72% of their GDP [7].

More so, the significant costs associated with acquiring, operating, and maintaining higher-performance computing systems could be overwhelming and challenging in the regions with the poorest economy.

Another challenge would be the insufficient number of skilled computational scientists and engineers to support and operate the computing resources. This may hamper the effective and efficient use of computing resources in the region.

## 7.3 Synergies with neighboring fields

The need for more computational performance in many fields of science is driving the search for more powerful architectures and applications. We have seen above that very close neighboring fields can and will develop with the need for powerful computing for Physics. The most obvious ones are the fields related to Artificial Intelligence and Quantum Computing. These two fields are providing and will provide an unprecedented boost in the power of computing for any research thematic.

### 7.3.1 Artificial Intelligence

Artificial Intelligence (AI) is already widely used in many domains in industry, research, communications, etc., and it is difficult to fully capture and describe the role it has taken on in our every day life.

Particle physics was one of the first fields of science in the late 1960s to study and use AI, in particular Neural Networks, to discriminate more accurately between signal and background, and also Deep Learning to increase analysis performance of the immense amount of data delivered by powerful colliders.

It is used in many other fields, some of them being security, machine control, work in extreme environments, and in particular in medical sciences: early diagnostics of pathology, second opinion for doctors, drug discovery and personalized treatment. Accordingly, the broader adoption of AI in healthcare systems in Africa would be of significant benefit for the continent.

Although AI techniques are still in their early stages, they have accelerated the progress in research, penetrated all facets of our life, and they contribute to considerable resource savings.

The 2024 Nobel Prize in Physics Went to AI Research and recognized John Hopfield and Geoffrey Hinton for foundation research in neural networks. The Nobel Prize Committee has awarded the 2024 Nobel Prize in physics for their fundamental discoveries in machine learning, which is key to artificial intelligence as it develops how a computer can train itself to generate information (Matthew S. Smith, 2024. IEEE Spectrum [9]).

### 7.3.2 Quantum Computing

Quantum computing is one of the most trending and promising chapters of all quantum technologies. The basic idea behind its development is the possibility to rely on the quantum properties of matter at the microscopic scale, mainly quantum superposition and quantum entanglement, in order to build up computing hardware (quantum circuits) and software (quantum algorithms), that can handle complex problems which are out of reach of conventional computing resources, in a reasonable amount of time.

Quantum superposition has been demonstrated a long time ago and routinely used in several applications such as atomic clocks and interferometry, using inter alia the basic Rabi oscillations phenomenon. However, quantum entanglement was by far a more elusive phenomenon that has required significantly more effort from the physics community to provide fully accepted evidence of it. This field was triggered by the groundbreaking experimental work of A. Aspect in the 1980's, which demonstrated the violation of Bell's inequalities and proved the existence of quantum entanglement. Further research conducted by A. Zeilinger and others was

2450 able to implement quantum teleportation, based on quantum entanglement, opening up the possibility to  
2451 effectively consider technological applications of these quantum properties.

2452 Quantum Computing uses qubits, similar to the bits in classical computing, but offering the advantage  
2453 of multiple outputs, as opposed to just 2 outputs, 0 and 1, for the standard electronic bit. This quantum  
2454 quantum property, if embedded in a quantum computer, would enable the resolution of complex problems  
2455 in an exponentially faster time than with a classical computer. In 2019, Google claimed that it solved a  
2456 sampling problem in 200 seconds which would have taken 10,000 years on a classical computer. Notably, the  
2457 engineering of qubits has proven to be very challenging, and many governments and private corporations  
2458 worldwide are heavily investing in this research. Not only is it very difficult to build a processor based on  
2459 qubits, but another related challenge is to build software and algorithms to exploit its capabilities. Progress  
2460 in AI, Quantum Computing, and in general in Computing Sciences is one of the most important approaches  
2461 to deal with the avalanche of data in all fields of science, and to speed up the process of discoveries that  
2462 impact our everyday lives. Synergy between the work of research scientists and computing experts is essential  
2463 to explore the quantum world. The rapidly growing field of quantum information and quantum engineering  
2464 will require quantum-aware engineers [3].

2465 In Africa, Quantum technologies, and especially quantum computing, have been recognized by the physics  
2466 community as important fields, and several teams across the continent engaged significant efforts and means  
2467 for research and capacity building accordingly. It is important to mention the pioneering role of South Africa  
2468 in this field. The country has several universities working on quantum computing and related topics, and  
2469 has already endorsed a national quantum road map, on the same footing as most of the developed countries  
2470 in the world. Several other countries are following this path, including Morocco, Egypt and Tunisia.

2471 Numerous initiatives have been implemented to foster collaborations across Africa. It is worth citing the  
2472 series of Quantum Africa Conferences, initiated in 2010 in South Africa and held every two years. A number  
2473 of other informal networks, either national, regional or continental, are actively organizing on-line events in  
2474 the field of quantum computing, in addition to training schools and workshops.

2475 The African School of Physics (ASP) has included Quantum computing as part of its training program  
2476 regularly and the lectures are appreciated by the young attendees, showing their interest in this field. It is  
2477 highly recommended to keep the momentum on this topic and to continue the efforts for capacity building  
2478 and stronger involvement of African physicists in this emerging and trending discipline.

## 2479 **7.4 High priority Future Needs from Scientific Community Con-** 2480 **sultations**

2481 We have consulted a scientific community belonging to more than 15 research fields about their experience  
2482 accessing computing facilities and their training and education in computing sciences. Parts of the answers  
2483 are summarized in figure 7-1: the largest number of responses stress the lack of budget for computing, the  
2484 lack of technical support, and the fact that the management does not understand the need of computing for  
2485 research.

2486 On computing resources available to achieve their work, the largest number of responses – more than 50% –  
2487 find the computing resources to be highly insufficient and the percentage goes up to 66% when counting only  
2488 scientists using their local resources. They point at the lack of budget for computing, the lack of technical  
2489 support and the fact that the management does not understand the need of computing for research.

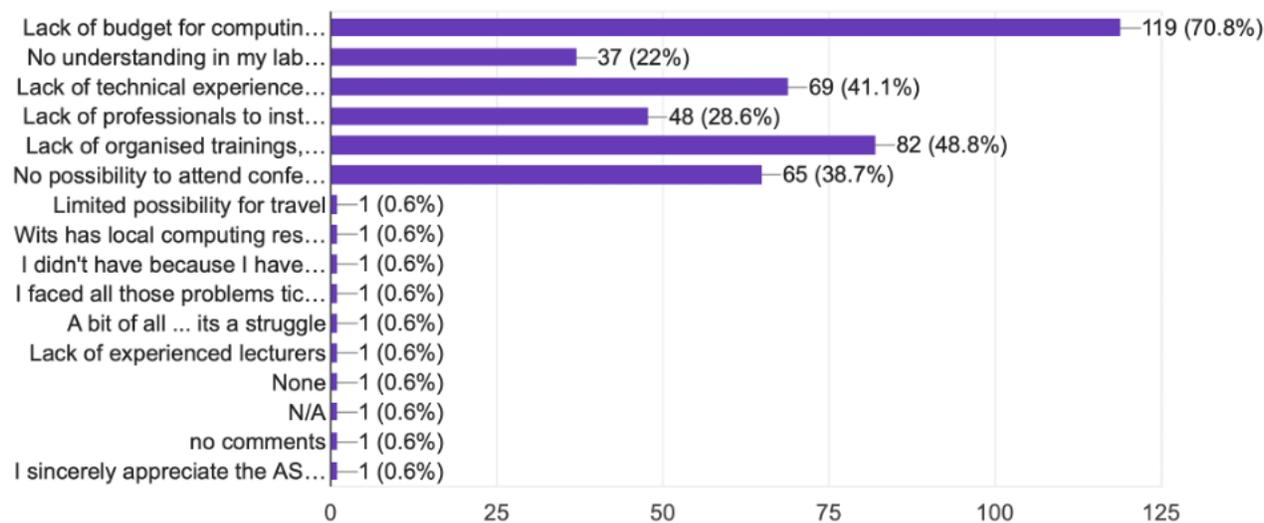


Figure 7-1: Main obstacles to the use of computing by scientists: the largest bottleneck is the lack of budget for computing in physical sciences. The problem might arise from the lack of funding as well as from the wide spread opinion that scientists do not need computers and computing infrastructures to perform their research. This last point is also raised as we see in the graph that 22% of the answers highlight a "No understanding in their lab" of the necessity of computing.

2490 On Education and Training, the participants stress the lack of organized training and workshops and  
 2491 the difficulty to attend those meetings organized abroad. Concerning this specific point, more detailed  
 2492 information is found in figure 7-2: 74.4% of the scientists are not provided with courses and lectures, or an  
 2493 insufficient level thereof. Comprehensive analysis of the survey from which the statistics are extracted can  
 2494 be found in [19].

## 2495 7.5 Recommendations and perspectives

2496 Considering the answers provided by the survey cited above and to improve the situation and boost the  
 2497 scientific research in Africa, we draw the following guidelines:

- 2498 • **Develop computing infrastructure and build a knowledgebase:** Infrastructure should be made  
 2499 available and, if already existing, improved by a significant level in order to provide easy access to  
 2500 data and enough computing performance to process the massive and/or complex data samples. Major  
 2501 components of the underlying infrastructure are:
  - 2502 – **Network:** Since networks are vital for the access to data and information, an essential part of  
 2503 Computing services is the access, availability and performance of the network, i.e., Academic  
 2504 and Research Network in Africa. This is not only true at the local level in universities and  
 2505 research centers, but even more so at the national and international level with connections to other  
 2506 countries. Most of the countries have, at scientific level, a poor network and slow connections to  
 2507 each other: one needs to get a global picture of the existing situation and compile the needs of all

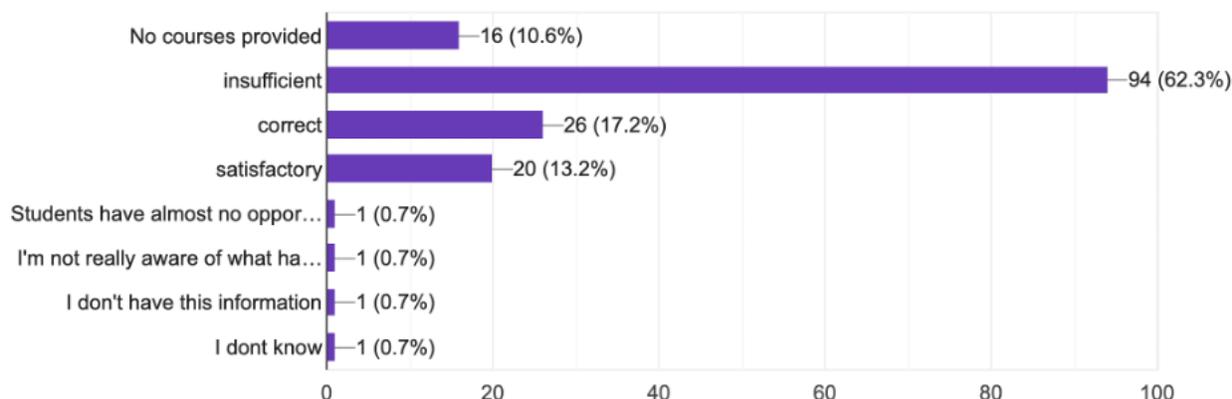


Figure 7-2: Teaching and Training: details are provided about the status of the computing know-how: more than 70% of the answers point to a nonexistent or insufficient level of courses and training.

constituents in order to draw up a strategy for improvement. It is imperative for all countries to share their knowledge. An African coordinated initiative would be a real asset to the continent.

- **Storage and Computing Power:** these are necessary to store and process the data, which is the only way to produce results and advance science. The computing needed is more and more sophisticated now that Artificial Intelligence and Deep Learning have entered the game in all fields of science. As suggested by some of the participants, large data centers shared within a country or with other countries within Africa would certainly be a solution that would federate the resources, and decrease the costs and disparities between universities and countries.

- **Qualified technical staff** is necessary to deploy and run these computing resources and make them available to the physics research scientists that would not be able to deal with Cloud deployment or computer storage access by themselves. Here a collaboration between different countries (within Africa and beyond) could be a fruitful initiative to share IT technicians, setup a few test sites, and start setting up an infrastructure on site.

- **Build Knowledge and include computing in Education:** The poll has highlighted the insufficient level of education in computing. Many solutions should be envisaged simultaneously:

- **Increase the number of computing courses** in the courses of physics and other science students.

- **Train IT professionals** to prepare and operate the infrastructure. These professionals are an important piece of the game as they are the ones that can deploy the complex infrastructure and follow up on the progress in the field.

- **Organize regular workshops and trainings.** This would be highly beneficial for knowledge sharing and to stay at the forefront in computing where evolution is very fast. But this also would have an important positive side effect: Researchers have highlighted the fact that they quite often work isolated. These workshops are the best place to meet their peers and initiate collaborations that would be very beneficial to raise research productivity.

- **Establish Communities of Practice.** Many research computing facilities in Africa face the common problems of isolation and staff retention. Most groups operate in relative isolation and struggle to engage with peers. This is largely owing to the lack of financial resources to facilitate in-person engagements since the vast majority of scientific computing workshops occur outside

of Africa. Another contributing factor towards isolation is simply the lack of awareness of any accessible broader communities in Africa.

- **Establish sustainable workforce development pipelines.** While there is an identified need to train and upskill the technical workforce in Africa to operate and maintain advanced research computing resources, any workforce development pipelines must be sustainable. Research institutes that manage to upskill their technical staff face a subsequent challenge of retaining the newly-skilled staff who now have opportunities to migrate to higher-paying industries with more attractive resources.
- Last but not least, **national and international collaboration** with peers more experienced in these fields would provide accelerated knowledge transfer and build mutually beneficial collaboration.

- **Harnessing Cloud Computing for Africa’s Scientific Research Infrastructure:** The rapid evolution of computing capabilities to meet the growing demand for data processing presents a significant challenge to Africa’s scientific research infrastructure. To keep pace with the computing requirements for today’s vast amounts of data, there is a critical need for constant optimization of computing resources. Cloud computing offers a cost-effective solution to this challenge. While traditional High-Performance Computing (HPC) systems require substantial investment in acquisition, operation, and maintenance, cloud computing provides a viable, lower-cost alternative. Although cloud computing has its limitations, its adoption by African researchers and institutions could bridge the gap in accessing essential computing resources for high-quality research. Additionally, embracing this technology has the potential to stimulate further research and advancements in cloud computing and data center management, fostering innovation in these fields.

- **Prioritizing Sustainable Investments in HPC Centers for Africa’s Development:** Instead of providing financial aid or loans to African nations, developed countries should prioritize direct investments in sustainable projects, such as the establishment of HPC centers within the region. These efforts should include the training of personnel to operate and manage such centers, ensuring long-term success. This approach would contribute to achieving the Sustainable Development Goal 9 (Industry, Innovation and Infrastructure) included in the 2030 Agenda for Global Education of the UNESCO (ref. to be added here) and significantly enhance the region’s computing capabilities to meet present and future demands.

- An example of an initiative to address a sustainable HPC development pipeline is South Africa’s HPC Ecosystems Project [?]- A project that oversees a now ten-year partnership between Southern African countries and international computing facilities which has led to the establishment of more than thirty-five HPC systems in eleven African countries and provided technical training to over 700 participants. Through the Project’s engagements, a virtual community of practice for emerging HPC Administrators has grown to incorporate more than 350 members from five continents, which prioritises sustainable workforce development and adoption of advanced research computing best practices.

## 7.6 Conclusion

The unavoidable and exponential increase of computing in all science fields including fundamental and applied sciences necessitates the availability of computing resources, the growth of computing awareness in the scientific communities and the inclusion of computing in education. Although certainly not extensive and complete, some key recommendations are drawn in the section above that might fill the gap that is visibly present when one compares African research with that of other continents. Investing in computing

2580 is one of the highest return on investment that a country can expect. It would provide to the youth of all  
2581 countries an opportunity at the level of their hopes and ambitions.

The top priority is raising the awareness of governing bodies and stakeholders at each level; continent, state, university, and research centers about the crucial role of computing in research and sciences. But beyond sciences, it would have a large societal impact and would keep Africa in the race for knowledge, better living and peace.

Global and long scale planning is necessary as this evolution needs building networks, facilities and educating new generations of women and men to adopt the rapidly evolving computing landscape. Budget should be expressly dedicated to computing: it would include all equipment needed for scientists, students and technicians for education, research, and R&D (Research and Development) and the budget to build, connect and run large-scale facilities to host and access the exponentially increasing volume of data.

As the demand for computing capacity is growing enormously, close collaboration between countries is the most efficient way to provide the needed resources. None of the main discoveries of the last decade would have been made possible without the collaborative work effort and the setup of closely connected powerful data centers distributed all over the world.

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# Earth Science Working Group

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## 2602 8.1 Introduction and Motivation

2603 The earth sciences represent a major and interdisciplinary field that is fundamentally underpinned by physics  
2604 and physical principles. The term ‘Earth Sciences’ is thus a broad umbrella term that encompasses scientific  
2605 investigation a variety of different scales (sub-micrometer through to planetary scale), and which focusses on  
2606 a variety of different environments. These environments include those located at earth’s surface (the so-called  
2607 critical zone which includes the biosphere, the hydrosphere, and the geosphere), but also extends inwards deep  
2608 into the earth’s mantle and core, and outwards through the atmosphere and out to the cryosphere. Although  
2609 the specific scientific sub-disciplines that fall within the realm of the earth sciences are too many to enumerate,  
2610 those that are most reliant on a strong physics foundation include: hydrogeology, geophysics, geophysical fluid  
2611 dynamics, atmospheric physics and aeronomy, ocean physics, space physics and astronomy, environmental  
2612 physics, meteorology, climatology, tectonics, seismology, gravity and magnetism, mineralogy and petrology,  
2613 geochronology, ecotoxicology, among others. Additionally, almost all sub-disciplines of the earth sciences  
2614 rely on measurements of physical properties to characterize and understand observed phenomena (e.g., Syono  
2615 and Manghnani, 1992 [1]; Doel, 2013 [2]; von der Heyden et al. 2020 [3]). As such, inclusion of the Earth  
2616 Sciences is a crucial addition to any documents or policies related to the future of physics on the African  
2617 continent (e.g., the African Strategy for Fundamental and Applied Physics (ASFAP)).

2618 As anthropogenic impacts continue to change the planet in which we live (e.g., Cracknell and Krapivin,  
2619 2008 [4]), it is becoming ever more important to understand how natural processes are being affected by  
2620 this change. This understanding will help both to inform the design of any mitigation measures that are  
2621 put forward, and to predict the environmental responses in a case where human activity continues under  
2622 a ‘business-as-usual’ scenario. Multiple references have highlighted that Africa is particularly vulnerable to  
2623 environmental change (Stige et al. 2006 [5]; Nkomo et al. 2006) especially given that a vast proportion of  
2624 its inhabitants live life at, near, or even below the bread-line (Nkomo et al. 2006 [6]). For these reasons, a  
2625 road map detailing the current state of affairs and future (envisaged) directions of the Earth Sciences is of  
2626 both highly timeous and of distinct geographic importance.

## 8.2 Challenges

Two considerations posed moderate challenges towards the overarching goal of uniting the earth sciences as a single entity under the greater umbrella of the African Society for Fundamental and Applied Physics (ASFAP). The first of these is the sheer number of sub-disciplines and communities that identify as earth scientists (see an incomplete list of sub-disciplines detailed in section 11.1). To identify and develop rapport with key individuals situated within each of these sub-disciplines required some effort from the two conveners of the working group, whose respective networks were somewhat limited to those of geology, geochemistry and environmental sciences. The second challenge relates to the multi-disciplinary nature of the earth sciences, which results in some workers struggling to identify their affiliation to physics, versus to other key disciplines that underpin earth sciences. For example, a geochemist may feel that his or her field is more closely aligned with chemistry rather than with physics. An important aspect that should be included in any physics policy document, that encompasses earth sciences, is a formal definition that delineates the relationship between the two.

## 8.3 Scientific activities

The activities of the Earth Sciences working group have arguable not been as prolific as those undertaken by several of the other ASFAP working groups. Despite this, the working group has experienced some successes and highlights. These include:

- Ongoing scientific and strategy related interactions with the broader ASFAP community (Haddad et al. 2022 [7]);
- A planned mini-symposium to coincide with International Earth Week 2021 (ultimately postponed to avoid a clash in dates with the African Geophysical Society);
- Development of a mailing list comprising twenty-three email addresses of individuals who are passionate about the future of earth sciences on the African continent;
- Successful presentation of the Earth Sciences working group achievements at a major regional earth sciences conference (Geocongress 2023 (11-13 January 2023; Stellenbosch, South Africa));
- Successful design and distribution of a targeted survey investigating the perceived future needs of the African earth sciences community (see Section ??).

## 8.4 Survey design and responses

The developed survey comprised ten questions of which four probed insights into the meta-data of the respondent (e.g., experience level, field of study, country of habitation), and four questions provided the main source of data for further scrutiny. These four questions were open-ended, and sought to elucidate which issues are most prevalently impacting the African earth sciences, and how additional funding would serve to further improve the status of this important field of science. These four questions were:

- Please detail any barriers (e.g., access to students, funding, analytical equipment, researcher support, etc.) that currently hinder your abilities to conduct earth science research on or for the African continent?

- 2663 • If you were awarded US\$ 1000 towards advancing the physics-related needs or future goals of the earth  
2664 sciences, kindly explain how you would best spend it?
- 2665 • If you were awarded US\$ 1 million towards advancing the physics-related needs or future goals of the  
2666 earth sciences, kindly explain how you would best spend it?
- 2667 • Please leave any other remarks which may serve to advise future physics strategy development for  
2668 advancing the status of earth sciences on or for the African continent.

2669 An advantage to this open-ended style of questioning is that it opened up opportunity for unforeseen responses  
2670 (i.e., the responses are not limited to those on a prescribed list). Over thirty respondents completed the  
2671 survey, with respondents comprising a broad array of nationalities including 30% of respondents each from  
2672 west Africa and southern Africa, 20% from east Africa, and 10% each from north African and other countries  
2673 outside of Africa, as shown in Figure 8-1.

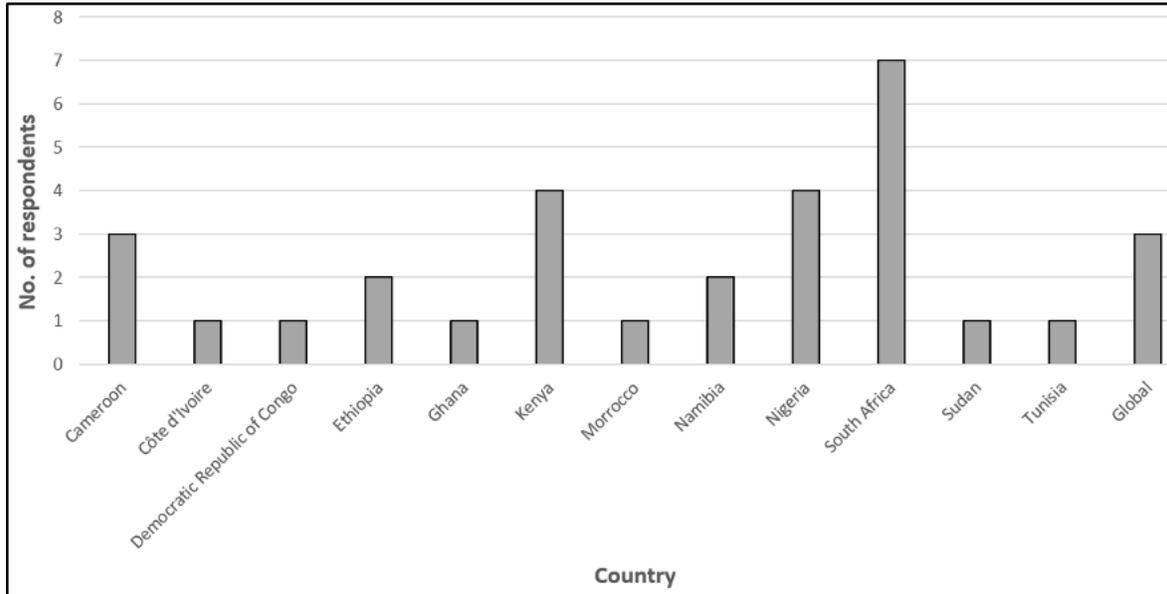


Figure 8-1: A summary of the respondents' countries of employment. 'Global' refers to countries outside of Africa.

2674 Moreover, there was a good spread of experience levels and earth science sub-fields represented in the survey,  
2675 Figures 8-2 and 8-3. Survey responses were interpreted following qualitative data analysis protocols, using  
2676 the 'data that glows' methodology of MacLure, 2013 [?].

## 2677 8.5 High priority future needs

2678 Based on survey responses, the needs of the African Earth Sciences community can be divided broadly  
2679 between those requiring high monetary inputs, those requiring smaller monetary inputs, and those that  
2680 require other forms of support or incentivisation.

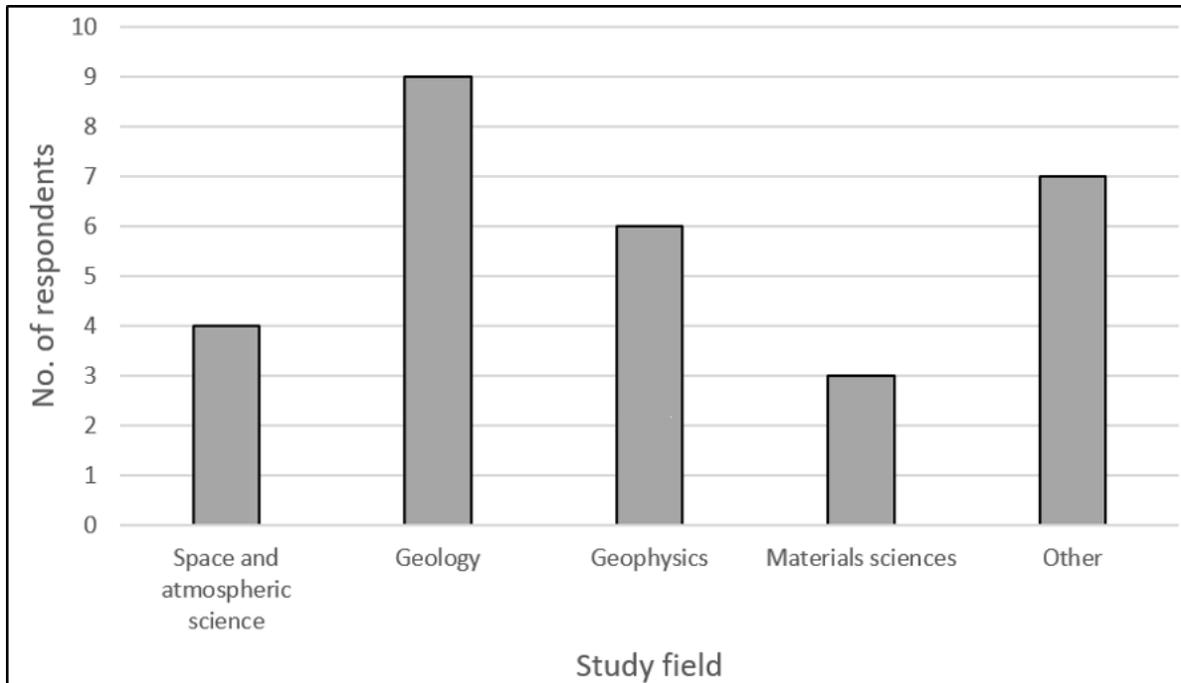


Figure 8-2: A summary of the respondents' study fields. 'Other' includes a diverse array of study fields including remote sensing, geoscience education, particle physics, among others.

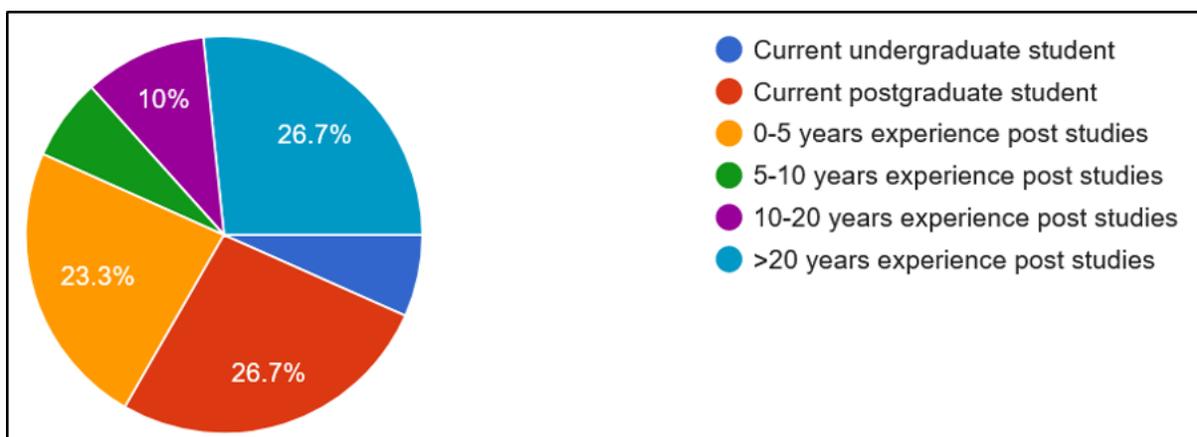


Figure 8-3: Summary of the indicated experience levels of the different respondents, showing a good mix in experience.

### 2681 8.5.1 Needs requiring high degrees of financial support

2682 In a hypothetical scenario in which survey participants were offered one million USD towards achieving their  
2683 research goals, the majority of respondents indicated that they would utilize this money towards setting up  
2684 high-end laboratory facilities that could be utilized towards investigating local- and global research questions.  
2685 This response was received from respondents ranging across all of the different sub-disciplines of the earth  
2686 sciences, and across all of the nationalities and experience levels. Examples of the types of large analytical  
2687 labs suggested include broad-band and short period seismic equipment; a flume for fluid dynamics research;  
2688 multiple meteorological mini-weather stations; among others. Interestingly, two different models for research  
2689 equipment were proposed. Some respondents felt that large research equipment should be housed at a  
2690 centralized and stable research facility (e.g., a well-established and reputable university). This is captured  
2691 by the following statement:

2692 Anonymous respondent A: “Provide critical research equipment to one of the universities that has the  
2693 capacity to house and operate it, provided that the facility be available to other researchers within the  
2694 country.”

2695 An alternative model suggested a series of small laboratories set up across a more expansive geographic  
2696 area, importantly comprising rural regions where labs must necessarily be run by off-grid e.g., photovoltaic  
2697 power solutions. Most respondents highlighted that for any funding awarded towards a new laboratory, a  
2698 subset of the funding needs to be set aside for technical staff training, for operating expenses and for funding  
2699 of associated student projects. Some respondents also highlighted that large amounts of financial support  
2700 could also be split into smaller tranches for utilization towards enhancing student and researcher training.  
2701 Suggested training vehicles included bursaries for undergraduate and post-graduate students, overseas visits  
2702 and conference/workshop attendance for researchers, and towards attracting international post-doctoral  
2703 research fellows to African laboratories.

### 2704 8.5.2 Needs requiring lower degrees of financial support

2705 In line with the responses received for the larger grants, most respondents highlighted that smaller grants  
2706 (i.e., 1000 USD) would be best utilized towards acquiring smaller items of equipment or towards funding  
2707 student bursaries. Concerning the latter point, several respondents indicated that these bursaries should  
2708 be awarded on a competitive basis and according to merit-based criteria. Surprisingly, several respondents  
2709 indicated that the funding would be used to repair or upgrade existing equipment, with the concerning  
2710 implication being that these items are currently not operating at their optimum performance levels. Other  
2711 uses for the small grant awards included field trips, capacity building through local workshops, publication  
2712 costs, and towards partnering with science communication companies to help develop ongoing popular media  
2713 such as apps, comics, TV, etc. that advocate for the earth sciences.

### 2714 8.5.3 Other needs and suggestions arising

2715 The final open question of the survey attracted a range of other recommendations, all geared towards  
2716 enhancing the status of earth sciences on or for the African continent. A large proportion of these focused  
2717 on the need for enhanced collaboration and networking between African researchers. Collaboration, and  
2718 vehicles that drive collaboration, need to be enhanced both for intra-country and intra-continent interactions.

2719 Vehicles identified that would help facilitate collaboration include improved across-border data sharing, and  
2720 development of more enabling government policies, funding and academic/research support. It was also  
2721 suggested that improved industry-university linkages should be facilitated and nurtured, since these linkages  
2722 are mutually beneficial (e.g., Heath, 2000; Agrawal, 2001; von der Heyden, 2019 [10, 9, 11]).

2723 A second key focus area relates to ensuring a sustained talent pipeline for future generations of African earth  
2724 scientists. This may be achieved by establishment of outreach programs aimed at attracting High School  
2725 students to our important discipline. Dedicated investment into Geoscience education initiatives would also  
2726 be useful, particularly if they are underpinned by good educational research, and designed to have longevity.  
2727 As indicated in previous sections, offering bursaries to dedicated and hard-working students will also help to  
2728 ensure a sustained supply of future thought leaders and industry professionals who will drive the science and  
2729 its various practical applications forward. Also indicated previously, these students will need to be trained  
2730 in good laboratories, of which there are currently a dearth. This again underpins the need for financial  
2731 investment into state-of-the-art equipment.

2732 Anonymous respondent B: “Doing Research in physics needs quality equipment.”

2733 Anonymous respondent C: “It is necessary to modernize the laboratories of the earth sciences to supervise  
2734 many students for their Ph.D.”

2735 Other approaches that would serve to strengthen the standing of earth sciences on the African continent  
2736 would be through focus on issues that are topical both to the continent and globally. For example, topics  
2737 such as green energy, global climate change and critical metals all fall within the focus area of the earth  
2738 sciences and are all relatively easily supported by large international funding bodies. Linked to accessing  
2739 large grants, an important skillset that needs better development among local researchers is the ability to  
2740 write strong and competitive research grants. This is succinctly captured in a statement by Anonymous  
2741 Respondent D: “Spread, democratize as aggressively as possible the skills of successful writing of large grant  
2742 proposals.”

## 2743 8.6 Conclusions and perspectives

2744 Based on the somewhat limited feedback received from a survey initiative set up by the ASFAP earth sciences  
2745 working group, the largest and most inhibitory barriers affecting the African earth sciences are 1) a perceived  
2746 dearth of funding and, 2) limited access to high-end analytical facilities. Towards negating the first inhibitor,  
2747 funders are encouraged to open up new funding vehicles that explicitly aim to advance the African earth  
2748 sciences, particularly if the research areas are topical and of societal and environmental relevance to our  
2749 continent (and globally). Furthermore, African researchers need to be better equipped to write, defend  
2750 and deliver on large grant proposals. There is a great opportunity to introduce greater circularity into the  
2751 training provided to upcoming researchers. That is, not only should next generation scientists deliver good  
2752 science, but they should also be trained to write highly-competitive grants.

2753 Anonymous Respondent E: “Postgraduate Students willing to work on the use of physics and physics concepts  
2754 and methods will be encouraged and drawn into the multidisciplinary research consortium which will be  
2755 established with a solid foundation/background underpinned by Physics. The above mentioned research  
2756 and education consortium will then apply and submit research funding proposals for more research funds.  
2757 Physics education and research, physics concepts and methods will be used as background for a greater  
2758 societal and industry impact leveraging of localized and decolonized African realities.”

2759 Towards mitigating the perceived dearth of analytical facilities, a worthwhile departure point would be  
2760 to compile a list of all earth sciences analytical facilities located on the African continent. This list

2761 should be augmented with details of the associated research costs and the availability/openness of the  
2762 unit to intra-continental collaborative efforts. Collaboration can be stimulated by developing strong and  
2763 mutually-beneficial research agreements between countries, laboratories, research institutions and industry  
2764 on the continent. Whereas other parts of the world are engaging in anti-globalisation movements, a general  
2765 absence of this attitude on the African continent will be beneficial towards preferential and expedited local  
2766 advancements.

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# Energy Working Group

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## 2795 9.1 Introduction

2796 Access to modern energy services is essential to achieving basic social needs by promoting economic de-  
2797 velopment. Modern energy services, particularly electricity and gas, affect productivity, health, education,  
2798 safe water, and communication [1]. Energy has a significant impact on socio-economic development in any  
2799 country because it encourages investment, innovation, and the formation of new businesses that promote  
2800 the creation of jobs, inclusive growth, and shared prosperity throughout the entire economy [2]. This fact,  
2801 along with the strong links between energy and the Millennium Development Goals (MDGs), makes it even  
2802 more important to address the challenges and prospects of energy service provision in Africa. Developing  
2803 countries' decisions on the growth of their energy sectors will significantly impact future energy consumption  
2804 trends, fuel preferences, trade patterns, and other relevant aspects in addition to their development. Over  
2805 the past two decades, Africa has exhibited a significant increase in energy consumption, with a reported  
2806 45% increase [3]. However, the energy infrastructure in many areas remains underdeveloped, leaving the  
2807 demands of the population unmet. Despite the wealth of energy resources available to cater to domestic  
2808 needs, many countries continue to lack access to modern energy services. Approximately 620 million Africans,  
2809 which account for two-thirds of the population, do not consume electricity, and a further 730 million rely  
2810 on traditional biomass for cooking. Even for those with access to energy, the quality and cost of supply are  
2811 often found to be subpar [3].

2812 The energy sources used in Africa vary from country to country. However, the most commonly utilised energy  
2813 sources on the continent are oil, coal, natural gas, hydroelectricity, and renewable sources such as solar, wind,  
2814 and geothermal power. It is worth noting that the International Energy Agency (IEA) states that Africa  
2815 possesses 60% of the world's best solar resources, yet only 1% of the installed solar PV capacity. Furthermore,  
2816 the IEA predicts that solar PV will be the most cost-effective power source in many regions of Africa by 2030.  
2817 Affordable and dependable energy are key factors in Africa's economic and social progress. The COVID-19  
2818 pandemic has highlighted the importance of a stable energy supply. Without electricity, the measures put  
2819 in place by the government to contain the virus would have been unbearable. Access to electricity allowed  
2820 people to work from home; schools continued functioning through online classes; and governments continued  
2821 their operations (e.g., through virtual court systems). Electricity also facilitated water utilities to continue  
2822 supplying clean water for handwashing, which was an essential guideline for reducing the spread of the virus  
2823 [4], [5]. Increased access to affordable and dependable energy can play a significant role in mitigating economic  
2824 disruptions caused by the pandemic. As countries prepare for economic recovery, African governments must

2825 focus on creating more job opportunities and stimulating economic growth. Investing in energy access can  
2826 help achieve both goals[6].

2827 The transition towards clean energy on a global scale presents promising prospects for the economic and  
2828 social growth of Africa. As of May 2022, countries committed to achieving net zero emissions accounted for  
2829 more than 70% of the century. This includes 12 African nations contributing to over 40% of the continent's  
2830 total CO2 emissions [7]. The commitment of these nations to achieve net zero emissions contributes to the  
2831 transformation of the global energy sector due to the declining costs of clean technology and shifting global  
2832 investments. African nations, the majority of which are signatories to the Paris Agreement on Climate  
2833 Change, are well-positioned to benefit from technological advancements and attract increasing amounts of  
2834 climate finance [6].

2835 For the African government to ensure greater energy access to its population, diversification of energy sources  
2836 will play a key role, which will include investing in new sources of energy, especially renewables such as wind  
2837 and solar energy, as well as pooling them together to ensure sufficient supply.

## 2838 9.2 Sources of energy and resources in Africa

2839 Africa is endowed with various resources that meet the energy needs of different countries. Different countries  
2840 in Africa have different energy mixes as their sources of energy, including

- 2841 • Hydroelectric energy: in Africa, several countries are tapping hydroelectric as part of the source of  
2842 utility energy; the following are some of the biggest in Africa.
  - 2843 – The Grand Ethiopian Renaissance Dam (GERD) – 6,450 MW: Previously known as the Millen-  
2844 nium Dam, the Grand Renaissance Dam in Ethiopia has been under construction since 2011 and  
2845 is set to become the largest dam on the continent upon completion. Located on the Blue Nile,  
2846 the dam will generate an estimated 6, 450 MW per year in the Benishangul–Gumuz region near  
2847 Ethiopia's border with Sudan.
  - 2848 – Aswan High Dam – 2,100 MW: Located near the city of the same name in southern Egypt, the  
2849 Aswan High Dam ranks as the continent's second-largest dam. Built across the Nile, the dam is  
2850 the largest embankment dam in the world, with a height of 111 m and length of 4,000 m. By  
2851 powering 12 generators, each at a rate of 175 MW, the dam has a total generation capacity of  
2852 2,100 MW.
  - 2853 – Cahora Bassa Dam – 2,070 MW: One of the two major dams on the Zambezi River, the Cahora  
2854 Bassa Dam in Mozambique is the largest hydropower plant in southern Africa. Power was  
2855 generated through five 415 MW turbines with a combined capacity of 2,070 MW. Most of the  
2856 power generated by the Cahora Bassa Dam is exported to South Africa through the Cahora Bassa  
2857 high-voltage direct current (HVDC) line system, with two conversion stations located in Songo,  
2858 Mozambique, and Apollo, South Africa.
  - 2859 – Gilgel Gibe III Dam – 1,870 MW: The Gilgel Gibe III Dam located southwest of Ethiopia's  
2860 capital, Addis Abeba, is a roller-compacted concrete dam and hydroelectric power plant built on  
2861 the Omo River. The Gibe III power station forms part of a cascade of dams, including the Gibe  
2862 I dam, with a capacity of 184 MW, and the Gibe II power station, with a capacity of 420 MW.  
2863 Plans are currently underway to add Gibe IV and V dams with capacities of 1,472 MW and 560  
2864 MW, respectively, to the Gibe Cascade. Currently, during its commissioning process, the future  
2865 electricity generated by the plant is expected to provide half of its capacity to Ethiopia, with the  
2866 other half expected to be exported to Kenya (500 MW), Sudan (200 MW), and Djibouti (200

2867 MW). Under the country's current development plans, Ethiopia has pledged to generate 95% of  
2868 its energy generation from hydropower.

- 2869 – Inga Dams – 1,775 MW: Comprised of two single dams, the Inga 1 (351 MW) and Inga II (1,424  
2870 MW), Dams in the Democratic Republic of Congo (DRC) currently operate at a combined capacity  
2871 of 1,775 MW. Built on Inga Falls, one of the largest waterfalls in the world, hydroelectric dams  
2872 currently work at merely half of their potential capacity. The expansion of the dam has generated  
2873 interest from nations and power companies all over Africa that have expressed interest in the  
2874 pursuit of a Grand Inga project estimated to cost \$80 billion, which would become the largest  
2875 power station in the world with a capacity of up to 70 GW.
- 2876 – The Kariba Dam, 1,626 MW, is located between Zimbabwe and Zambia. It is 128 m tall and 579  
2877 m long and is the largest man-made dam in the world. Currently, with a total installed capacity  
2878 of 1,626 MW, the dam is under expansion to increase its yield. Power stations located on the  
2879 north and south banks of the dam provide Zambia and Zimbabwe with their respective energy  
2880 sources.
- 2881 – Merowe Dam – 1,250 MW: In terms of its size, with a length of 7km and height of up to 67 meters,  
2882 the Merowe Dam in northern Sudan is the largest contemporary hydropower project in Africa by  
2883 size. Situated on the Nile, the hydropower dam consists of 10 turbines, each with a capacity to  
2884 produce 125 MW for a combined total of 1,250 MW.
- 2885 – Tekezé Dam – 1,200 MW: With a height of 188 meters, the Tekezé Dam in Ethiopia is the tallest  
2886 dam on the continent. Situated on the Tekezé River, a tributary of the Nile, the \$360 million  
2887 dam is one of the largest public works projects in the country. The dam's powerhouse contains  
2888 four 75 MW turbines, each generating 300 MW of electricity for a combined total of 1,200 MW.  
2889 Akosombo Dam – 1,020 MW: Located at the base of Lake Volta, the Akosombo Hydroelectric  
2890 Dam in southeastern Ghana draws its hydropower from the world's largest person-made lake in  
2891 the world, with a surface area of 8,502km<sup>2</sup>. Initially constructed to provide electricity for the  
2892 country's aluminum industry, the power plant currently has an installed capacity of 1,020 MW,  
2893 and provides electricity to Ghana, Togo, and Benin.
- 2894 – Kainji Dam – 760 MW: Built on the Niger River in Nigeria, the Kainji Dam provides electricity  
2895 to all of the west-African country's major cities. Despite the intention of designing a dam with  
2896 an installed capacity of 960 MW, only eight of the proposed twelve turbines have been installed,  
2897 reducing the capacity of the plant to 760 MW. The Kainji Dam, with a length of 10km, is one of  
2898 the longest dams in the world.

- 2899 • Thermal energy
- 2900 • Wind power
- 2901 • Solar power
- 2902 • Geothermal energy

### 2903 9.3 Energy pooling in Africa

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# Fluid and Plasma Working Group

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## 2923 Abstract

2924 Abstract: In physics, a fluid is a liquid, gas, or other material that continuously deforms under an applied  
2925 shear stress, or external force. They are substances which cannot resist any shear force applied to them.  
2926 Meanwhile, plasma refers to an electrically conducting medium in which there are roughly equal numbers  
2927 of positively and negatively charged particles produced when the atoms in a gas become ionized. In this  
2928 report, the concept of fluid and plasma physics is briefly outlined, followed by an overview of the status and  
2929 impact of fluids and plasma physics education and capacity development in Africa.

2930 Keywords: Fluids and plasma physics; Magnetohydrodynamics; Education and capacity development in  
2931 Africa

## 2932 10.1 Introduction

2933 Adequate knowledge in fluid and plasma physics is a necessary prerequisite for development of technology and  
2934 innovation, and thereby constitutes a key input into the transition to a knowledge-based economy [1]. Ap-  
2935 plications of fluids and Plasma physics range from energy production by thermonuclear fusion to laboratory  
2936 astrophysics, creation of intense sources of high-energy particle and radiation beams, and fundamental studies  
2937 involving high-field quantum electrodynamics [2]. Plasma is being used in many high tech industries. It is  
2938 used in making many microelectronic or electronic devices such as semiconductors. It can help make features  
2939 on chips for computers. Plasma is also used in making transmitters for microwaves or high temperature films.  
2940 Fluids and Plasma research are leading to profound new insights on the inner workings of the sun and other  
2941 stars, and fascinating astrophysical objects such as black holes and neutron stars. The study of fluids and  
2942 plasma enable prediction of space weather, medical treatments, and even water purification [3]. Majority of  
2943 plasma phenomena observed in real experiments can be explained by a fluid model, in which the identity  
2944 of the individual particle is neglected, and only the motion of fluid elements is taken into account [4]. The  
2945 theoretical study of plasma as fluids are governed by the concept of magnetohydrodynamics which involved  
2946 a combination of conservation of conducting fluid mass, charges and momentum equations coupled with  
2947 state equation and Maxwell equations of electromagnetism [5]. Plasma may involve the dynamics positively  
2948 charged ion fluid and negatively charged electron fluid. In a partially ionized gas, for the dynamics of fluid of  
2949 neutral atoms may also be involved. The neutral fluid will interact with the ions and electrons only through

collisions. The ion and electron fluids will interact with each other even in the absence of collisions, due to the generation of the electric and magnetic fields [6]. The magnetohydrodynamic approach treats the plasma as a single fluid with mass density  $\rho_m = n_e m_e + n_i m_i$ , charge density  $\sigma = q_e n_e + q_i n_i$ , mass velocity  $V = (n_e m_e v_e + n_i m_i v_i) / \rho_m$ , current density  $j = q_e n_e v_e + q_i n_i v_i = q_e n_e (v_e - v_i)$  and total pressure  $p = p_e + p_i$  as outline in the equations below [7, 8, 9]:

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (nV) = 0 \quad (\text{Mass conservation}); \quad (10.1)$$

$$\frac{\partial \sigma}{\partial t} + \nabla \cdot (nj) = 0 \quad (\text{Charge conservation}); \quad (10.2)$$

$$\rho \left( \frac{\partial V}{\partial t} + V \cdot \nabla V \right) = \sigma E + j \times B - \nabla P \quad (\text{Momentum conservation}); \quad (10.3)$$

$$P = C n^\gamma \quad (\text{Equation of state}); \quad (10.4)$$

with the addition of Maxwell equations.

where the subscripts  $i$  and  $e$  represent the ions and electrons, respectively,  $C$  is a constant,  $\gamma$  is the ratio of specific heat  $C_p/C_v$ ,  $t$  is the time,  $B$  is the magnetic field strength,  $E$  is the electric field,  $T$  is the temperature,  $n$  is the particle density,  $\eta$  is the resistivity.

## 10.2 Status of Fluids and Plasma Physics Internationally

Fluid and plasma research is advancing rapidly, with fluid dynamics focusing on computational methods like CFD, turbulence modeling, and microfluidics, benefiting industries such as aerospace, automotive, and medicine. Plasma research is highlighted by efforts in fusion energy, particularly ITER, alternative confinement methods, and applications in space propulsion, medicine, and materials processing. Global collaborations and funding are key drivers, with AI and machine learning accelerating simulations in both fields. Emerging technologies like quantum computing hold promise for more complex simulations, while sustainable energy solutions and space exploration remain critical application areas. ITER (International Thermonuclear Experimental Reactor) is a large-scale international project aimed at demonstrating the feasibility of nuclear fusion as a sustainable, safe, and virtually limitless energy source. It is designed to be the world's largest tokamak—a device that uses magnetic fields to confine and control plasma, the hot, charged gas where fusion reactions occur, similar to those in the sun. Located in southern France, ITER is a collaborative effort involving 35 countries, including the European Union, the U.S., China, Russia, Japan, India, and South Korea. The main goal of ITER is to achieve a sustained fusion reaction where the energy output exceeds the energy input, paving the way for future fusion power plants. It is expected to produce 500 megawatts of thermal power from 50 megawatts of input power, demonstrating the practicality of fusion as a reliable energy source without the carbon emissions or long-lived radioactive waste associated with nuclear fission. Though ITER won't generate electricity directly, it will serve as a crucial stepping stone for future commercial fusion reactors.

## 10.3 Status of Fluids and Plasma Physics in Africa

Due to the lack of necessary research laboratories infrastructure, technical support, and so forth in many academic and research institutions in Africa, relatively few scientists in the field of fluids and plasma physics have managed to perform at a level competitive with the best in the world. The figure 1 below depicts the level of research output in the fluids and plasma physics in Africa [10].

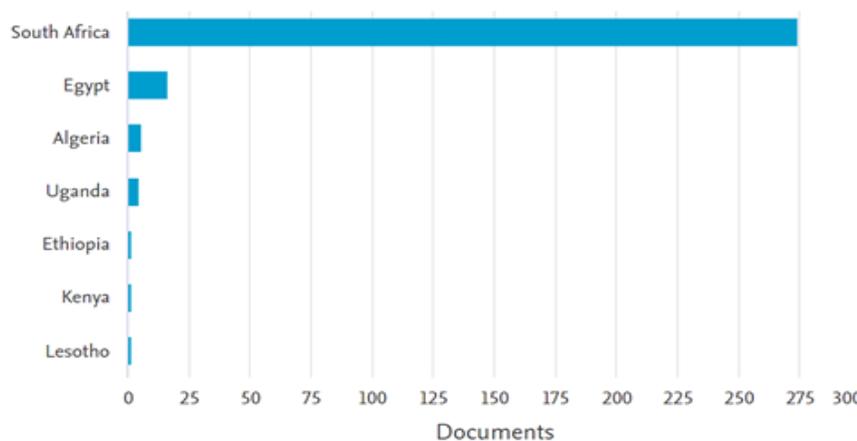


Figure 10-1: Fluids and plasma physics research output in Africa (source-SCOPUS database [10])

From figure 10-1, it is obvious that very few countries and scientists within Africa are engaging in productive research in the field of fluids and plasma physics. The largest visible research output on fluids and plasma physics comes from the institutions in South Africa, followed by the institutions in Egypt, Algeria, Uganda, Ethiopia, Kenya and Lesotho. Moreover, Fluid and plasma physics research in Africa is emerging, with growing importance in areas such as environmental management, renewable energy, healthcare, and space science. Fluid dynamics research is primarily focused on addressing challenges related to water resource management, hydrology, and climate modeling, as well as optimizing renewable energy systems like wind and hydropower, with South Africa, Egypt, and Kenya being key contributors. In the biomedical field, fluid dynamics is being applied to healthcare solutions, particularly for cardiovascular diseases and drug delivery systems. Plasma physics research, though still in its infancy, is expanding, with South Africa playing a leading role in fusion energy research and space propulsion. Plasma applications in medical fields, such as sterilization and wound healing, are also being explored across the continent. Countries like Nigeria and Algeria are contributing to plasma physics research, especially in areas like satellite propulsion and environmental remediation. International collaborations and regional partnerships are essential for building research capacity and infrastructure, with future directions focusing on sustainable energy solutions, climate adaptation, and healthcare advancements to address Africa's socio-economic challenges. Meanwhile, research and academic institutions in several African countries may be engaging in some research activities in fluids and plasma physics, however, their output may not be visible on the SCOPUS database.

## 10.4 African Participation in ITER Fluid & Plasma Physics Research

Fluid and Plasma research, especially in fusion energy, offers the potential for clean, limitless energy, while also contributing to space propulsion, advanced manufacturing, and medical applications like sterilization and cancer treatment. African participation in ITER (International Thermonuclear Experimental Reactor), led by South Africa, is particularly important for the continent's involvement in cutting-edge plasma physics and fusion energy research, enabling knowledge transfer, capacity building, and contributions to global scientific efforts. This involvement not only supports Africa's energy sustainability goals but also fosters international collaboration and technological growth in areas such as satellite propulsion and environmental remediation. As African countries engage in global scientific initiatives, they position themselves to address critical socio-economic challenges through these advanced research fields.

## 10.5 Fluid & Plasma Physics Education and Capacity Development in Africa

The challenges of education and capacity development in the field of fluids and plasma physics in Africa include inadequate funding of science education at secondary and tertiary levels, lack of infrastructure, absent of physics-based industries, poverty, etc. [11]. To excel in physics & science education and training in Africa is to conquer Mount Everest without the aid of additional oxygen. Meanwhile, scientific advancement cannot occur without quality education; to achieve that quality, African countries will require significant investment at all educational levels. African scientists have to convince their governments, businesses, and the public that investment in physics education is beneficial and will lead to economic development and an enhanced quality of life [1]. Physics curricula should emphasize project work and problem solving, with a complement of activities in entrepreneurship. Figure 10-2 below depicts a strategy that African countries' may adopt for education and capacity development in fluid and plasma physics.

The proposed capacity development strategy envisages a close and mutual interaction between the African educational institutions, research institutions, and industries. Moreover, post-doctoral research activities should be encouraged in the field of fluid and plasma physics in African tertiary and research institutions, scientists in Africa should be encouraged to publish their research outputs in mainstream peer-review academic journals for global visibility.

## 10.6 Recommendation and Conclusion

To improve fluid and plasma research, international collaboration, and education in Africa, policymakers should increase investment in Research & Development by boosting public funding and incentivizing private sector involvement. They need to build and modernize research infrastructure by creating centers of excellence and upgrading university labs. Strengthening education in STEM (Science, Technology, Engineering, and Mathematics) fields is crucial, with updated curriculums, graduate scholarships, and vocational training. Fostering global and regional collaborations, including partnerships with initiatives like ITER, will provide African researchers access to cutting-edge technologies. Industry-academia linkages should be promoted to translate research into practical applications, while innovation hubs and incubators can support startups. Retaining talent through competitive salaries, funding, and return programs for African scientists abroad is

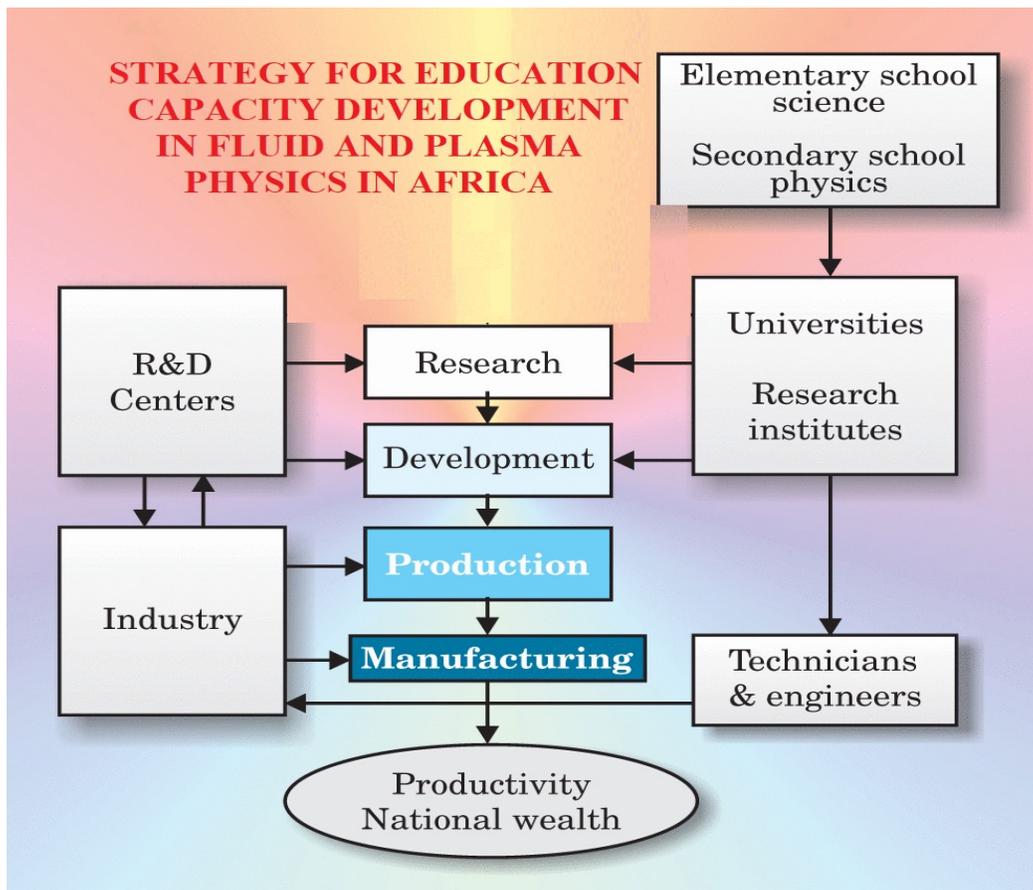


Figure 10-2: Strategy for education capacity development in fluid and plasma physics in Africa

3039 essential to combat brain drain. Finally, public awareness campaigns and youth STEM engagement initiatives  
3040 will help build a strong scientific culture and drive future research in fields critical to Africa's development,  
3041 like clean energy, space technology, and healthcare.

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# Instrumentation and Detectors Working Group

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## 11.1 Introduction and Motivation

By construction, this working group is transversal and multidisciplinary, and its activities are related to all other physics groups. The Instrumentation and Detectors Working Group aims to identify existing or new initiatives and projects within a wide range of instrumentation, which should be further developed in order to become valid proposals to provide access and/or create new facilities across Africa. The role of this WG is to coordinate and encourage such initiatives and to provide assistance in the process of writing concrete proposals toward the so-called 'White papers' [\[Ref\]](#).

## 11.2 Major challenges for scientific activities

In the early phase of the WG, a small and probably insufficient attempt was made to generate an approximate overview of existing (active) facilities in Africa by scanning through web pages, conference proceedings and other miscellaneous sources of information. This process turned out to be fairly difficult, especially in the physics domains outside of the competences of the WG conveners. However, the prejudice that most of the instrumental centers are concentrated in very specific regions on the continent, e.g., South Africa, Namibia and in the Northern part of Africa, seemed to be confirmed, while very few are located in the sub-Saharan countries of central Africa.

Some of the large research activities are also described in chapter 4 on various instrumentation used in astronomy and cosmology across the whole continent, in chapter 3 on accelerator technologies and in chapter 16 with respect to the participation of several research groups in particle physics experiments, especially at CERN[1] in Geneva, Switzerland: Researchers from universities and laboratories in Morocco, Egypt, and South Africa are members of these large international collaborations like ATLAS, ALICE, and CMS and are contributing to High Energy Physics Experiments. Recently, physicists from Nigeria, Algeria, and Tunisia have joined these collaborations.

3091 In the U.S., the university of Antananarivo has joined the DUNE[11] long base line neutrino experiment and  
 3092 the new facility of an electron ion collider[12] at Brookhaven National Laboratory in New York has attracted  
 3093 researchers from Egypt, Tunisia, and Zambia. Lastly, Senegal is involved at the Thomas Jefferson National  
 3094 Accelerator Facility in Virginia[24] and the Facility for Rare Isotope Beams in Michigan[25].

3095 African countries can contribute to the field of experimental physics, thanks to the international character of  
 3096 this field of physics. In the development of these collaborations, African laboratories profit from knowledge  
 3097 transfer and the installation of new facilities, which opens up further possibilities for future activities.

3098 Examples of relatively large centers with an important activity in instrumentation are the nuclear facilities  
 3099 with accelerators at iThemba Labs[2] and several astrophysics observatories such as the South African  
 3100 Astronomical Observatory (SAAO)[3] and Square Kilometer Array (SKA)[4] in South Africa, the High  
 3101 Energy Stereoscopic System (HESS)[5] in Namibia, and larger research centers such as the Center National  
 3102 de l'Énergie, des Sciences et des Techniques Nucléaires (CNESTEN)[6] in Morocco and the Center for  
 3103 Development of Advanced Technologies (CDTA)[7] in Algeria. Other smaller instrumentation-focused centers  
 3104 exist also in other countries, that includes the Lasers Atoms Laboratory at Cheikh Anta Diop University  
 3105 and the Radiocarbon Laboratory of the Institut Fondamentale d'Afrique Noire (IFAN)[8] in Senegal, the  
 3106 Atomic Molecular Spectroscopy and Applications Laboratory at the University of Tunis El Manar in Tunisia,  
 3107 and the Center for Energy Research and Development (CERD)[9] in Nigeria, among others. Various small  
 3108 research groups established a multi-country collaboration to establish a larger network of complementary  
 3109 scientific capabilities like the African Laser Center[26]. There are many other laboratories on the continent  
 3110 with various instruments to conduct research, however, not only a large fraction are known to be inactive  
 3111 due to lack of resources to repair some key components, albeit with some needed minor repairs, but also the  
 3112 large majority being unknown to the African scientific community.

3113 A first meeting of the WG took place in November 2021, with the principal goal of helping in the submission  
 3114 of Letters of Intent (LoIs) designed to be a call to the African scientific community to obtain inputs for  
 3115 the African Strategy for Fundamental and Applied Physics (ASFAP). These LOIs were further analyzed by  
 3116 structuring the collected information on existing facilities. This initial survey was complemented with other  
 3117 information collected from presentations at various scientific meetings, conferences, and workshops such as  
 3118 ACP2021[10] and others. Two main issues were raised repeatedly:

- 3119 • There is a strong consensus that the main problem researchers face is the need and easy accessibility  
 3120 of experimental facilities to conduct their research; and
- 3121 • The second essential need is to overcome the lack of educational training centers in instrumentation  
 3122 for basic and advanced experimental physics.

### 3123 11.3 Analysis of submitted Letters of Intent (LoIs) related to 3124 instrumentation

3125 After the first set of submitted LoIs, several were identified that possibly relate to instrumentation needs.  
 3126 These LOIs were grouped in three categories as listed below (the numbers in the brackets refer to the  
 3127 submission identification of the LoI). A graphical representation is provided by Fig.11-1:

- 3128 1. Extensions of existing facilities:
  - 3129 • (Radio)-Astronomy (51, 54, 56, 67)

- 3130           • Accelerator centres (17, 24)
- 3131    2. New facilities
- 3132           • Astronomy: local observatories for North Africa (14)
- 3133           • Astroparticle underground (15)
- 3134           • African millimetre telescope (33)
- 3135           • Am-Be neutron source (39)
- 3136           • AfLS (not a special LoI)
- 3137           • Instrumentation for AfLS (58, 59, 61,66)
- 3138    3. Centers of Excellence (within which the instrumentation part was not always explicit or clear)
- 3139           • Graphen Flagship (4)
- 3140           • Energy centre of excellence (5)
- 3141           • NANOAFNET(10)
- 3142           • Quantum physics and biology (19, 23, 27, 49)
- 3143           • Education, ICEPA (68), Internet of Things

3144 Three types of LoIs spanning over many fields of physics emerged, some proposing extensions of already  
3145 existing facilities, others the creation of new facilities. A third category of LoIs concentrated on centers of  
3146 excellence to address specific topics, emphasizing collaboration between African countries.

3147 In the spring 2022 the conveners of the WG started to approach the authors of the existing LoIs directly  
3148 with two goals: (1) to compile more details pertaining to instrumentation and (2) to encourage a plan for  
3149 the organization of a global collaborative effort; the latter aiming to coordinate concrete action items and  
3150 to assist in instrumentation needs. However only two meetings could be held, on May 5<sup>th</sup> and June 9<sup>th</sup>,  
3151 gathering a total of 21 and 14 participants, respectively. Further meetings were planned but canceled due  
3152 to problems identifying dates accommodating the speakers and conveners' availability. The beginning of the  
3153 summer 2022 break put an end to that round of meetings.

3154 On May 5<sup>th</sup> three LoIs were discussed, namely letter #39 (Am-Be neutron source), #54(Low Frequency(<  
3155 1 GHz) RadioInterferometric Arrays), and #33 (The first millimeter-wave radio telescope). The following  
3156 meeting on June 9<sup>th</sup> centered on two existing facilities at iThemba Labs (#17, #24) and #10, UNESCO-  
3157 UNISA[22] and NANOAFNET[23]. Brief summaries for the former are listed below.

3158 **LoI #39: Am-Be neutron source** proposes to extend the use of Am-Be neutron sources for teaching  
3159 and applied research beyond Nigeria to other African countries. Transferring this technology will  
3160 stimulate new collaborations. Neutron sources are technically much easier than research reactors to  
3161 probe materials with thermal neutron reflection technique or neutron activation analysis. Only 8  
3162 African countries have research reactors: Algeria(2), DR Congo (2), Egypt (2), Ghana (1), Libya (1),  
3163 Morocco (1), Nigeria (1), and South Africa (1).

3164 **LOI #54: Low Frequency(< 1 GHz) RadioInterferometric Arrays** which is an already growing in-  
3165 ternational collaboration between Gabon, New Zealand, and South Africa that explores the time  
3166 dependent density of the ionosphere, which has a large impact on many communication channels  
3167 with satellites but also on radio-astronomy. Arrays of GPS stations can monitor the Total Electron  
3168 Content (TEC) of the ionosphere. Transient Array Radio Telescopes (TART) or a scaled-down version  
3169 of The Long Wavelength Array (SDLWA) address astrophysical topics.

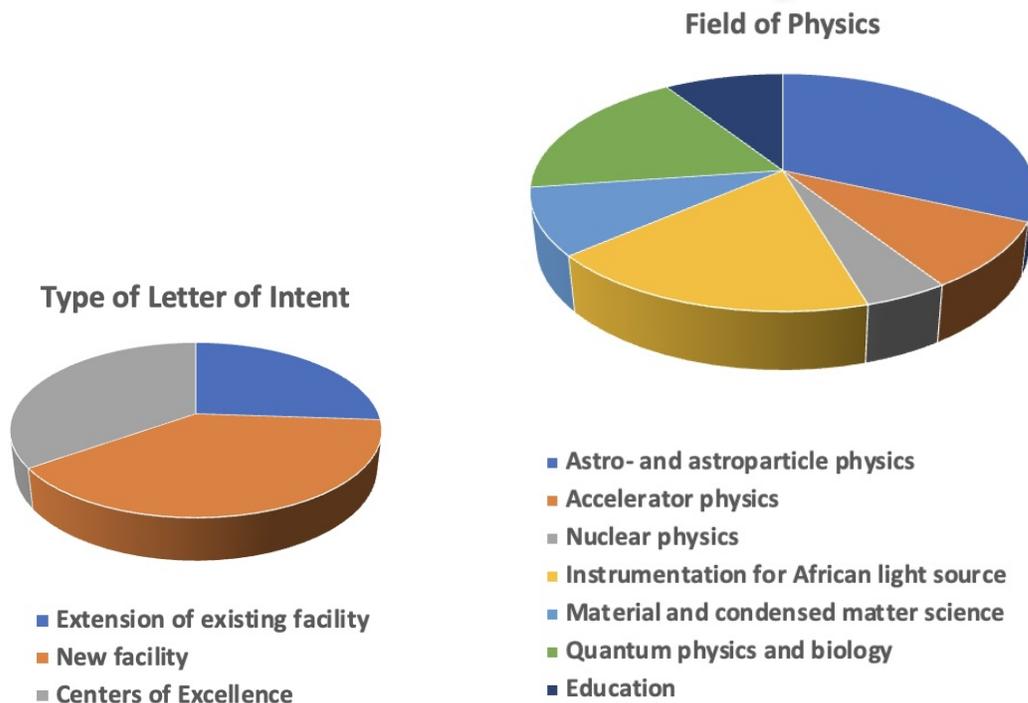


Figure 11-1: The Letter of Intents submitted by the African scientific community grouped by type (left) and sub-field of physics (right).

3170 **LOI #33: The first millimeter-wave radio telescope** which is a “single dish” radio telescope cur-  
 3171 rently being built in Namibia. It will open new perspectives for astrophysics in Africa as well as  
 3172 new international collaborations, especially if the telescope is incorporated in the world wide Event  
 3173 horizon telescope[27].

3174 All the above mentioned projects are built on some already existing experimental activities and have the  
 3175 potential for the future to create African-wide collaborations. The existing facilities at iThemba Labs do  
 3176 already attract scientists from other countries like Algeria, Senegal, Burkina Faso, and Nigeria; however,  
 3177 there is quite some room to further increase such collaborations.

3178 In the discussions following the presentations, it became evident that one of the most important short-  
 3179 comings was in fact the problem of finding enough person power to widen the scope of these projects beyond  
 3180 the country where these activities are located presently. Especially for the astrophysical related projects this  
 3181 is a bit surprising because Africa has a fairly large astronomy community, particularly in East Africa.

3182 One of the projects, namely the proposal for an underground laboratory in a tunnel in South Africa (LoI #15)  
 3183 took a very positive development during the last years into a strong collaboration now called PAUL (for Paarl  
 3184 Africa Underground Laboratory) and is described in more detail in chapter 17. It has been published[14]  
 3185 and presented at several conferences[13]. Unfortunately, because of difficulties to find a convenient time slot,  
 3186 this project could not be reviewed by the Instrumentation and Detector Group. The proposal consists in  
 3187 the creation of a new underground facility in the existing Huguenot tunnel similar to existing underground  
 3188 laboratories in the world. If realized in the future, it will create unique research possibilities in many fields

3189 of physics for the African continent. It is a prime example of successful collaboration building between many  
3190 African and international scientists.

3191 Unfortunately, the start of the LoI-review could not be continued after the summer break, for various reasons,  
3192 mainly manpower, and the lack of participation and resonance within the community.

## 3193 11.4 High priorities

3194 Several ideas of how to improve the lack of know-how in instrumentation and experimental facilities were  
3195 discussed in many meetings. The existence of more such facilities would certainly also increase the number  
3196 of people interested to extend their experimental research activities. As mentioned already in the previous  
3197 section, difficult communication between the researchers and engineers over the vast African continent is a  
3198 further obstacle to progress in the fields. While it is difficult to prioritize any of the ideas presented in the  
3199 LOIs, the Instrumentation and Detector Working Group identified three areas that could serve as a basis for  
3200 improving the state of scientific excellence in Africa.

### 3201 11.4.1 A proposal for an International Center for Experimental Physics in 3202 Africa (ICEPA)

3203 Within the Instrumentation and Detector working group a proposal for an “International Center for Ex-  
3204 perimental Physics in Africa (ICEPA)” was discussed in order to address the lack of experimental training  
3205 facilities in Africa. Some ideas were sketched and then submitted as a LoI (#68). The LoI was also presented  
3206 at a meeting of the Physics Education working group. The idea for such a school was born from the apparent  
3207 lack, but high need for experimental education and know-how in most African countries. The concept is  
3208 very much inspired by the African Institute for Mathematical Sciences (AIMS[15]) and the US Particle  
3209 Accelerator School[28], as well as other educational centres like the Southern African Institute for Nuclear  
3210 Technology and Sciences (SAINT[16]) or the Sèmè City[17] in Benin.

3211 The proposed center would consist of a master-like curriculum of typically one and a half year, including  
3212 a 6-month research project and would include high-level lectures with a major component on hands-on  
3213 experiences. A final examination and a recognised diploma (the association to a university will be required  
3214 in such case) would conclude the cursus. While the proposed training centre is conceptually very similar to  
3215 AIMS, it focuses on experimental techniques used in physics and is strongly oriented towards instrumentation.  
3216 For the latter, the idea is to build experimental installations and facilities at strategic locations on the African  
3217 continent. The instrumentation could partially be contributed or donated by international collaborators and  
3218 universities. These donors ideally should also take the responsibility to maintain the equipment, at least for  
3219 the first years, until a local staff has been trained and qualified.

### 3220 11.4.2 Small physics experimentation and the Internet of Things

3221 Another very interesting and potentially powerful possibility with the goal to foster experience in instrumen-  
3222 tation, is the intense use of micro processors and controllers for education. Furthermore, it is much easier  
3223 to establish.

3224 Most of today's physics experiments use sensors converting measured physical quantities into electronic  
3225 signals, which are finally acquired and treated with computers. This means that skills in electronics,  
3226 computer interfacing and programming are essential for an experimental physicist. Micro-controllers are  
3227 mass produced[19] and for this reason they have become extremely cheap. This is a major advantage for  
3228 countries with small budgets. On the other hand, these micro-controllers have become very powerful with  
3229 many low-cost standardized interfaces like GPIO, I2C, I2S, Can bus etc.[20], but still with high precision.  
3230 Examples of sensors easy to implement are:

- 3231 • sht30: temperature and humidity sensor
- 3232 • PlanTower pms5003 (sensor with laser technology measuring light deflection through dust particles)
- 3233 • Analog devices MAX 2769 GPS receiver
- 3234 • MPU6050 accelerometer and gyroscope
- 3235 • and many, many more

3236 Very divers experiments can be made for a few dollars using these devices such as:

- 3237 • Medical measurements like ECG, heart rate, oxygen content in the blood etc.
- 3238 • Environmental measurements like air or water quality
- 3239 • Meteorologic measurements of air temperature and humidity, soil moisture, wind speed etc.
- 3240 • Smart farming experiments
- 3241 • and many more.

3242 Some of the micro-controllers integrate network interfaces (Ethernet or WiFi, BlueTooth or GSM) allowing  
3243 them to be connected to the Internet. Measured data can be transferred to servers and further analyzed and  
3244 displayed there. These servers can give world-wide access to the measurement results. These are systems of  
3245 type "Internet of Things"[18]. It is easily possible to provide documentation of experiments on the Internet  
3246 using Wiki pages. The software needed for data readout, readout, analysis and communication with the  
3247 Internet can be made available through github[21], allowing easy collaboration between groups of physicists  
3248 working on similar subjects across borders. Unfortunately there are very few universities in Africa providing  
3249 courses on the Internet of Things, despite the very limited budget needed to set up such a course and the  
3250 great potential for the students they would have. Teaching digital electronics, data analysis, micro-controller  
3251 programming of WEB programming would give the student chances in a wide range of industries also outside  
3252 of physics.

### 3253 11.4.3 Regional instrumental conferences

3254 Regional conferences focused on instrumentation and detectors across different fields could be one way  
3255 of enhancing the exchange of knowledge and expertise between scientists of neighboring countries and to  
3256 stimulate new collaborations.

## 11.5 Conclusion, synergies with other fields and perspectives

3258 After an enthusiastic start in 2021/2022 in the context of the ASFAP townhall meeting in the Spring 2022, the  
3259 activities of the Instrumentation and Detector working group came to an apparent hold during the Summer  
3260 2022. Therefore the group could not guide the proponents of LoIs to generate White Papers. The activities  
3261 also suffered from a lack of interaction with the other working groups, whose input is urgently required  
3262 because instrumentation can only be developed in a global context of physics and education. Examples  
3263 for the latter are the proposed instrumentation school (ICEPA) and the implementation of "The Internet  
3264 of Things" into universities curricula. The mobilization of the African scientific community itself is still  
3265 insufficient to develop a strategy and the proposed projects and to find African leaders as spokespeople for  
3266 these.

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# Light Sources Working Group

3303 SESAME Light Source (Synchrotron Light for Experimental Science and Applications in the Middle East),  
3304 Allan, As-salt, Jordan- on leave from: Department of Physics, Helwan University, Cairo, Egypt

## 3305 *Preface*

3306 “Immeasurable studies have been implemented, many reports, models and calculations strikingly revealed  
3307 that the atmosphere is warming, 16 of the 17 warmest years on record occurred since 2001 according to  
3308 NASA, one 8<sup>th</sup> of all species on the planet are at risk of being lost, 2.2 billion people do not have regular  
3309 access to clean fresh water [1], forests disappear [2], oceans are polluted [3].”

3310 Major catastrophes are queuing on clean water, food security, disaster management models, human health,  
3311 climate change, sustainable energy, environment. In a recent article by Antje Vollmer [4], the author signifies  
3312 that the most important focus is to be on how to answer the so many evolving questions and challenges  
3313 facing the mankind, on how to get actions from science and in particular from the large-scale infrastructures.  
3314 Vollmer summarizes the nature and importance of these facilities: as intrinsically international, inter-,  
3315 multi- and cross-disciplinary and excellence driven – have possession of a fantastic triangle core of research,  
3316 education, and innovation.

3317 Light sources among such large-scale infrastructures present a spectacular scientific portfolio spanning  
3318 from physics, chemistry, biology, new materials, energy research, pollution, food, medicine and pharma,  
3319 engineering and smart materials research, to art restoration, cultural heritage, and paleontology. As a  
3320 consequence, a growing user community is monitored both in numbers and in acquired skills and experiences,  
3321 which paves the way to further developments and cooperation with a common goal to address the imposing  
3322 challenges of the years to come.

3323 Africa is not an exception in the human race of advancing science and technological grounds towards the  
3324 implementation of the Sustainable Development Goals. Many challenges are accruing with an accumulative  
3325 mode such as establishing and/or consolidating cutting-edge large scale research infrastructures, addressing  
3326 the so many local and/or regional concerns, as well as strengthening industrial development for a sustainable  
3327 economy. Into the discussion point, is an African Synchrotron light source offering plentiful scientific  
3328 techniques to support extensive capabilities in basic science and applied science. This has been under-  
3329 valued and under-resourced over the years. It is time to revive the vision that Africa must take its equal  
3330 place as a co-leader in the global scientific process, along with all the social-economic benefits thereto. With  
3331 a global prospective, a light source in Africa presents an ambitious international project that will provide a  
3332 high-impact multi-disciplinary science and technology, and would represent a major step of science diplomacy  
3333 towards the Pan-African vision and play an important role in stopping the African scientific diaspora, and  
3334 perhaps even reversing it as the diaspora returns.

3335 This report sheds some light on the vital importance of establishing an African light source facility that is  
3336 projected to serve Africa -and beyond- with a strong involvement of young scientists and African diasporas.  
3337 Consecutively, this aims at stimulating new partnerships between countries and organizations to together  
3338 address the several mutual concerns of science, education, and economic development, with an impact that  
3339 will robustly go beyond any “national” science.

## 12.1 Introduction and Motivation

### 12.1.1 General overview on Science Missions, challenges, and impact

In March 2024, the International Science Council, ISC, has launched the “Global Call for Pilot Missions and for Visionary Funders to support Science Missions for Sustainability” [5]. The Call aims at a universal action that is collectively projected to realize the United Nations Sustainable Development Goals, SDGs, as per the 2030 Agenda (Fig.12-1). The Call signifies a strategic proposal towards a transformative future for science and humanity. Such a determined objective towards collaborative and sustained actions necessitates a standardization of priorities [5].



Figure 12-1: United Nations Sustainable Development Goals, SDGs, as per the 2030 Agenda [13].

Additionally, a joint measure that can significantly alter science funding systems is intended in strengthening the science’s impact on realizing the SDGs. This imposes a fundamental transformation in our scientific thinking and practices on how we do conduct research, utilize and apply scientific findings, and how can we prioritize and allocate funding to tackle the most persistent challenges.

The ISC Call underlines the instance for which the science funders can play a leadership role in funding specific science grounds encouraging them to stepping out of “business-as-usual” approaches towards a worldwide renovation beyond traditional science models. This entails innovative strategies and collaborative actions on all levels. For instance, scaling up the investment in science to strongly support transdisciplinary and inclusive mission.

The ISC’s groundbreaking report - “Flipping the Science Model: A Roadmap to Science Missions for Sustainability” that was unveiled at the 2023 UN High-Level Political Forum, articulates such a looked-for visionary model. It points out at elevating tailored partnership between scientists and policy makers to new heights of rigid solutions that match the scale of the most critical challenges of complex sustainability via integrated and fully actionable knowledge [6].

Large-scale infrastructures supporting big science such as CERN was strongly supported by the scientific community. At the present time, the world needs to think with the same visionary CERN-mindset to tackle

3364 urgent existential risks, principally in the regions where the SDGs progress is lacking the most due to many  
 3365 inconsistent burdens arising from global encounters such as energy, water, food security as well as climate  
 3366 and health with the aim of advancing their equity and sustainability.

3367 As per the ISC depiction, the “Science Missions for Sustainability” are defined as the scientific missions that  
 3368 vigorously engage with society to address multifaceted sustainability challenges by having defined goals,  
 3369 solution-oriented focus, and time-bound nature [6]. To endorse the anticipated transformational actions, the  
 3370 Science Missions are considered to be significant in scale, and by the determined application of inter- and  
 3371 transdisciplinary approaches (Fig.12-2). Furthermore, the conceived strategy that Science Missions must  
 3372 focus on societal, economic, and political aspects within each domain beside the technological innovations  
 3373 is also well-thought-out for which identifying the root causes and overcoming the several complications and  
 3374 obstacles are crucial steps towards a reliable and sustainable development.



Figure 12-2: Collective projection of Science Missions in realizing the UN Sustainable Development Goals [5].

3375 Complex world situations require that both funding structures and time concrete plans are considered for  
 3376 a practical execution. With this, regional science hubs are expected to ensure that science is inclusive and  
 3377 up to standards. In its comprehensive report “Flipping the science model: A Roadmap to Science Missions  
 3378 for Sustainability”, the International Science Council, has formulated a number of key messages: among  
 3379 them, taking the responsibility in funding science in a different way aiming at achieving long-term global  
 3380 sustainability goals. This entails furnishing supplementary mechanisms beyond the common practices of the

3381 traditional science model that is marked by the absence of trust with stakeholders, as well as toxic models  
3382 of competition.

3383 The ISC strategies regarding the criteria of Science Missions, and irrespective to their individual design  
3384 and focus, present a set of objectives and expectations [5]. Illustrations of possible acts are listed below to  
3385 contribute to the mission's co-design and implementation: a) Establishing mechanisms for regular exchange  
3386 between all stakeholders, b) Building collaborations between science, decision-makers, and communities, c)  
3387 Mobilizing existing scientific infrastructure and knowledge across disciplines and ensure the integration of the  
3388 social sciences in shaping and implementing the missions, d) Enabling within- and cross-regional scientific  
3389 collaborations.

3390 In an attempt to cope with these objectives, the call aims at finding well-designed solutions convoluting  
3391 local and global efforts which in turns requires extensive and inclusive collaborative schemes as well as an  
3392 immense investment in multidisciplinary and interdisciplinary basic and natural sciences from the problem  
3393 identification to the solution implementation [6]. The commission estimates "a collective investment of a  
3394 billion dollars per annum that is not even 1% of global annual R&D investment would significantly accelerate  
3395 the progress of the 2030 Agenda."

3396 The tangible vision that Africa must receive its comparable spot as a co-leader within the global scientific  
3397 arenas among its peers becomes more evident – in sharing equivalent responsibilities, commitments, and  
3398 deliverables towards the global scientific societies. Africa is not an exception in the human race of advancing  
3399 science and technological grounds towards the implementation of the Sustainable Development Goals. Many  
3400 challenges are accruing with an accumulative mode such as establishing and/or consolidating cutting-edge  
3401 large scale research infrastructures, addressing the so many local and/or regional concerns, as well as  
3402 strengthening industrial development for a sustainable economy. Into the discussion point, are synchrotron  
3403 light sources offering plentiful scientific techniques to support extensive capabilities in basic science such as  
3404 physics, chemistry and biology, in consort with applied science arena including biomedicine, pharmaceuticals  
3405 and drug design, agriculture, environment, air, soil, and water pollution, besides materials science and  
3406 industrial applications, with an emerging focus on energy and climate change. Furthermore, comprehensive  
3407 insights can be also identified in cultural heritage, archaeology and bio-archaeology domains [7].

3408 In accordance with the above vision, it is fundamentally critical at this stage to signalize the unfair fact  
3409 that Africa is the only continent that is being deserted without such an advanced technology of synchrotron  
3410 light sources' infrastructures – this fact represents the core motivation of the Light Sources Working Group  
3411 mandated by The African Strategy of Fundamental and Applied Physics, ASFAP [8, 9] to provide advice  
3412 on strategies towards light sources in Africa, with considerations of compact light sources, synchrotron light  
3413 sources, and other related topics relevant to an African context - e.g., capacity building. This reveals the  
3414 importance of an African Light Source establishment to fulfill the vast scientific community's demands. Over  
3415 and above, examining the major challenges and concerns in conjunction with the ASFAP relevant Working  
3416 Groups wherever applicable.

3417 A light source for Africa presents a rich opportunity for a regionally well-adjusted contribution within the  
3418 worldwide economy (Fig.12-3). In the comprehensive report on light sources towards the Middle of the  
3419 Century, Vollmer A. indicates that Africa will soon become the home to the best part of the world's youth  
3420 expected to be a major part of revitalizing the economic circumstances in their respective regions [4]. A  
3421 major statistic estimates that Africa as a whole has 169 scientists per 1 million people (cf. Europe 20  
3422 times more), undoubtedly infers that such a number has to be enlarged in order to realize a well-developed  
3423 economy. A few orientations are furnished to attain that goal, such as a tangible investment in science and  
3424 technology, facilitating international cooperation, and brain-drain circulation - at all levels.

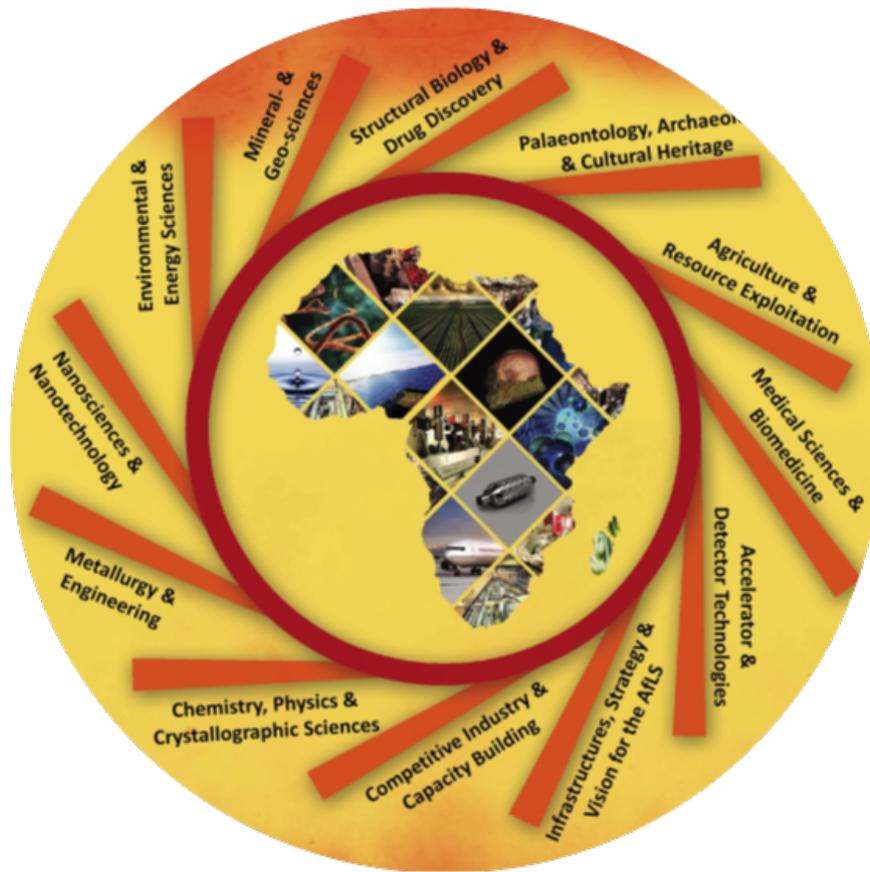


Figure 12-3: The African light source is expected to promote local and regional research platforms, massive advanced human capacity building and employment in Africa. Additionally, it is foreseen to be a prominent mega-science techno-industrial and fundamental research facility. [10]

3425 This reporting sheds some light on the vital importance of establishing an African light source facility  
 3426 that is projected to serve Africa -and beyond- with a strong involvement of young scientists and African  
 3427 diasporas, women scientists, as well as scientists from developing countries. Consecutively, this will stimulate  
 3428 new partnerships between countries and organizations to address the several mutual concerns of science,  
 3429 education, and economic development, with an impact that will robustly go beyond any “national” science.

### 3430 12.1.2 Introduction to light sources, their scientific, economic, and societal 3431 impacts

3432 Light sources, specifically, synchrotron light sources, have opened up vast opportunities for investigating  
 3433 different types of matter across numerous applications contributing to scientific progress and sustainable  
 3434 development.

3435 Synchrotron radiation, emitted through the acceleration of particles at nearly the speed of light in a curved  
3436 path, covers a wide range of electromagnetic radiation, including X-rays, ultraviolet, visible light, and infrared  
3437 radiation. These properties make it a valuable tool for studying the microscopic world in various scientific  
3438 fields, including physics, chemistry, biology, biophysics, life sciences, and material sciences. They also  
3439 have practical applications in energy, pharmaceuticals, medicines, public health, agriculture, environmental  
3440 studies, and energy storage. They not only offer insights into the present and future but also allow researchers  
3441 to explore the past, including cultural heritage, archaeology, bio-archaeology, and palaeontology.

3442 During the last decades, a huge increase in the use of accelerators-based techniques is witnessed in a wide  
3443 range of scientific applications. In Europe alone, the number of synchrotron facilities has increased from only  
3444 three facilities in the 1960s to 14 synchrotron sources and 7 Free Electron Lasers over 10 European countries in  
3445 2021 serving more than 24000 users per year leading to a drastic oversubscription of requested instruments  
3446 [4]. Technically, light sources can foster initiatives and science missions that aim to dynamically involve  
3447 developing regions mobilizing a broader community through larger international enterprises. This facilitates  
3448 creating a healthy environment for joint collaborations, attracting scientists working abroad in an attempt to  
3449 diminish – or to effectively reverse- the brain-drain gap, as well as, addressing local and/or regional concerns  
3450 such as health, environment, water, pollution, human heritage among others. These facilities provide free  
3451 access to scientific user communities that is exclusively based on the scientific excellence and merit. In this  
3452 context, “light sources operate in a democratic mode, conventionally attained by using scientific cooperation  
3453 to promote understanding between people from different traditions, religions, and political systems –Herman  
3454 Winick”.

3455 The impact of advanced light sources on science and society in the developing world on addressing national  
3456 and global concerns cannot be underestimated. In addition to facilitating awareness to benefit human well-  
3457 being, science proved to be a valuable share of diplomacy — scientific cooperation to work on problems across  
3458 borders and without boundaries, cooperation made possible by the international language and methodology  
3459 of science. This strategy allows scientists to get beyond ideologies and form relationships that allow diplomats  
3460 to defuse complicated political situations. Moreover, synchrotron light sources can frontward the traditional  
3461 educational systems, the employment status, brain-drain reversal, besides the human capacity building which  
3462 is alleged to be the backbone of any advanced society. Through collective brainpower and constructive  
3463 partnerships and collaborations, establishment of light sources has begun in developing countries decades  
3464 ago, now in operation, with upgrades, besides new facilities those are either under construction or in the  
3465 planning phase.

3466 With this, they advance, not only scientific discoveries, but also the predictable economic strength by  
3467 developing different industries taking into account the scarce resources and incomes.

3468 In Europe, almost all European synchrotron facilities have either recently done major up-upgrades or are  
3469 planning to do so in the next decade. ALBA, BESSY II@HZB, DIAMOND, ELETTRA, PETRA III, and  
3470 SLS (in alphabetical order) are planning up-upgrades, as well as MAX IV (Sweden), the ESRF (The European  
3471 Synchrotron Radiation Facility) are back to service after a tremendous and innovative upgrade. As well,  
3472 several non-European Synchrotrons are in the process of up-upgrading such as APS and ALS in the USA, CLS  
3473 in Canada, SIRIUS in Brazil, SPring-8 in Japan [4].

3474 Therefore, in an attempt to catch this wild evolving scientific and technical race of light sources around the  
3475 world, African scientists – through collaborations, agreements and training fellowships – are also in a race  
3476 with time to set up the first facility ever in the continent. In this contribution, the significant need of such  
3477 facilities to the African continent is emphasized (Fig.12-4).



Figure 12-4: Distribution of synchrotron light sources around the world.

### 12.1.3 Motivation for establishing an African light source

The argument that Africa is facing numerous challenges cannot be misjudged. For several reasons, some of these challenges is common to the rest of the world, but others are distinctive and are regionally incomparable. This has affected all aspects of life and the future of the young generations together with an obvious underestimation of the standing of science grounds affecting thousands of African scientists and diasporas. In this regard, the establishment of an African Light Source (AfLS) can play a crucial role in the region, for the African community and elsewhere. The AfLS can open wide doors to scientists from all over the world to demonstrate their capacity and to overcome traditional and technical obstacles as much as they can. From this perspective, it can – and will- show credible contributions in improving and advancing societies towards the SDGs as well (Fig.12-5). In actual fact, African countries are already involved in numerous scientific activities and research programs in international light sources (Fig.??).

The straightforward objective of the ASFAP is to establish and to advance a capacity building in physics education and research being the case in other regions of the world. With no exception, scientific and economic challenges need to be addressed in African continent, with the dream that Africa, too, should take its equivalent identity as a co-leader in the global scientific arena. With this, the requisite of having the ASFAP has turned out to be indispensable for Africa. Among other working groups, there is the ASFAP Light Sources WG that is mandated to investigate, report, highlight, and advise on the necessity of establishing an African light source – the first of its kind in Africa.

One of the major outcomes, is the results of the assessment survey that was launched by the ASFAP Light Sources Working group. The survey aimed at collecting a considerate input from the African scientific community – and internationally-based community- on the case of founding an African light source. The subsequent purpose of the survey is to well prepare and establish collaborative research themes and angles.



Figure 12-5: Informative chart illustrating how an African Light Source can address all 17 United Nations Sustainable Development Goals, which are an urgent call for action by all countries. [10]

3500 Recent statistics shows that one third of the survey's participants have previous experience in light sources  
3501 facilities (Fig.12-6).

3502 It is worthy to mention that 77.1% of the survey's participants are resident citizens in African countries,  
3503 while 12.3% are African diasporas. Participants from nineteen African countries (Nigeria, Morocco, Kenya,  
3504 Cameroon, Senegal, South Africa, Ethiopia, Tunisia, Uganda, Algeria, Ghana, Sudan, Egypt, Ivory Coast,  
3505 Zambia, Mozambique, Togo, Congo, and Sierra Leon. Participants from 13 non-African countries have also  
3506 contributed to the survey. Specifically, from USA, India, Pakistan, Italy, Germany, Jordan, UK, France,  
3507 Malaysia, Peru, Canada, Japan, and Portugal (Fig.12-7). The strong position of the African researchers  
3508 having current/future synchrotron-related interest(s) is illustrated in (Fig.12-8).

3509 In this reporting, some assembled inspirations out of the survey will be shared in the following sections. The  
3510 expected scientific impacts of light sources have grabbed the attention of the participants, with this, their  
3511 detailed motivations were provided into the survey as follows:

- 3512 • Light sources technology must be more available and cheaper for all geographical areas in Africa and the  
3513 world as it provides cutting-edge tools for advancing almost any branch of science,
- 3514 • Highlighting the profile of the African Science, capacity building, local technology, local infrastructure,  
3515 enhanced networks and participation in international collaborations, as well as bringing up a strong factor  
3516 towards the African wealth,
- 3517 • Supporting the Pan-African initiative of Africa having its own scientific light source,
- 3518 • The critical requisite of new and practical solutions to human health and energy-related materials discovery  
3519 and development,

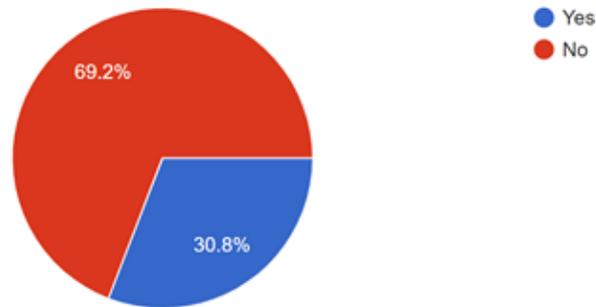


Figure 12-6: Outlook on the African scientists and researchers having previous experience in light sources facilities.

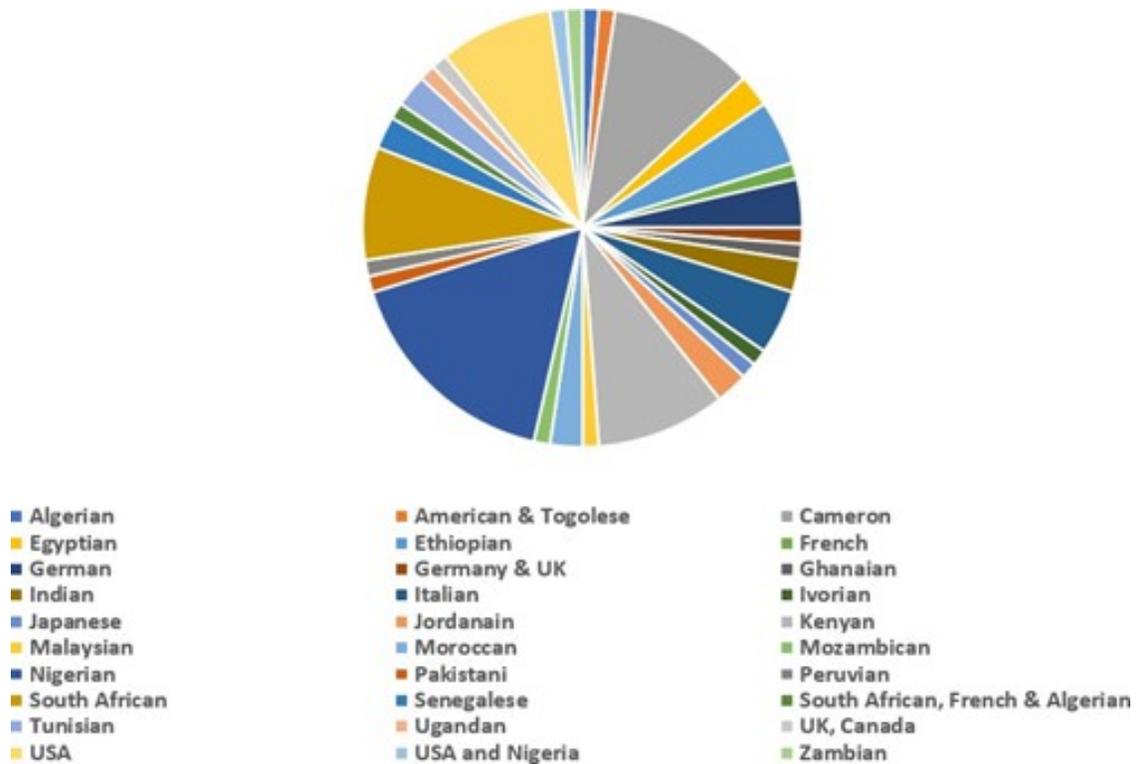


Figure 12-7: Nationalities of the participants responded to the ASFAP Light Source Working Group.

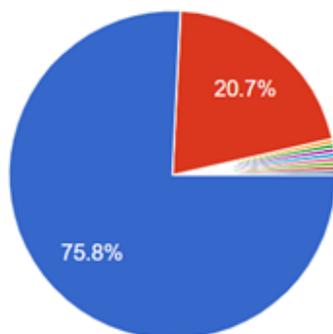


Figure 12-8: The position of the African researchers (75.8%) having current/future synchrotron-related interest(s).

- 3520 • A light source facility will support many other research fields, providing a framework for central research  
3521 and education in Africa. It will also attract the international community and boost the regional economy in  
3522 providing jobs,
- 3523 • Validating a sort of independence against exogenous markets and policy forces,
- 3524 • Solving local problems with greater economic output, by means of light sources one can develop solutions  
3525 and products to raise the balance of trade for Africa,
- 3526 • Diversification of the types of research questions posed, particularly in medicine, energy and materials.  
3527 Escape from European fixation on batteries and fusion,
- 3528 • With the abundance of mineral resources in Africa, this is a great opportunity for further exploration  
3529 and usage to get out of poverty. Additionally, discovering novel molecules capable of curing diseases and  
3530 infections that affect the population,
- 3531 • Fostering scientific and technological excellence; prevent or reverse the brain drain by enabling world-class  
3532 scientific research; build cultural bridges between diverse societies, as well as education and capacity building,
- 3533 • Increase number of publications in African countries,
- 3534 • Addressing of brain drain and societal issues; Promotion of knowledge base economies,
- 3535 • Transfer the know-how among the related countries, and bridging communities through collaborations.

## 3536 12.2 Major challenges

3537 There is no doubt that such global research infrastructures do have a strong impact on economy, food security,  
3538 and disaster management. For this case study of the ASFAP Light Sources' survey, it was acknowledged that  
3539 73% of the participants expect societal impact of light sources in the form of establishing a common culture  
3540 of knowledge, competitive local industry, entrepreneurship, and capacity building. 62.4% of the participants  
3541 have declared an interest to be employed in a light source facility when established, which again, shows the  
3542 genuine awareness and attentiveness to such an axis of national development (Fig.12-9).

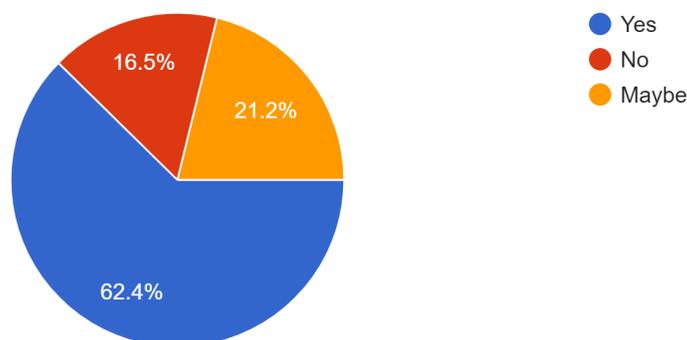


Figure 12-9: The segmented response of the African researchers showing interest in employment at light sources.

3543 On the other hand, instituting a synchrotron light source often goes beyond the financial capacity and the  
 3544 allocated governmental budget to science - even with a dedicated initial budget- of a single country. Hence,  
 3545 it embodies a real bottleneck for the low economically-standing countries – for which is the circumstance  
 3546 of many African countries. Then again, the condition can be also deteriorating as a direct influence by the  
 3547 human capacity deficiency, that yet again, signifies the necessity to reverse the brain-drain issue.

3548 Due to the absence of their national facility, some major obstacles and challenges are intensely facing the  
 3549 African Scientists when attempting to pursue scientific research in worldwide facilities in the interim of the  
 3550 making of the first African Light Source. Chief research requirements reported through the ASFAP survey  
 3551 on light sources are depicted in (Fig.12-10), and other challenges were communicated as follows:

- 3552 • Lack of basic and/or preliminary research equipment in own country,
- 3553 • Bureaucracy in the facility of destination, and/or bureaucracy in own country,
- 3554 • Lack of funding schemes (travel and mobility, project expenses, etc.),
- 3555 • Lack of training opportunities to develop the required professional skills,
- 3556 • Lack of dedicated and qualified human resources.

### 3557 12.2.1 Relevant scientific activities

3558 Light sources provide free access to the scientific user community based upon scientific excellence and  
 3559 open data. Human health is a hot subject matter that requires multifold approaches and strategies from  
 3560 understanding the molecular basis of diseases, development of diagnostic approaches, and consequently to  
 3561 identify effective and affordable treatments. This is primarily initiated by studying to the development of  
 3562 diagnostic methods that leads to early preventive actions, to treatment involving innovative therapies.

3563 Neurodegenerative diseases such as Alzheimer, Multiple Sclerosis, and Parkinson, degenerative medicine,  
 3564 diabetes and diabetic foot, Preeclampsia, cancer of all types, HIV, HCV, Malaria, wound healing, and



Figure 12-10: Difficulties facing scientists in Africa as has been raised by participants to the Light sources survey.

3565 pharmaceuticals are just a few examples to mention (Fig.??). Therefore, the challenge for the scientific  
 3566 community is to develop new and creative means for acquiring, processing and interpreting the complicated  
 3567 bio-molecular information involved with tissues, single cells or cells in a microenvironment, at cellular and  
 3568 sub-cellular resolution. Synchrotron facilities open the door for a huge number of biological and biomedical  
 3569 applications, where high spatial resolution and high-quality information are a must utilizing synchrotron  
 3570 radiation techniques such as Infrared microspectroscopy, structural biology, drug polymorphism, chemical  
 3571 and elemental mapping, micro-computed tomography as they and other techniques and modalities can render  
 3572 very specific, as well as, complementary information on relevant subjects.

3573 For instance, the status of the human health in Africa represents a huge pillar of scientific research by African  
 3574 scientists and others. Many diseases are there to be investigated and treated. (Fig.12-11) sheds some light on  
 3575 some of the targets to be explored, while (Fig.12-12) indicates the leading causes of death in Africa recorded  
 3576 in 2019.

3577 In addition to human health growing concerns not only in Africa but worldwide, it is also significant to  
 3578 retrieve some informative data on the prospect of the potential cross-disciplinary collaborations and links  
 3579 to light sources user-communities which may be achieved by creating multi-folds' links with academia and  
 3580 industrial sectors, as well as, initiating and/or strengthening the basic interdisciplinary collaborations in  
 3581 different scientific activities. Results of the survey showed the following aspects in which a light source  
 3582 facility can serve communities in various disciplines:

- 3583 • Materials for Energy systems, biomedical engineering, and plant molecules exploitation,
- 3584 • Drug discovery and materials development - including different vaccine development,
- 3585 • Agriculture where chemists will synthesize and crystallize fertilizers for crop production, and new techniques  
 3586 to be applied to new fields such as imaging for paleontology, archaeology, optics and photonics, pharma, etc.

3587 Amongst the research interests and scientific activities those were favored by the participants of the survey  
 3588 came on top the basic and/or applied science, followed by life sciences, materials sciences, cultural heritage  
 3589 and archaeology, accelerators' physics and technology, optical instrumentation, beamlines development, as  
 3590 well as experimental instrumentation and data analysis approaches. A thought-provoking input was also  
 3591 attained by the fact that 76% of the researchers and students opted for current and/or future synchrotron-  
 3592 related interests.

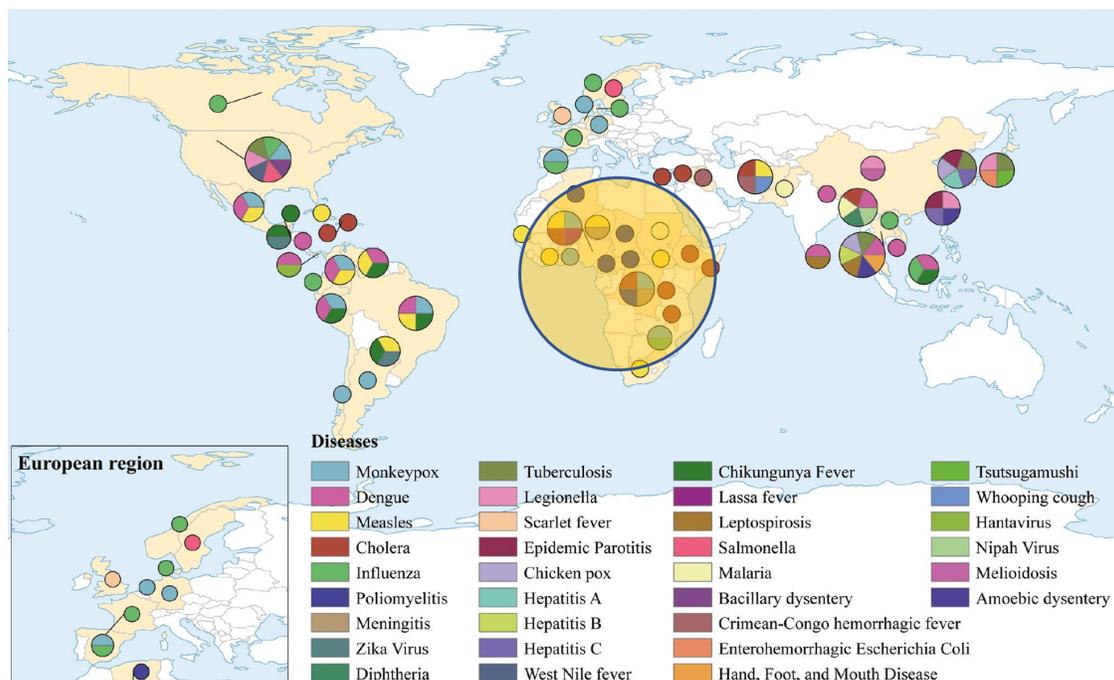


Figure 12-11: Global Infectious Diseases in January 2023.

3593 (Fig.12-13) shows the required synchrotron techniques, which confirms the necessity of establishing such a  
 3594 facility. Moreover, geographical distribution, collaborations with other research institutions, access to remote  
 3595 databases and software, as well as advanced instrumentation, were assigned as higher priorities for research  
 3596 chief requirements. 70% of those who participated showed a previous experience in light sources facilities,  
 3597 while 61% opted for a looked-for employment given the opportunity and depending on qualifications.

3598 Besides, 88% opted for their willingness to initiate interactions on different axes of collaboration and  
 3599 assistance with other African groups. Additionally, 81% marked their need for advanced training regarding  
 3600 the general use of such available infrastructures, with a descending order of financial, technical, and scientific  
 3601 support.

3602 The participants were also invited to provide their insights on what sort of changes are essential to allow  
 3603 better use of networking facilities to improve the current scientific activities. Some collected opinions were  
 3604 as following:

- 3605 • The urgent need to highlight the scientific impact of using synchrotron facilities and addressing what kind  
 3606 of research could be conducted in such facilities,
- 3607 • Design specific outreach activities targeting the undergraduate students,
- 3608 • Scientists everywhere have challenges with stable funding, it is likely more acute in Africa than in the US,  
 3609 EU and Asia,

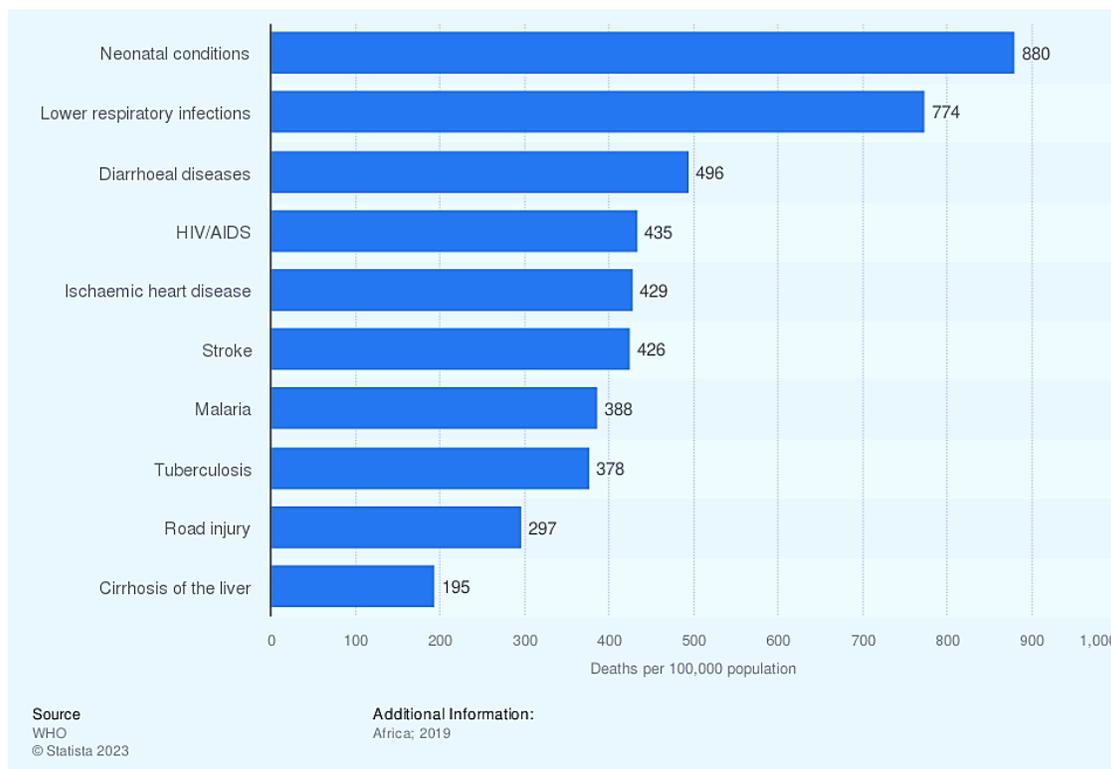


Figure 12-12: Leading 10 causes of death in Africa in 2019 (in deaths per 100,000 population).

- 3610 • Establishment of more local facilities with clustered partnerships (Intra-continental and extra-continental),  
 3611 and sharing equipment available in Africa cross countries and/or within a single country through its different  
 3612 institutions,
- 3613 • Launching dynamic collaborations to expose the underprivileged institutions,
- 3614 • Building Bilateral/multilateral agreements within Africa via major international agencies.

### 3615 12.3 High-priority future needs

3616 Aligned on the broad perceptions indicated in the ISC reporting on the new models of science for sustain-  
 3617 ability, and in the context of the climate emergency and the imperative energy transition, a central question  
 3618 arises about the science-informed solutions if they are satisfactorily practical and acceptable by governments  
 3619 and society. This kind of challenges necessitates a sort of integration of technical and climate sciences  
 3620 alongside social sciences. However, a further critical question arises: are policy-makers, civil society, and the  
 3621 private sector sufficiently engaged with the science system to identify the most urgent research questions in  
 3622 the beginning? [6].

3623 It is important to refer here to the report [6] in identifying the importance of "... committing resources to  
 3624 the process of co-defining issues and co-implementing solutions by scientists, policymakers, funders and other

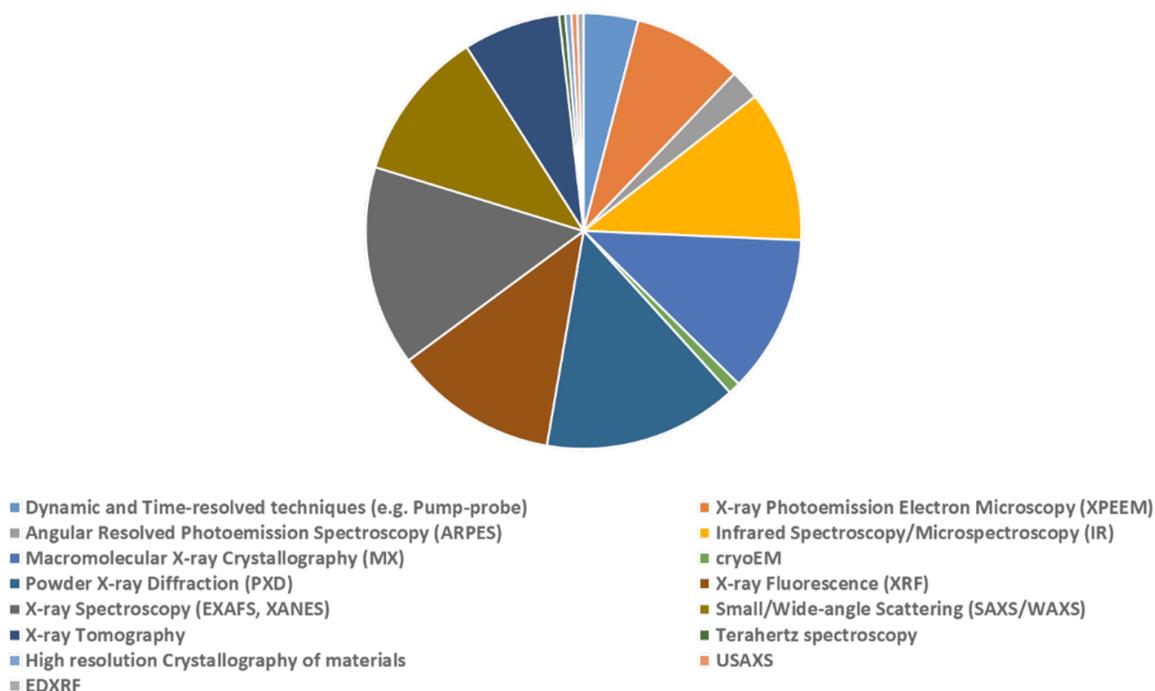


Figure 12-13: Favorable techniques reported through the ASFAP survey on light sources.

3625 relevant stakeholders rather than focusing on narrow, predefined or singular outputs and outcomes alone by  
 3626 scientists alone. Ultimately, their goal is to deliver the ‘how’ not the ‘what’ of science for sustainability,  
 3627 by promoting a viable model for global cooperation which addresses complex local and regional challenges  
 3628 in service of a more sustainable planet and a dignified future for humanity.” Accordingly, the focus of the  
 3629 discourse must now shift from ‘what’ to ‘how,’ identifying the mechanisms needed to fund and achieve the  
 3630 desired outcomes.

### 3631 12.3.1 Prioritized domains and their motivations

3632 The scale and long-term nature of the science missions would require pooling and matchmaking of financial  
 3633 support by different funders as demonstrated by the ISC reporting on flipping the traditional model of  
 3634 science [5, 6]. This would best be accomplished through a central fund created by all participating funders  
 3635 and partners, or regional funds, or instead, by dedicated hub funders. As it the case of founding an African  
 3636 Light Source, this implies a fundamental shift in how science is funded.

3637 It is valid and binding more than ever to consider that engaging the end-users is essential to ensure the  
 3638 research is designed to generate actionable knowledge and develop a plan for its uptake. However, the  
 3639 evidence suggests that the existing funding mechanisms often fail to recognize and transform complex systems  
 3640 underlying sustainability challenges. That is, the detailed report of the ISC calls for stakeholders to unite  
 3641 around these challenges, and sends out another thought-provoking question: “Science has a vital brokering

3642 role in co-creating solutions to the current sustainability problems. The question is how.” One possibility  
3643 could be to bring together the best of global science in dedicated full-time multidisciplinary hubs that can  
3644 serve as good facilitating environments for Sustainability Solutions Teams, with adequate financial support  
3645 and institutional shielding to deliver not just knowledge outcomes, but also action outcomes.

3646 As a general reflection, diverse considerations can embody the aforementioned case of establishing a light  
3647 source in Africa as a high priority, such as the next major drives are elucidated in the next section.

### 3648 **12.3.2 How can light sources tackle priorities and the future needs of Africa** 3649 **aligned with the SDGs?**

3650 To address the above multiple challenges and more, a huge demand in the implementation of cooperative  
3651 models is evidently viewed. In addition to their scientific and technological advancements, synchrotron light  
3652 sources proved to convey a valuable segment of diplomacy — that is based on scientific cooperation ceasing  
3653 complications across borders. Through them, collaborations were made possible only using the neutral  
3654 language of science. This in line, can encourage new partnerships on the national and international levels  
3655 to address mutual demands of scientific and societal challenges, and education and economic development  
3656 as well. Additionally, there are indirect impacts that come along those cannot be underestimated. Some  
3657 examples are illustrated as follows:

- 3658 • Establishing a world-class and applied research interdisciplinary research laboratories,
- 3659 • Addressing the many local and regional concerns (for instance; human health, environment, materials and  
3660 energy, cultural and human heritage, etc.),
- 3661 • Providing a vigorous environment for successful collaborations and allowing the essential space needed for  
3662 individual career development,
- 3663 • Attracting African diasporas thus drawing back the brain-drain alarm and in the same time resolving  
3664 the internal brain-drain to other sectors as well, this is the case as the majority may tend to target other  
3665 fields rather than natural sciences or engineering where the remuneration for jobs in economy for example  
3666 are much higher than for scientists and with many excellent young scientists choosing such more profitable  
3667 careers,
- 3668 • Training and preparing graduate students who will no longer need to go abroad to industrialized countries,  
3669 which implies a minimum of infrastructure and some interesting projects to take place and to be constantly  
3670 developed in the home country and/or region,
- 3671 • Promoting development of high-tech industry (capacity building),
- 3672 • Based on several statistical figures, one of the most important aspects to be also tackled is the gender  
3673 balance concern. Light sources have also shown to be effective in reducing such a gap as much as possible  
3674 being an open and flexible environment that is based only on scientific merit and skills.

## 12.4 Synergies with neighbouring fields

“Science and research being intrinsically international will further intensify all efforts of interdisciplinary, multidisciplinary, cross boundary cooperation – also in an institutionalized way – to help solving the major challenges of the next decades” – Antje Vollmer.

Light sources are one of the best examples of an open and multidisciplinary research infrastructure. They provide strong opportunities for integration through networking and cost-sharing, as well as promote multidisciplinary collaboration with the wider global community, while promoting science diplomacy and peace at large. Moreover, environmental problems, advanced materials, cultural heritage valorization are all complex issue intrinsically involving cross-disciplinary collaboration.

As depicted in (Fig.12-14), light sources can serve communities in various disciplines such as materials physics, atomic and molecular physics, biophysics, optics and photonics, pharma, materials and energy systems, biomedical engineering, and plant molecules exploitation. With this strong basis, it is well-comprehended and highly recommended to set synergies of collaboration and strategies between the neighboring fields of ASFAP Working Groups. To mention a few, the Light Sources WG has a great share of integrated activity planning with the ASFAP Accelerators, Biophysics, Earth Science, Energy, Materials, and Medical Physics working Groups [12].

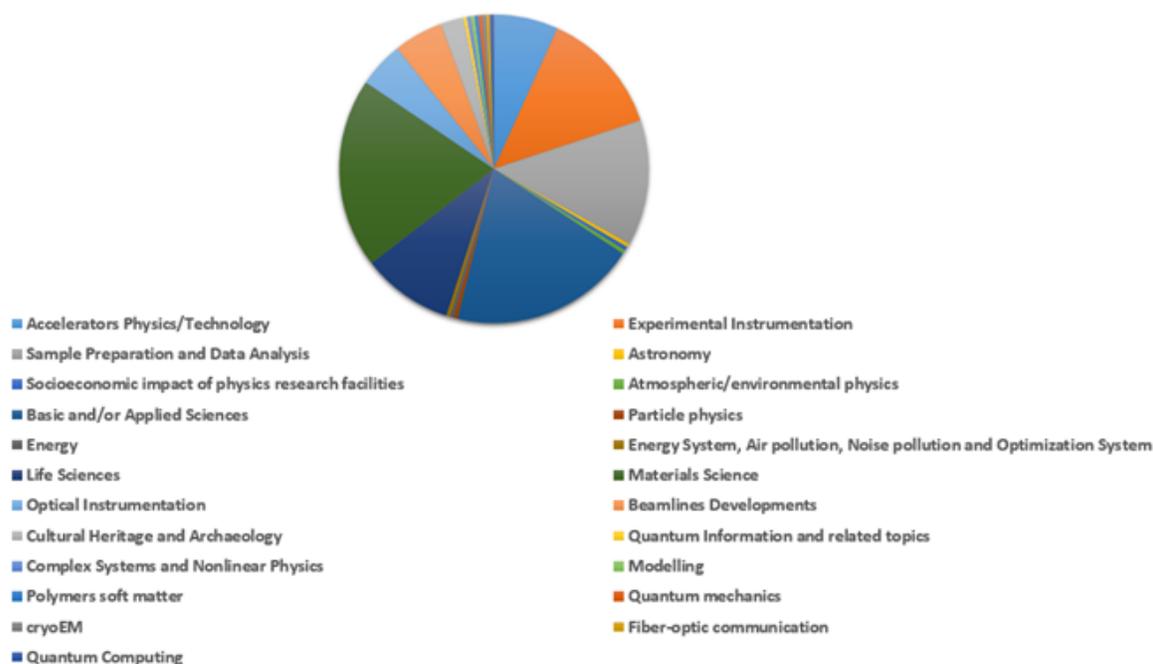


Figure 12-14: The scientific communities that light sources can be of great assistance, in addition to the ASFAP defined Working Groups.

Accordingly, there is a robust impact of convolution with close fields demonstrated by the clear need to have a research large-scale infrastructure in Africa, specifically an African light source to cope with challenges that Africa is facing. For such projects, it is always vital to gain some insights from the scientific community in

3694 all scientific domains on how can African countries join forces to overcome the major challenges to establish  
3695 its own light source. Below are some of them:

- 3696 • Reaching the Critical Mass. Ensuring mobility, training, and enrollment of large multi-skilled young  
3697 scientists through workshops and conferences and funding,
- 3698 • Establishing common and joint infrastructures to be that can be shared among all scientific communities,  
3699 with this, instituting centers of excellence, sharing experiences and complementary equipment are also vital  
3700 targets,
- 3701 • Developing a concrete strategic vision for a light source facility - Engaging complementary domains which  
3702 may better convince policymakers and the international community to support such a vision,
- 3703 • Co-leading an intense educational system on the research capabilities of integrating light sources and their  
3704 importance to scientific revolution in Africa,
- 3705 • Investing in the science that drives light sources in the rest of the world, e.g., to solve local health challenges  
3706 such as malaria, famine and technological advancement,
- 3707 • It is only through scientific discoveries and common research activities that tackle preexisting problems  
3708 and those raised by the side effects of technologies can be met.

## 3709 12.5 Policy making and societal impact

3710 Synchrotron facilities play a vital role in fundamental, applied, and industrial research, driving technological  
3711 advancements and fostering collaborations across boundaries. Equally, the establishment of a synchrotron  
3712 light source in Africa has significant potential for scientific progress and socioeconomic development.

3713 Enormous potential lies at the very thin interfaces between governmental policy makers and the funding  
3714 agencies/sectors and between science and its users.

3715 Based on the launched survey, the participants have provided some insights on the high priority needs, for  
3716 example, the participants have demonstrated a number of concerns that may be considered for setting a  
3717 practical strategy for founding an African light source in Africa:

- 3718 • In Africa, this might have to be done on region basis to develop a major science facility policy in general (as  
3719 part of STI policies, respectively), and a light source policy in particular, which can be then developing joint  
3720 policies given other conditions, e.g. transportation routes. Such policies may be furnished in cooperating  
3721 with the African Union and/or other African institutions,
- 3722 • Designing collaboration themes as well as joint funding programs to meet the expenses of such a huge  
3723 infrastructure to establish the first African Light Source,
- 3724 • African governments can also seek joint funding partnerships that involve the private sector,
- 3725 • Mutual cooperation in top-down and bottom-up organizational patterns. Herein, the participants point  
3726 towards the fact that it would be hard to strongly justify "bottom-up" approach without the realization of  
3727 the concrete evidence of current and/or near-future demands - The multinational aspect of such a project  
3728 should not be forgotten - coming under the umbrella of a Pan-African society such as the AU or perhaps a  
3729 regional one like SADC, ECOWAS, etc. is an important parameter in setting up mutual/eventual decisions,

3730 • Raising awareness among African Heads of State and the African Union on the need to implement their  
3731 light source for controlled and therefore sustainable development. With this, a scheme of mutual cooperation  
3732 in bench-marking degrees, entry visas, mobility programs and exchange funds is highly beneficial.

## 3733 12.6 Conclusion and perspectives

3734 Science is striving to keep pace with the sustainability challenge, yet it has largely relied on a traditional  
3735 model. As expressed in numerous reports and studies, more must be done. Additional modalities and  
3736 tailored strategies are yet needed for science to effectively lead to actions.

3737 Aligned with this pattern, it was thoughtfully expressed and planned in the new ISC Global Commission  
3738 calling for Science Missions to design practical models to ensure the integration of science within other  
3739 perspectives and with different domains to better achieve the 2030 Agenda.

3740 As demonstrated in the previous sections, light sources are the best example of an open and multidisciplinary  
3741 research infrastructure that can effectively deliver the required incorporated themes. They provide strong  
3742 opportunities for integration through networking and cost-sharing, as well as promoting multi-disciplinary  
3743 collaborations with the wider global community, while promoting science diplomacy and peace at large.  
3744 Moreover, environmental problems, advanced materials, cultural heritage valorization are all complex issues  
3745 those intrinsically involve cross-disciplinary collaborations.

3746 Nevertheless, and as tremendously displayed, thousands of science examples can demonstrate the massive  
3747 contributions of light sources to solving the challenges of the years and decades to come. However, these  
3748 facilities do not see themselves as self-sufficient. For thousands of users from academia and industry, with  
3749 intense cooperation between research institutions and universities throughout a wide range of scientific  
3750 disciplines, they can be considered as crystallization seeds for multi- and interdisciplinary work, as well as  
3751 acting as hubs for transnational scientific liaison.

3752 This is highly considered -and without exception- for light sources-related methods with relevant techniques  
3753 based on microscopes, ion and other particle beams, neutrons, lasers and high magnetic fields.

3754 In conclusion, there is more to science than theories, experiments, and abstract knowledge. There is the  
3755 responsibility to bring the world closer together for the benefit of humanity for - at least- the next generations  
3756 in Africa and the whole world - if not for us as well. For peace. For justice, fairness and equal opportunities.  
3757 Light sources are sources of radiation, yet, they are also sources of hope for a better future – where only the  
3758 scientific merit does control our fate.

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# Condensed Matter and Materials Physics Working Group

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## 3797 13.1 Introduction and Motivation

3798 In 1956 John Bardeen, Walter Brattain, and William Bradford Shockley were awarded the Nobel Prize in  
3799 Physics *for their research on semiconductors and their discovery of the transistor effect*. Their discovery is  
3800 considered as a milestone in Human civilization as it opened the way to the development of the modern  
3801 technology. Without the chips manufactured from semiconducting materials, one needs to imagine life  
3802 without computers, communication systems, healthcare and medical devices, transportation and automotive  
3803 technologies, energy generation, home appliances among others.

3804 Humanity is now entering a new technological era marked by the quantum revolution including but not  
3805 limited to quantum computing, quantum sensing and quantum encryption. *The quantum era is arriving,*  
3806 *and it will be transformational!* [56].

3807 Regarding its huge industrial and security impact, quantum technology has rapidly reached the realms  
3808 of policymaking. A Furious international race will soon emerge to master the fundamental concepts of  
3809 quantum computing and to find suitable platforms to build quantum-bits (qubits) the elementary block of a  
3810 quantum computer. Recently, many countries and international organizations (such as NATO) have adopted  
3811 their national quantum strategies, where a key policy objective is manufacturing quantum computers with  
3812 improved error correction. To achieve this multidisciplinary objective, worldwide Condensed Matter Physics  
3813 (CMP) community is devoting great efforts to study existing material candidates and predict new possible  
3814 materials including two-dimensional (2D) systems, superconductors, topological materials... Beyond the  
3815 realization of quantum computers, CMP community is mainly focusing on the fundamental concepts of  
3816 quantum computing, quantum sensing, quantum metrology...encompassing various efforts in engineering,  
3817 computer sciences, atomic-molecular and optics (AMO) and photonics.

3818 Condensed Matter Physics is a highly interdisciplinary field of research attracting more than 46% of the  
3819 Physicists in the world [57]. It aims to understand the properties of the condensed phase of matter  
3820 characterized by a large number of interacting constituents, which covers solid, liquid, soft matter, optical

lattices of cold atoms, classical and quantum matter, complex systems including economical, biological systems... CMP is at the basis of the modern and nano-technology and is a keystone in the development of new technological era. Based on fundamental and innovative applied research, CMP provides not only new fundamental Physical concepts but also cutting-edge experiments to explore and control matter at different scales ranging from the atomic and nano-scale to the mesoscopic and macro-scale.

CMP is a tumultuous evolving field with a strong overlap with Materials Physics (MP), a Physics branch focusing on the synthesis, characterization and exploration of materials for applications in diverse fields as energy, biology, medicine, environment...

Beside the quantum computing race, many countries across the world are heavily investing in CMP&MP, to realize on-demand semiconductors, so-called the New Oil [58], and which are required for the cutting-edge technological devices. This *Chips* race, led by the United States and China, is not limited to silicon-based semiconductors but includes emergent 2D materials and in particular graphene<sup>1</sup> and its heterostructures, transition metal dichalcogenides, etc.

To stay in this chips race, Europe has mounted a variety of flagship and reserach supporting programmes including the European Alliance on Semiconductors [59], the Graphene Flagship [60], Research & Innovation programmes on Chemicals and advanced materials [62], European Chips Act [61], etc.

The natural question which arises at this point is about **the position of Africa in this global tech race.**

As mentioned in Ref. [63] *Africa is far behind in semiconductor technology, despite some glimmer of hope in countries such as Kenya and South Africa.* But, ironically, *many of the minerals used in semiconductor chips are indeed from Africa.* [63]

**Africa is lagging behind in the global research activities in CMP and advanced materials** which are intentionally designed materials with on-demand properties meeting the technological requirements of specific applications [64].

**Africa needs to catch up with the worldwide tech race** to avoid a further marginalization and to take advantage of its natural resources which are still exploited by non-African countries without benefits for the Continent [65].

Therefore, **fostering CMP and MP research for tech applications becomes crucial** not only for the economy development of the Continent and its sustainability but also for geopolitical challenges raised by countries heavily investing in technology.

Consequently, establishing an **African strategy for the future CMP and MP research policy** is substantially required as an evidence for Africa commitment in joining the global tech race and insuring its economical sovereignty and geopolitical security.

In this contest, the working group on CMP and MP (WG-CMP&MP) has been created within the ASFAP to come out with a **road-map for the future research plans in Africa in the area of Condensed Matter Physics and Advanced Materials.** This road-map is based on the outcomes of several open meetings and workshops with researchers from different African countries and from diaspora, and on the analysis of the received LOIs and responses to surveys. The long-term discussions involved more than one thousand African researchers at different career levels: Heads of research centers, stakeholders, startup founders, permanent researchers, postdoc fellows, Ph.D, Master and Bachelor students, etc.

The objectives of the present strategy can be summarized as follow

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<sup>1</sup>Graphene, known as the wonder material, is the first 2D crystal discovered in 2004 by Geim and Novoselov who have been awarded the Nobel Prize of Physics in 2010...

- 3861 • Identifying the challenges forming the greatest barriers to promote research and innovation in CMP,  
3862 Advanced Materials, quantum technologies and related topics.
- 3863 • Identifying the strategic areas of research in CMP and MP where Africa should invest to join the global  
3864 technological race.
- 3865 • Identifying the priority actions to bridge the gaps at the Educational and research levels.
- 3866 • Setting a clear guideline for the future development of research and innovation in CMP and MP in  
3867 Africa within a scientific and economic win-win approach.

## 3868 13.2 Major challenges

3869 Condensed Matter Physics research is critical for technological advancement and economic development  
3870 globally. However, many African countries face challenges in investing adequately in CMP due to limited  
3871 resources. The main challenges faced by physicists across the continent in the field of CM and MP can be  
3872 categorized as follows:

### 3873 • Education

- 3874 – Unreliable educational background

3875  
3876 For a successful catch-up, learning is the key for African countries considered as the ‘late-  
3877 latecomers’ to industrialization and technology [66]. However, learning in CMP&MP with an  
3878 international standard requires strong background in Physics, Mathematics, computing, and good  
3879 knowledge in chemistry for students willing to pursue an experimental research career. However,  
3880 in the most African countries the curricula in the Bachelor and Master levels are far below the  
3881 international standard requirements [67].

- 3882 – Limited Master and Ph.D programmes

3883  
3884 In Africa, the majority of Bachelor students in Physics have not the opportunity to be enrolled  
3885 in Master and Ph.D programmes in CM and MP. Except South Africa and certain North African  
3886 countries (Algeria, Tunisia, Morocco, and Egypt), teaching Physics in several African countries  
3887 is limited to basic concepts without any connection with ongoing international research activi-  
3888 ties [73]. The gender balance is also an issue. Girls are less likely to pursuit a Master or a Ph.D  
3889 programmes in CM and MP as it is depicted in Fig. 13-1 showing the gender and age distributions  
3890 of the participants to the survey launched by the WG-CMP&MP. All the African grouping regions  
3891 have been represented in the survey as shown in Fig. 13-1(c).

- 3892  
3893 – Limited number of qualified researchers/trainers

3894  
3895 When African universities decide to set-up programmes in CMP&MP at the graduate levels, there  
3896 may often not be qualified teachers and trainers fulfilling the international standard requirements.  
3897 Several topics, including quantum information, modern computational techniques, advanced ma-  
3898 terials, etc. cannot be covered in the curricula of the majority of African universities. These  
3899 topics, among others, are already included within the Master programmes running since several  
3900 years in several international universities.

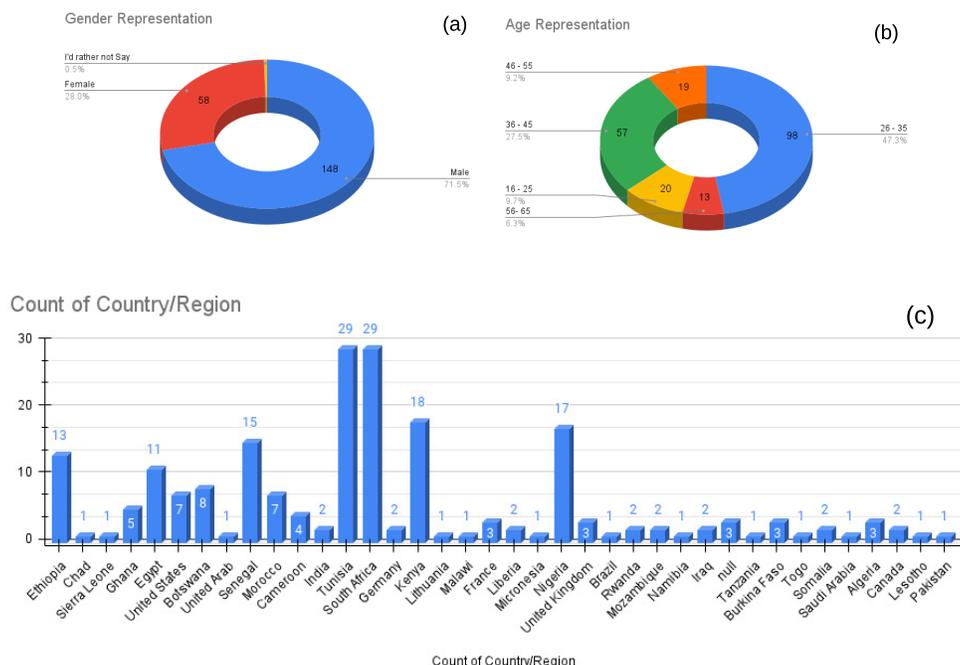


Figure 13-1: Statistics of the online mini-workshop organized by the CM-WG. (a) The gender participation ratios. The age (b) and country (c) distributions of the attendees [74].

Some African countries may propose training terms in international institutes for their teachers and students to perform themselves in specific topics. However, travel and visa application can be a nightmare for an African researcher and in particular students. On the other hands, it is usually difficult to raise funds to cover such visits. When grants are available, they are often not sufficient to cover the life-cost in US, Europe and Asia and researchers need to undertake endless bureaucratic procedures.

– Limited teaching equipment

Offering a successful Master and Ph.D programmes in CMP&MP requires several hands-on sessions in computation Physics, lab sessions, training in materials synthesis and characterization using research equipment etc. With the exception of South Africa, these key-stone training programmes cannot be implemented in the most of the African universities regarding the irregular power supply, the lack of computer facilities, the unsteady internet connectivity, the absence of clean rooms and the basic research equipment for Materials Science.

– Unemployed Physicists with Ph.D in CMP&MP

In most of the African countries offering Ph.D programmes in CMP&MP, the majority of the PhD holders end up unemployed. As noted in one of the submitted LOIs, *"this can be linked to a lack of innovations: most graduates nearly add no value to the companies they are employed in, regardless of whether they graduated with upper honors from the university or not. This is*

3924 *due to the fact that the quality of our research facilities is going low and the time taken by most*  
 3925 *university professors to offer quality research is low since the learner-teacher ratio is high” [103].*

3926 Some of African PhD holders in CMP&MP manage to have postdoc positions in North America,  
 3927 China and other Asian countries but most of them may remain jobless for several years.

3928 At the international level, there is “a PhD factory” in developed countries and “supply has  
 3929 outstripped demand although few PhD holders end up unemployed”. [68]. However, there rarely  
 3930 unemployed physicists [69, 70, 68] since if they do not manage to have a full time job in academia,  
 3931 they are absorbed in industry which is the largest employment base for Physics Ph.D holders.  
 3932 This change in career pathway is made possible since Ph.D students, in developed countries,  
 3933 acquire during their academic journey several skills opening the way for well-paid jobs beyond  
 3934 academia [70].  
 3935

3936 – Career Progression Barriers  
 3937

3938 The primary role of lecturers in government-funded universities is teaching, leaving limited time  
 3939 and resources for research activities. This teaching-centric approach hampers the development of a  
 3940 vibrant research culture within academic institutions. Furthermore, most African countries suffer  
 3941 from limited or absent research positions, which creates barriers to career progression. Without  
 3942 recognition and support for research contributions, lecturers face challenges in advancing their  
 3943 academic careers and gaining international recognition.

3944 – Brain Drain

3945 Most African countries allocate minimal resources to scientific research, resulting in underinvest-  
 3946 ment in CMP infrastructure, equipment, and human capital. The lack of such funding and career  
 3947 opportunities drives talented CMP researchers to seek employment abroad, leading to a loss of  
 3948 expertise and a brain drain phenomenon.

3949 • Research

3950 – Challenges with existing research infrastructure  
 3951

3952 **For experimentalists in CMCMP&MP**, there is a big need for synthesis and characterization  
 3953 facilities, including equipment for producing nanostructured materials.

3954 In Africa, there are a few hot spots with upgraded instrumentation as

3955 \* **In South Africa:**

3956 The Centre of Excellence in Materials, Energy and Nanotechnology (CoE-MEN) is hosted  
 3957 by the University of the Witwatersrand (South Africa) and set-up by the African Research  
 3958 Universities Alliance (ARUA) [Materials, Energy and Nanotechnology \(CoE-MEN\) - ARUA](#)  
 3959 [\[79\]](#).

3960 The CSIR-hosted National Centre for Nanostructured Materials (NCNSM) focuses on the  
 3961 modelling, synthesis, characterisation and fabrication of new and novel nano-structured ma-  
 3962 terials with specific properties [National Centre for Nano-structured Materials — CSIR](#) [80].  
 3963 NRF - iThemba Laboratory which is a national facility for pure and applied research, devel-  
 3964 opment and training in Accelerator based Sciences. It’s Materials Research arm hosts the  
 3965 UNESCO-UNISA Africa Chair in Nanosciences and Nanotechnology and the 3MV Tandetron  
 3966 laboratory for research, modification and characterization of materials using low energy ion  
 3967 beams, add other centres in ZA. [Home — iThemba LABS \(tlabs.ac.za\)](#)

3968 Department of Science and Technology/Council of Mineral Technology (DST/MINTEK).

3969 Nanotechnology Innovation Centre (NIC) [25] which is geographically spread across the  
 3970 country with activities aimed at addressing national priorities highlighted by both the national

- 3971 nanotechnology strategy and the national research and development strategy. The Mintek  
3972 NIC structure was built on the foundation of the national system of innovations (NSI) to  
3973 focus on driving South Africa's transformation from a resource-based economy towards a  
3974 knowledge-based economy using nanotechnology.
- 3975 \* **In Egypt** The centres for Imaging and Microscopy and for Nanotechnology at Zewail City  
3976 of Science, Technology and innovation (Egypt) [81]
- 3977 \* **In Morocco** The Advanced Materials Pole at the Moroccan foundation for Advanced Science,  
3978 Innovation and Research (MAScIR) where research activities in the fields of materials and  
3979 nanomaterials are oriented towards applied research and innovation [82].
- 3980 \* **In Algeria** The Research Center in Semiconductors Technology for Energetic (CRTSE)  
3981 devoted to materials sciences and technology with applications in energy conversion, pho-  
3982 tovoltaic and storage, sensing, optoelectronics and photonics [83].
- 3983 \* **In Tunisia:** The Research and Technology Centre of Energy (CRTE<sub>n</sub>) is a R&D structure  
3984 focusing on semiconductors Sciences for applications in photovoltaic cells [84].  
3985 The centre of Research in microelectronics and nanotechnology foreseeing the synergy between  
3986 Materials science and microelectronics [85].
- 3987 \* **Botswana:** The Botswana Institute for Technology Research and Innovation (BITRI) which  
3988 hosts the Centre for Materials Science (CMS) [32]. BITRI hosts a state of the art facility for  
3989 conducting research and development in mineral beneficiation, biotechnology, materials science  
3990 and nanotechnology.
- 3991 \* **Mauritius:** The Centre for Biomedical and Biomaterials Research (CBBR)[37]. It is the  
3992 University of Mauritius Pole of Innovation for Health which hosts the biomaterials, drug  
3993 delivery and nanotechnology units.
- 3994 \* **Uganda:** African Centre of Excellence, Centre of Materials, Product Development and  
3995 Nanotechnology (MAPRONANO ACE) at Makerere University. The Center was developed  
3996 out of the need to strengthen research and training in the thematic areas of materials science  
3997 and engineering, nanotechnology and nanomedicine in order to develop human resource  
3998 capacity in applied science engineering disciplines for the development of the great lakes  
3999 region. <http://www.mapronano.mak.ac.ug/>
- 4000 \* **Rwanda:** East Africa Institute for Fundamental Research (EAIFR) which is a partner  
4001 institute of the Abdus Salam International Centre for Theoretical Physics (ICTP) and it is  
4002 also a Category 2 UNESCO institute. The institute is located at the University of Rwanda. Its  
4003 main areas of research and teaching include Condensed Matter Physics, Physics of the Solid  
4004 Earth, High Energy, Cosmology and Astroparticle Physics. [About Us — EAIFR \(ictp.it\)](#)
- 4005 \* **The African Materials Research Society (AMRS)** [104] was launched in 2002 to  
4006 establish and strengthen collaboration between the USA and Africa to promote the materials  
4007 research capacity in Africa. Among other initiatives, the main meeting of the AMRS is a  
4008 series of biennial international Conferences that are hosted in the different countries within  
4009 the five regions of Africa to bring together scientists, industry researchers and Government  
4010 representatives from the USA, Africa and the rest of the world. The objectives of the society  
4011 are;
- 4012 · To promote excellence in all aspects of materials research in Africa through creating a
  - 4013 platform for maximizing collaboration that will ensure that experts in the field work
  - 4014 together.
  - 4015 · To ensure that materials research contributes significantly to the various national strate-
  - 4016 gies for social equity and poverty alleviation in a constructive and sustainable manner
  - 4017 by engaging the governments, industry, universities and entrepreneurs among other or-

ganizations that can promote awareness of the benefits of materials science in everyday life.

- To work closely with governments and state structures to develop appropriate policy and support for materials research and development.
- To build a network of materials researchers which encourages multinational and multi-disciplinary collaboration in materials research both within Africa and between African Researchers and the rest of the world.
- To identify and foster specific areas of materials research as appropriate in the different countries or regions of Africa.
- To promote information and resource sharing, exchange and development in materials science by actively engaging the representatives of the five regions of Africa so that they can provide information to the secretariat office which will communicate through the website and newsletters.
- To regularly host meetings, symposia and conferences with a view to promoting dialogue between materials researchers within Africa as well as with researchers outside the continent.
- To encourage downstream materials manufacturing and value adding activities in all countries in Africa.
- To strengthen the facilities and other resources for materials science in the further and higher education sectors. [105].

However, the available equipment, in most African countries, is old or defective, this is compounded by the fact that there is a shortage of trained technicians for maintenance. Getting dysfunctional equipment fixed is often unduly cumbersome and bureaucratic. Furthermore, African laboratories cannot afford upgraded instrumentation due to a lack of funds [73].

**For theorists using computational techniques**, the main challenge is finding computational facilities as high performance computers (HPC) or at least powerful workstations, to perform computationally intensive calculations. Such facilities are not available in the most of African countries. On the other hand, many numerical calculations need to be operated with commercial codes which are not affordable to many research laboratories. To use such codes, researchers need also to be enrolled in training programmes and workshops to keep being updated related computing techniques. However, African researchers are mostly left to their own resources and backgrounds, which is at the origin of the large gap between the research outcomes in computational Physics of African labs and other international research institutes.

There are a few attempts to boost computational Physics in Africa.

- \* HPC facilities are provided to researchers in South Africa [86], Egypt [87], Algeria [88]. The National Center for Scientific and Technical Research (CNRST) provides the Moroccan scientists with a remote-access to HPC [89].
- \* The annual African School on Electronic Structure Methods and Applications (ASESMA), organized by ICTP, offer the young African researchers an introduction to the computational electronic band structure and other atomistic simulation methods[75, 76, 77]

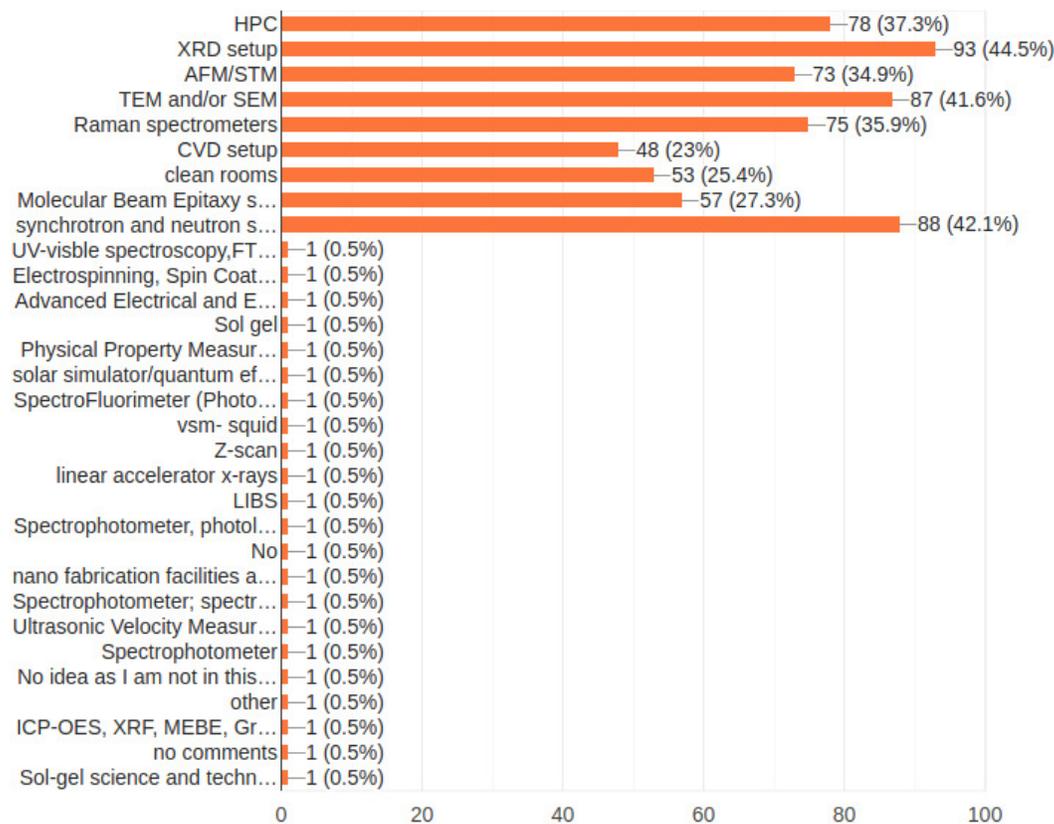
Figure 13-2 clearly shows the huge lack in equipment for African researchers in experimental and theoretical CMCMP&MP.

- Challenges with communication and dissemination

If African countries create a platform for Materials Physics and condensed Matter, which equipment you suggest to have



209 responses



If you are using numerical calculations, which problems are you facing?

209 responses

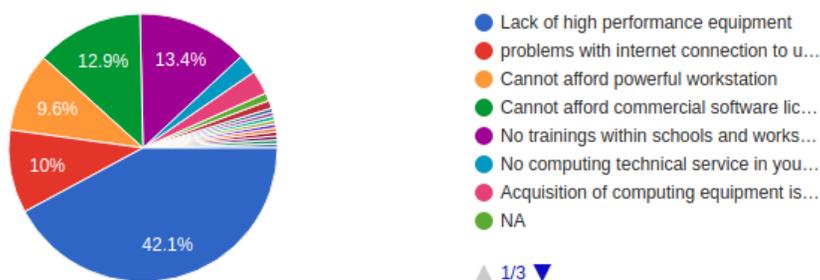


Figure 13-2: Survey responses concerning the equipment needed for experimentalists (top) and theorists (bottom) working in CMCMP&MP. [74].

4065 \* Participation to international research events

4066  
4067 Taking part to international events is a key ingredient in the development of the research  
4068 activities. There are plenty of scientific events in CMCMP&MP during the year in different  
4069 countries all over the world, where outstanding researchers are invited, including Nobel prize  
4070 laureates. These events offer the opportunity for African scientists to be in touch with the  
4071 ongoing international research activities, to discuss their results, build-up networks, establish  
4072 collaborations etc. However, access to such events is generally not possible for African  
4073 researchers for many reasons

- 4074 1. Due to the lack of funds in their home institutes and their low incomes, African attendees  
4075 cannot afford to cover the conference registration fees (which are usually around 500  
4076 Euros).
- 4077 2. Visas issues often plague African participation to international events even if the funds  
4078 are available [73].
- 4079 3. Many African researchers are isolated from the international networks and they do not  
4080 receive event announcements, in addition to problems with internet connectivity.

4081 \* Research paper publication

4082  
4083 Publishing the research results in outstanding scientific journals opens the way to researchers  
4084 to be recognized at the international level and to be part of the global networks. In CM-  
4085 CMP&MP there is broad panoply of outstanding journals, but many of them reject preprints  
4086 from African labs because the obtained results do not meet the journal standards. Let us put  
4087 bias aside and look for the reasons of the rejection.

4088 Regarding their poor infrastructure, African researcher cannot obtain results competing with  
4089 those of their peers in other international institutions. On the other hand, they do not  
4090 often have access to the data base nor to published papers. Most of the African institution  
4091 libraries are not subscribed into international journal publishers which require unaffordable  
4092 registration fees.

4093 Recently, many journals in MCMP&MP converted, fully or partially, to the open access  
4094 scheme, which allows African researchers, among others, to have access to the published  
4095 papers. However, the downside of the open access journals is the high publication charges  
4096 (around few thousands dollars per paper) which cannot be covered by African labs. Some  
4097 international institutions offer a free access to many journals for researchers from low-income  
4098 countries. In particular the American Physical Society (APS) [90] and ICTP within its  
4099 eJournals Delivery Service [91]. Nevertheless, the access to is limited to a few researchers due  
4100 to problem with information access,

4101 As shown in Table 13-1, the African countries with high publication rates in Materials science  
4102 and nanotechnology are those granted with a good infrastructure as discussed in the previous  
4103 section.

4104 In figures -5, -6, -7 (see Appendix) we depicted the publication records, during the last two  
4105 decades, of different African countries categorized by regions. The last panel shows a comparison  
4106 between two Africa countries with the highest African records (South Africa and Egypt) and some  
4107 other countries in the world with a comparable. This figure clearly shows that, despite its huge  
4108 natural and human resources, Africa is lagging behind the rest of the world in terms of research  
4109 in CM&MP, which explain why Africa is far behind in technology and industrialization.

4110  
4111 It is worth to note that despite the large community of African researchers working in CM&MP,  
4112 there are only four classified journals in the field and are low-ranked as shown in Fig. 13-3.

Country	Worldwide Rank	Country	Worldwide Rank
Egypt	31	Egypt	33
South Africa	41	South Africa	45
Algeria	47	Tunisia	55
Tunisia	49	Algeria	56
Morocco	54	Ethiopia	62
Nigeria	62	Morocco	64
Ethiopia	75	Nigeria	68
Cameroon	89	Ghana	86
Senegal	107	Cameroon	93

Table 13-1: Publication country ranking in Materials Science (left) and nanoscience and nanotechnology (right) during the period 1996-2022, after Scimago classification [78]

Title	Type	↓ SJR	H index	Total Docs. (2022)	Total Docs. (3years)	Total Refs. (2022)	Total Cites (3years)	Citable Docs. (3years)	Cites / Doc. (2years)	Ref. / Doc. (2022)	
1 <a href="#">Journal of Nanotechnology</a> 	journal	0.577 Q2	39	25	55	2070	253	51	4.07	82.80	
2 <a href="#">International Journal of Polymer Science</a> 	journal	0.411 Q2	50	56	276	3367	909	269	3.29	60.13	
3 <a href="#">Advances in Tribology</a> 	journal	0.368 Q3	22	0	13	0	39	13	2.82	0.00	
4 <a href="#">Journal of the Southern African Institute of Mining and Metallurgy</a> 	journal	0.242 Q3	43	73	289	2348	244	272	0.75	32.16	

Figure 13-3: African journals on Materials Sciences with WOS classification [78].

– Challenges with international collaborations

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Being a partner in an international research project breaks the scientific isolation of African countries and facilitate substantially their cross-border activities. There are several joint programmes boosting the participation of African countries in international consortia. In particular, EU proposes several collaboration schemes [92, 93, 94] as Euraxess Africa [95], Horizon-Europe [96], etc. Within such collaboration, many African students can have the opportunity to carry out internship in international labs.

Since international consortia brings together countries with complementary expertise, the African members need to bring a relevant contribution to the research activities of the consortium within a win-win approach. With the exception of South Africa and some North African countries, the participation of Africa to international projects is very limited. This is, basically, due to the unbalance between the international and African infrastructures and research outcomes, the lack of information on available collaborating opportunities, the absence of administrative structure

4127 for the project management in the African institutions etc.

- 4128  
4129 – Challenges with limited budgets

4130  
4131 As noted in Ref. [97] African countries are spending less than 1% of its gross domestic product  
4132 (GDP) on research despite the increase in the number of scientists in the past five years. South  
4133 Africa and Egypt allocate the highest budgets for scientific research which are respectively 0.83%  
4134 and 0.72% of their GDP [97].

4135 Setting-up a research lab in CM&MP requires investment in high performance equipment as those  
4136 indicated in Table 13-2. Regarding their limited budget, most of the African institutes cannot  
4137 manage to get one of these facilities.

4138 In international labs, experimental research in CM&MP involve many Postdocs, Ph.D and Master  
4139 students, in addition to trained technicians for machine maintenance. This is not the case of the  
4140 majority of African labs due to the lack of funds which prevent the recruitment of students and  
4141 postdocs, pushing Ph.D holders to unemployment. It is worth to stress that the stipend of Ph.D  
4142 student in Africa is in general much lower than the minimum wage.

Equipment	Price (in \$)
Lithography System	220 million – 500 million
Scanning electron microscopes	70,000 to 1,000,000
Transmission Electron Microscopes (TEM)	100,000 to 10,000,000
Molecular beam epitaxy (MBE)	minimum 1,000,000
Physical Property Measurement System (PPMS)	100,000 to 10,000,000
Clean room (per square metre)	1,500 to 6,000

4143 Table 13-2: Average price range of some equipment used in CM&MP [99, 98]

### 4143 13.3 High-priority future needs

4144 The current landscape of CMP research in Africa reveals a significant gap in infrastructure, funding, and  
4145 human capital. While some individual research efforts exist, the **absence of coordinated initiatives**  
4146 limits the impact and scalability of these endeavors. Furthermore, the lack of state-of-the-art equipment and  
4147 facilities hampers research progress and inhibits collaboration. Thus, to enhance the continent's scientific  
4148 capabilities and address pressing societal challenges, some high-priority future needs for an African strategy,  
4149 focusing on maximizing impact with limited resources, are identified as follows:

#### 4150 1. Education and capacity building

4151 Catching the tech race requires an immediate investment in Education which should not be limited to  
4152 teaching but should also include continuous training for teachers and researchers. There is an urge to  
4153 improve the curricula of CM&MP taught at different levels: Bachelor, Master and doctorate. Based  
4154 on the received LOIs and the outcomes of different meetings with African researchers in CM&MP, we  
4155 propose to reshape the teaching of CM&MP in Africa as follows:

- 4156 (a) Start teaching of CM&MP at the Bachelor level to raise the awareness of students about the  
4157 technological impacts of Condensed Matter Physics. The curricula should include an introduction

to solid states physics with lab and computation hands-on sessions. A teaching by project approach is strongly recommended with input from industry.

- (b) Build up **Pan African Master and related Ph.D programmes** an with exchange student program. The Master should involve African and International universities to insure training of African teachers and students. The African countries involved in such hub should be able to handle visa issues to facilitate the exchange of staff and students. Each Master programme could have a nodal point in an African country with a suitable teaching/research infrastructure. The teaching will focus on the fundamental and applied aspects of CM&MP as required by the participants to the survey launched by the ASFAP CM&MP working group (see figure 13-4). The proposed Master programmes are in following areas

If African countries create a joint Master programme for Materials and Condensed Matter Physics, do you think that

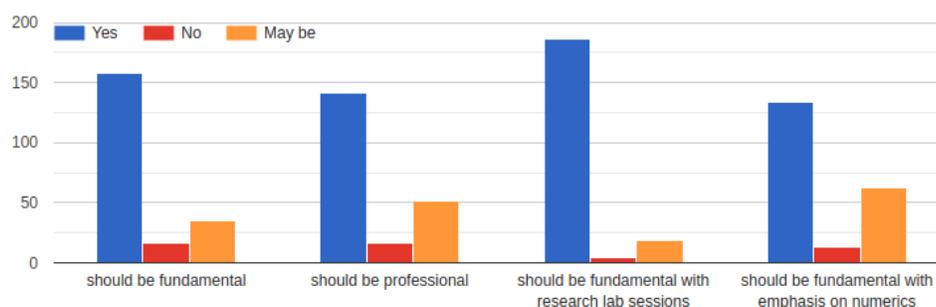


Figure 13-4: Survey responses concerning their preferences about the nature of a possible joint African Master programme in CMCMP&MP. [74].

- Master in Theoretical & computational CM:** with a strong focus on the fundamental aspects of solid states Physics, quantum matter and the related computational methods, including machine learning, AI and quantum computing. The students will be able to combine numerical and analytical skills to undertake Ph.D projects in advanced CM topics including but not limited to advanced materials and quantum information. This Master programme will lay on the existence of HPC infrastructure or at least powerful workstation to carry out numerical calculations. The teaching will be based on workshops and seminars organized with ICTP and other international research institutes. A pre-master year could be planned to students with major gaps in relevant background. After getting their Master degree, students should also be able to carry out a career in data science or quantum computing.
- Master in Experimental and applied CM&MP:** devoted to the fundamentals of experimental CM&MP and the technological applications. This is a key Master programme for the promotion of research in CM&MP. The students will learn the different techniques of synthesis, characterization of advanced materials and the methods to control their properties. The teaching should be mostly based (80%) on lab-courses carried out in research centers or labs with suitable equipment. The students will be able to master the key experimental methods to undertake Ph.D projects in experimental CM&MP or in R&D focusing on applied MP. After getting their Master degree, students should also be able to carry out a career in industry.

- 4188 • **Professional Master degree in Materials Physics and applications:** with a focus  
4189 on energy, water purification, food agriculture etc The students will also be trained on  
4190 entrepreneurship within startups and technology business incubators to help them setting-up  
4191 their own Materials Physics based-business.
- 4192 • **Master in quantum technologies:** This Master is already implemented in many inter-  
4193 national institutes. It will be an interface between three pathways: physics, engineering  
4194 and mathematics where students from different paths can interact within multidisciplinary  
4195 research projects and workshops. The topics include Quantum Computing, Quantum Sens-  
4196 ing, Quantum Simulation, Quantum Materials and Quantum Cryptography with advanced  
4197 practical training on quantum computing platforms, photonic quantum computers etc. The  
4198 details of the Master curricula could be discussed within an African strategy for Quantum  
4199 technologies.

4200 The Pan African University Institute for Basic Sciences, technology and Innovation (PAUSTI)  
4201 can be the engine to boost such joint education programmes in Africa [107, 106]. PAUSTI  
4202 mission focuses on forming leaders and innovators in the fields of Mathematics, Molecular Biology  
4203 and Biotechnology; Civil Engineering; Mechanical Engineering; Mechatronic Engineering and  
4204 Electrical Engineering.

- 4205 (c) Set-up an **International Centre for Experimental in Africa (ICEPA)** with a focus on  
4206 CM&MP. *"This is an educational centre for the training of young African students, postdocs and*  
4207 *junior faculty members in instrumentation for fundamental and applied experimental physics. The*  
4208 *educational programme foreseen would be equivalent to a Master curriculum at a university. Many*  
4209 *African universities do not have the necessary number of experimental facilities and instruments*  
4210 *at their disposal for training in experimental techniques and tools. The concept of the proposed*  
4211 *centre (named provisionally ICEPA in the following) has been inspired by the successful AIMS*  
4212 *centres for mathematical sciences and ICTP for theoretical physics. But for ICEPA the focus is*  
4213 *on experimental physics, strongly oriented towards instrumentation. The attachment to or at least*  
4214 *a very close link to a university or to an existing research centre will be necessary to train and*  
4215 *recruit qualified staff for the supervision of the experiments and to be able to issue an international*  
4216 *recognised diploma"* [102].
- 4217 (d) Strengthen the teaching activities at the Master and Ph.D levels by organizing regular schools in  
4218 specific on-demand topics as computational CM&MP, quantum matter, 2D materials, quantum  
4219 information etc. *"The Case of the African School for Electronic Structure Methods and Appli-*  
4220 *cations (ASESMA) shown that it is possible to build a network across sub-Saharan Africa with*  
4221 *world-class research with world-class research with a relatively low budget."* [76]

## 4222 2. Research

4223 Research on MP in African is generally limited to local natural materials and their applications in  
4224 particular area like construction, food, biology. To bridge the technological gap between Africa and At  
4225 the international level, the key research areas in CM&MP are, but not limited to, 2D and advanced  
4226 Materials for chips technologies, quan....

- 4227 • Enhance existing and establish new collaborative networks between universities, research institutions,  
4228 and industries within and outside Africa. These networks facilitate knowledge exchange, joint research  
4229 projects, and technology transfer.
- 4230 • Encourage public-private partnerships to provide funding, industry expertise, and market access,  
4231 fostering innovation and entrepreneurship in CMP.

- 4232 • Upgrade existing research infrastructure and establish new facilities equipped with state-of-the-art  
4233 instruments as well as facilitate access to advanced experimental and computational tools.
- 4234 • Invest in training programs, mentorships, workshops, and international collaborations to enhance the  
4235 capacity of African researchers in CMP.
- 4236 • Develop comprehensive and interdisciplinary curricula tailored to CMP by integrating theoretical  
4237 knowledge with practical skills.
- 4238 • Invest and fund advanced laboratories, research grants, and scholarships to attract and retain top  
4239 talent. This funding should support both basic and applied research, as well as capacity-building  
4240 activities.
- 4241 • Create dedicated research positions for CMP researchers within universities and research centers to  
4242 provide sufficient time, resources, and institutional support for conducting impactful research without  
4243 compromising teaching responsibilities.
- 4244 • Promote a culture of research excellence by incentivizing and rewarding research contributions. This  
4245 includes recognizing research outputs in performance evaluations, providing research-related training  
4246 and mentorship.

## 4247 13.4 Synergies with neighbouring fields

4248 Condensed Matter and Materials Physics exhibit numerous synergies with neighboring fields, fostering  
4249 interdisciplinary collaboration and driving scientific innovation across various domains.

4251 This can be illustrated through their intersection with Photonics and Optoelectronics in studying the  
4252 interaction of light with condensed matter systems and the development of optical and optoelectronic  
4253 devices [100]. CMP techniques, such as spectroscopy, nonlinear optics, and photonic crystal engineering, are  
4254 used to investigate the optical properties of materials and design photonic devices, such as lasers, LEDs, and  
4255 photodetectors, for communication, sensing, and imaging applications. Conversely, advances in Photonics  
4256 and Optoelectronics contribute to CMP research by providing tools and techniques for manipulating light-  
4257 matter interactions and harnessing optical phenomena for controlling and manipulating condensed matter  
4258 systems at the nanoscale.

4260 Besides, CMP relies on light sources, such as synchrotrons and free-electron lasers, for spectroscopy and  
4261 imaging experiments [101]. These techniques provide valuable insights into the electronic and structural  
4262 properties of materials at the atomic scale. Advances in light sources technology, such as high-brightness  
4263 beams and ultrafast lasers, enable CMP researchers to study dynamic processes in condensed matter systems  
4264 with unprecedented resolution and sensitivity. Furthermore, light sources offer a wide range of characteriza-  
4265 tion techniques, including X-ray diffraction, X-ray absorption spectroscopy, and photoelectron spectroscopy,  
4266 which are essential for studying the properties of materials in CMP. These techniques provide information  
4267 about the crystal structure, chemical composition, and electronic structure of materials, facilitating the  
4268 design and optimization of new materials for specific applications.

4270 Biophysics also intersects with CMP in studying the physical principles underlying biological systems'  
4271 structure, function, and behavior. CMP techniques, such as X-ray crystallography, spectroscopy, and

4272 microscopy, are used to investigate biomolecular structures, protein folding dynamics, and cellular pro-  
4273 cesses. Understanding the physical mechanisms governing biological systems' behavior has implications for  
4274 biomedical research, drug discovery, and biotechnological applications. Conversely, insights from biophysics  
4275 inspire CMP research, leading to the development of biomimetic materials and devices that mimic biological  
4276 systems' functionalities and properties.

4277

4278 On the other hand, Materials physics and Particle Physics researchers often share theoretical and exper-  
4279 imental techniques. Concepts from Particle Physics, such as symmetry breaking, gauge theories, and  
4280 renormalization, have found applications in CMP research, while techniques from CMP, such as effective  
4281 field theory and renormalization group methods, have been adopted in Particle Physics to study strong and  
4282 weak interactions.

4283

4284 Furthermore, collaboration between CMP and Condensed Matter Chemistry researchers enables a deeper  
4285 understanding of chemical processes at the molecular level and the development of innovative materials with  
4286 tailored functionalities.

## 4287 13.5 Environmental and societal impact

4288 Condensed Matter and Materials Physics is part of our everyday life as it plays a crucial role to describe  
4289 matter. Therefore, improved education in CMMP of the current and future generation will help to have a  
4290 more scientifically inclined and open minded society. This will help to ensure that Africa is well positioned to  
4291 have a critical mass of physicists with the knowledge, skills, creativity and versatility to face any challenge.  
4292 Due to the fact that CMMP embraces various fields, it instils interdisciplinarity in the mindsets of Scientists.

## 4293 13.6 Conclusion and perspectives

4294 In the past, availability of land, raw materials and labour were considered to be important economic factors  
4295 for African development while the pursuit for scientific information and knowledge were less considered. This  
4296 was primarily due to inward looking and short term thinking focused on tangible things in the short term  
4297 without thinking about how the search for new scientific knowledge could change the future of Africa to move  
4298 away from set ways of doing things. The late Professor John Desmond Bernal, a British Physicist in his book  
4299 "Science in History" stated that "It is now evident that the real source of wealth of a nation lies no longer in  
4300 the raw materials, the labour force or machinery, but in having a scientific, educational and technological base,  
4301 education has become the real wealth of the new age". As a result of limited investment in scientific research  
4302 by most African countries with almost all of them falling short of reaching the set minimum of investing  
4303 0.5% of their GDP in scientific research, economic development in Africa is still lagging behind that of the  
4304 Western world. It is painful to note that Africa is still more of a consumer rather than a producer although  
4305 a significant amount of mineral resources required for production of technological components are sourced  
4306 from Africa. Physics is a foundational pillar for development of basic science and technology. Therefore, for  
4307 Africa to advance to go beyond just catching up on the global scientific and technological race, it is necessary  
4308 to fully integrate physics in the education system of Africa. In the context of our report that focuses on  
4309 condensed matter and materials physics, it is critical that continental initiatives embrace its potential. For  
4310 example, the African Union's Agenda 2063 "The Africa we want" which is Africa's blue print and master plan  
4311 for transforming Africa into the global powerhouse of the future. For this to be fully realized, it is essential

4312 that continental science, technology and innovation policies are tailored to create an enabling environment  
4313 for the successful harnessing of the immense potential that lies in condensed matter and materials physics.  
4314 This cuts across a move towards elimination of limitations to access to education, access to equipment for  
4315 research and fostering a strong relationship within the triple helix context. The need for advanced tools  
4316 (experimental, computational and theoretical) to probe the structure and properties of materials is critical  
4317 for the significant advancement of condensed matter and materials physics in Africa hence the need for  
4318 significant investment and training. It should also be noted that having a improved understanding of the  
4319 value of seeking answers for scientific questions, the link between theoretical and experimental research and  
4320 their impact on current and future technological applications will contribute significantly to socioeconomic  
4321 development of Africa. However, for this to be realized, the value of condensed matter and materials physics  
4322 should be appreciated at the highest level of African governments hence the compilation of the African  
4323 Strategy for Fundamental and Applied Physics. Africa is the future of the world because of the abundance  
4324 of natural resources and having a significant percentage of a young population but it needs to speed up its  
4325 approach to scientific thinking in order to capitalize on its advantages.

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<sup>4476</sup> Appendix

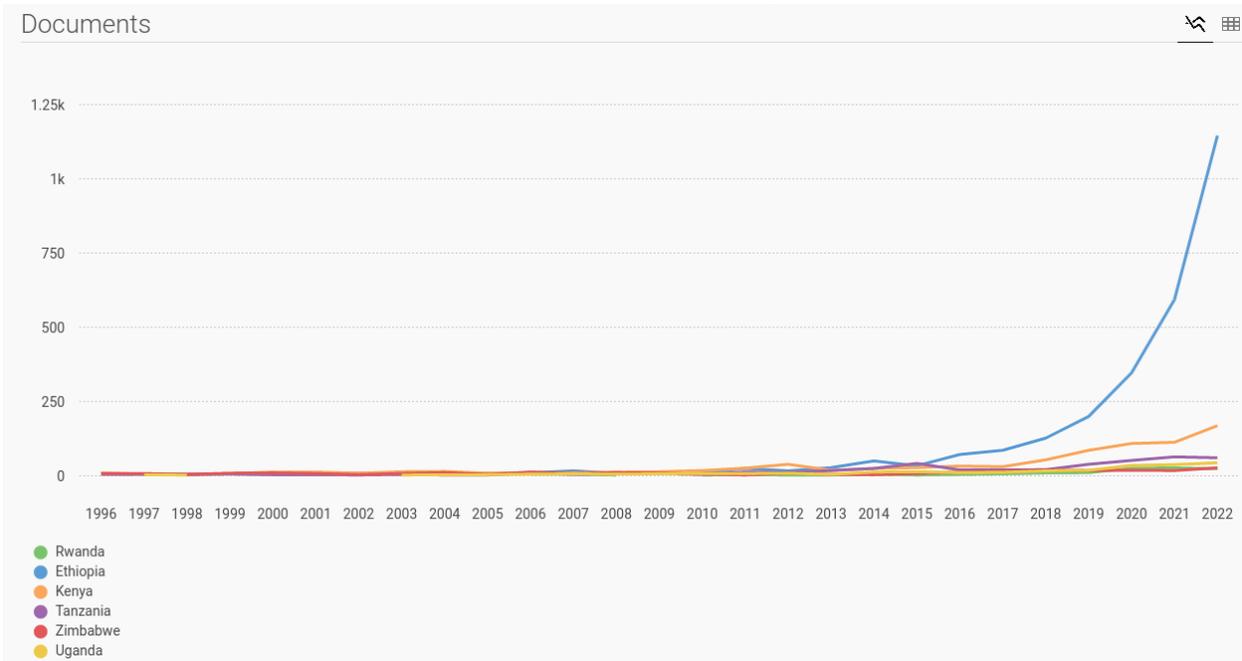
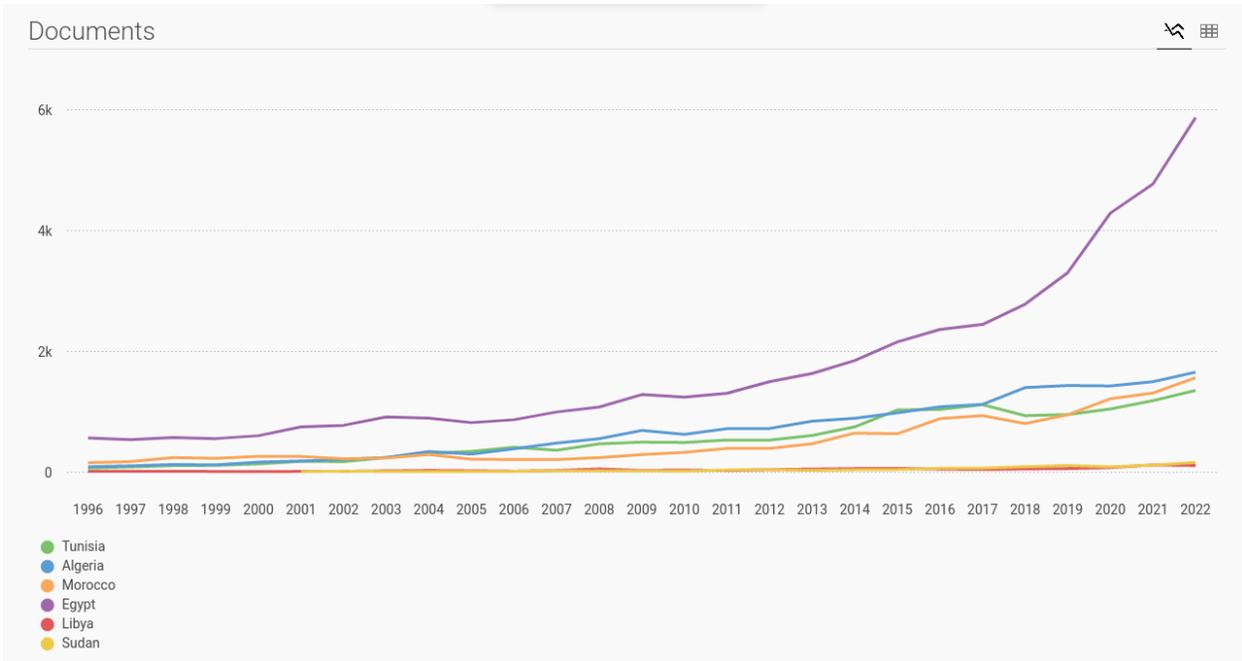


Figure -5: Number of publications per year in Materials Sciences for North and Eastern African countries, after Scimago Scimago.

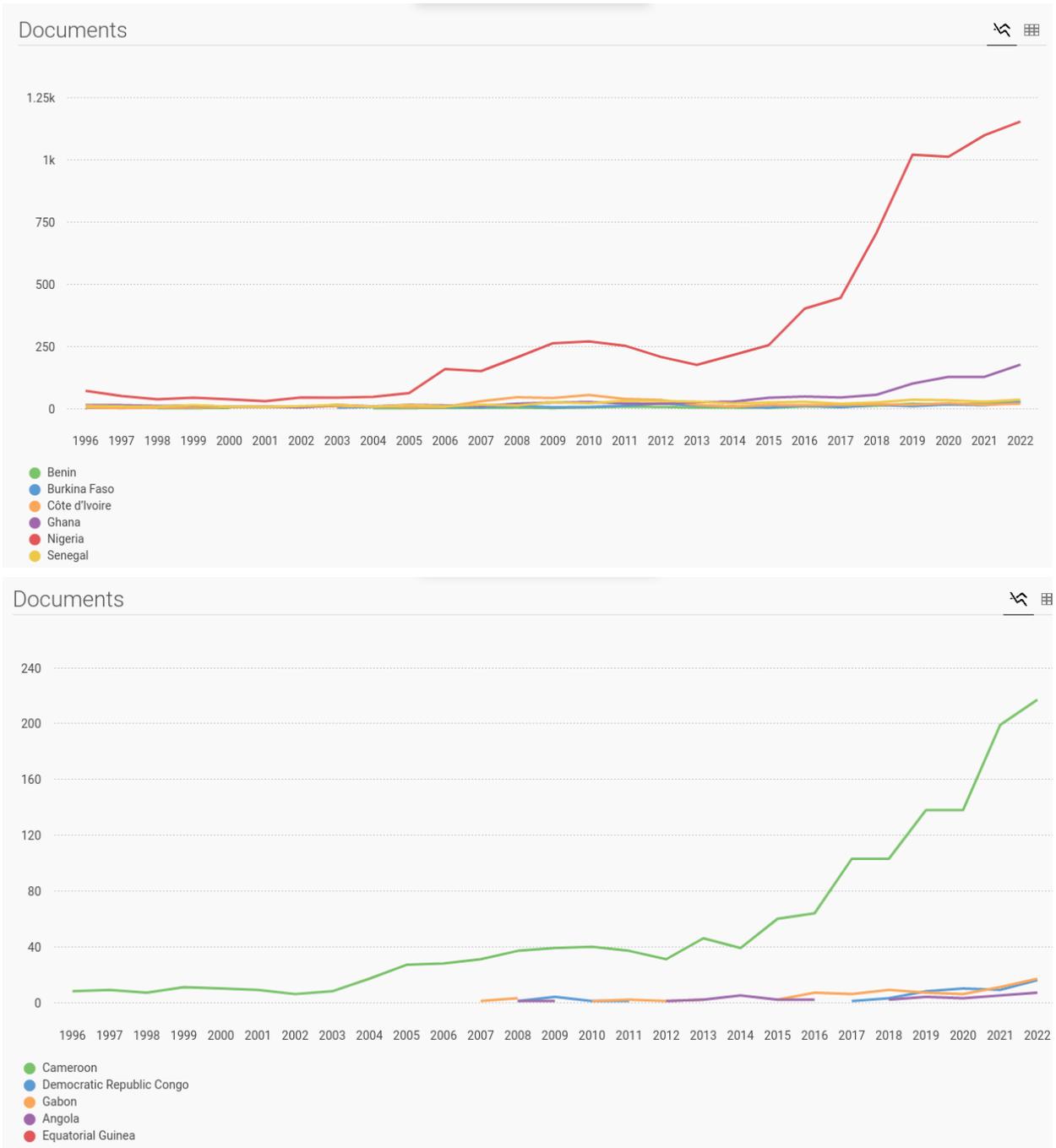


Figure -6: Number of publications per year in Materials Sciences for Western and Central African countries, after Scimago [78].

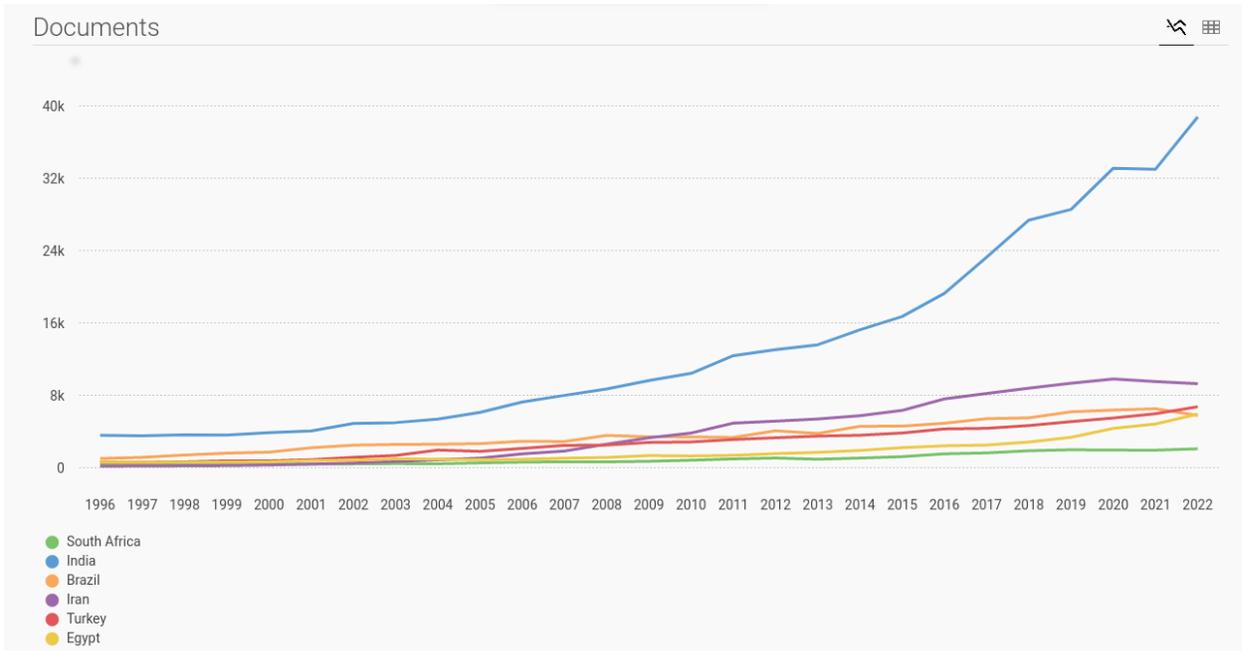
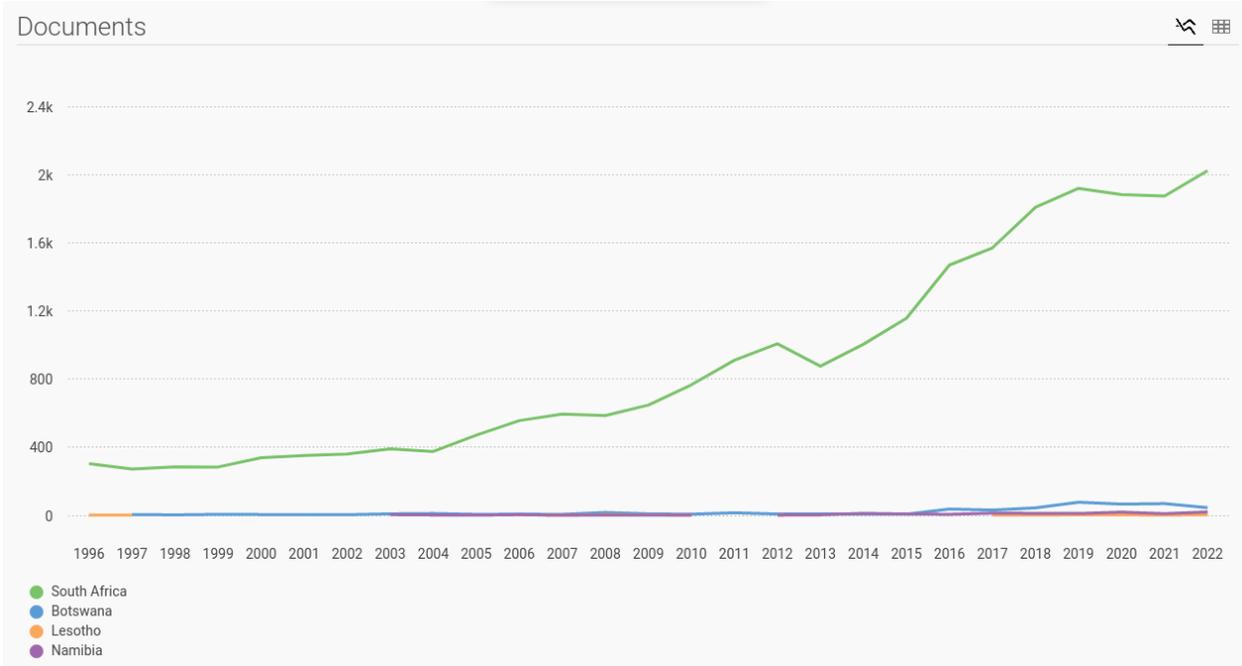


Figure -7: Number of publications per year in Materials Sciences for South African countries, Iran, Turkey, India an Brazil and countries in different continents, after Scimago [78].



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# Medical Physics Working Group

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## 4484 14.1 Introduction and Motivation

4485 Africa is rapidly acquiring high-tech medical imaging equipment such as multi-slice helical computed tomog-  
4486 raphy (CT) scanners, MRI scanners, as well as hybrid imaging technologies like combining single photon  
4487 emission tomography (SPECT) and positron emission tomography (PET) with CT. However, without  
4488 proper specialized support, this advancement in technology has the potential of significantly increasing  
4489 the population's exposure to ionizing radiation. The safe use of these technologies requires proper quality  
4490 assurance procedures, calibration of imaging equipment and optimization of the radiation dose to the patient,  
4491 which may not be properly done in the absence of a qualified medical physicist. The degree of involvement  
4492 of the medical physicist is determined by the complexity of the radiological procedures and the associated  
4493 radiation risks [1].

4494 The essential responsibility of the Qualified Medical Physicist's clinical practice is to assure the safe and  
4495 effective delivery of radiation to achieve a diagnostic or therapeutic result as prescribed in patient care [2,3,4].  
4496 The responsibilities of the medical physicist include: protection of the patient and others from potentially  
4497 harmful or excessive radiation; establishment of adequate protocols to ensure accurate patient dosimetry;  
4498 the measurement and characterization of radiation; the determination of delivered dose; advancement of  
4499 procedures necessary to ensure image quality; development and direction of quality assurance programs; and  
4500 assistance to other health care professionals in optimizing the balance between the beneficial and deleterious  
4501 effects of radiation; and compliance with applicable federal and state regulations [5].

4502 Unfortunately, in most African countries, there is a critical shortage or absence of qualified medical physicists  
4503 in hospitals, clinics and other health care facilities that use radiation technology. This problem is particularly  
4504 critical in diagnostic imaging units (either in diagnostic radiology or nuclear medicine) that usually have  
4505 no qualified medical physicist in their workforce [6, 7]. This may lead to patients receiving non-optimized  
4506 radiation procedures, resulting in inadequate diagnosis or treatment, or in extreme cases from the harmful  
4507 effects of radiation due to overexposure.

## 14.2 Major challenges Scientific activities

Medical physicists play a vital role in ensuring the safe and effective use of radiation and imaging technologies in diagnostic and therapeutic medical procedures. However, several factors pose challenges to the field that can impact their work and the quality of healthcare services in the region requiring strategic solutions and priority actions. Some of the key challenges include the following.

### 14.2.1 Limited Resources

Many African countries face significant challenges in terms of limited financial resources, leading to inadequate funding for healthcare infrastructure, including radiation therapy and diagnostic imaging facilities. The funding constraints impact the acquisition and maintenance of advanced medical equipment, professional training programs, and research opportunities. Many hospitals struggle to meet the rising demand for cancer care and other medical physics services, leading to delays in diagnosis and treatment, which directly affect patient outcomes. Furthermore, limited resources hinder the growth and retention of skilled medical physicists, as funding for education, competitive salaries, and professional development remains scarce. Addressing these financial challenges is crucial to advancing equitable, high-quality healthcare across the continent.

### 14.2.2 Shortage of Qualified Personnel

Africa faces a critical shortage of qualified medical physics professionals, a gap that greatly affects the delivery of essential healthcare services, especially in oncology and diagnostic imaging. The limited number of trained medical physicists hinders the safe and effective use of radiation in medical applications, leading to delays in treatment and increased risks for patients. This shortage is further exacerbated by insufficient training programs, limited funding, and few opportunities for professional growth, which also drive talented individuals to pursue careers abroad (brain drain). Consequently, many hospitals lack the expert oversight needed to operate advanced equipment safely and efficiently. Bridging this gap requires strategic investment in education, training, and retention to build a robust medical physics workforce and improve healthcare outcomes across the continent.

### 14.2.3 Inadequate Infrastructure

Some regions lack the necessary infrastructure for advanced medical physics services. This includes a shortage of modern equipment, such as linear accelerators, CT scanners, and other advanced imaging devices such as MRI machines. In facilities where this equipment is available, outdated technology and insufficient maintenance further compromise their effectiveness, leading to frequent breakdowns and extended downtime. Additionally, a lack of dedicated spaces for training and research in medical physics hampers the development of a skilled workforce. This infrastructural deficit creates a reliance on external support and limits the ability of healthcare systems to offer timely and safe medical physics services. Expanding infrastructure is critical to empowering African nations to provide comprehensive, high-quality healthcare independently.

#### 4542 14.2.4 Education and Training Gaps

4543 Insufficient training opportunities for medical physicists can lead to a lack of specialized skills. Comprehensive  
4544 education programs, including postgraduate training and continuous professional development, are crucial  
4545 to ensuring a competent workforce. Africa faces substantial education and training gaps in the field of  
4546 medical physics, which limit the development of a skilled workforce equipped to meet the continent's growing  
4547 healthcare demands. A few institutions offer medical physics programs within the region, with a number  
4548 of them under-resourced, with limited access to state-of-the-art equipment, research opportunities, and  
4549 specialized faculty. As a result, many medical physics professionals graduate with insufficient practical  
4550 experience to make them clinically competent to practice independently. Additionally, continuing education  
4551 and certification opportunities are scarce, leaving few pathways for professionals to upgrade their skills or  
4552 gain expertise in emerging technologies. More investment in accredited training programs, partnerships with  
4553 international institutions, and resources for hands-on experience are needed for building a self-sustaining  
4554 medical physics workforce across Africa.

#### 4555 14.2.5 Regulatory Frameworks

4556 The development of robust regulatory frameworks for medical physics in Africa is essential to ensure safe  
4557 and effective use of radiation in healthcare, but many countries on the continent lack comprehensive policies  
4558 in this area. Inconsistent or inadequate regulatory frameworks for radiation safety and medical physics exist  
4559 in many countries. A robust regulatory system is essential to ensure consistent standards for equipment  
4560 quality, radiation safety, and professional qualifications to ensure safe and effective use of radiation in medical  
4561 procedures. In most of African countries, medical physics is not recognized as a profession and medical  
4562 physicists are not required to register with a Health Professions Council. This could potentially have a  
4563 negative effect on the practice standards, training adequacies and credentialing requirements for medical  
4564 physics professionals.

#### 4565 14.2.6 Access to Continuing Education

4566 Access to continuing education for medical physics professionals in Africa remains limited, posing a significant  
4567 barrier to the advancement and quality of healthcare services that depend on up-to-date knowledge in  
4568 this highly specialized field. Rapid advancements in medical technology mean that professionals require  
4569 ongoing training to stay proficient in new techniques, safety standards, and equipment, especially in areas like  
4570 radiotherapy, diagnostic imaging, and nuclear medicine. However, few African institutions offer structured  
4571 programs for continuing education in medical physics, and international training opportunities are often  
4572 cost-prohibitive. This lack of accessible professional development leads to skill gaps, impacting the quality of  
4573 patient care and limiting the growth of medical physics as a field in the region. Increasing local opportunities  
4574 for continuing education through workshops, certifications, and partnerships with global institutions like the  
4575 IAEA and ICTP is crucial for building a competent, resilient healthcare workforce in Africa.

### 4576 14.2.7 Geographic Disparities

4577 Geographic disparities significantly affect the distribution of medical physicists across Africa, with most  
4578 professionals concentrated in the Northern and Southern regions of the continent. At the country level,  
4579 there are more medical physicists in the urban centers, leaving rural and underserved regions with limited  
4580 or no access to their expertise. The uneven distribution means that advanced healthcare services, such  
4581 as radiation therapy and diagnostic imaging, are predominantly available in a few major cities, creating a  
4582 barrier for millions of people who live in remote areas. Contributing factors include a lack of infrastructure,  
4583 fewer employment incentives in rural areas, and limited local training opportunities. Addressing these  
4584 geographic disparities requires investment in rural healthcare infrastructure, the establishment of regional  
4585 training centers, and policies that incentivize medical physicists to serve in underserved areas, ensuring more  
4586 equitable healthcare access across the continent.

### 4587 14.2.8 Lack of Research Opportunities

4588 Medical physicists in Africa face a significant shortage of research opportunities, which limits their ability to  
4589 contribute to scientific advancements and adapt innovations to the continent's unique healthcare challenges.  
4590 Research is essential for developing tailored solutions in radiotherapy and medical imaging to address Africa's  
4591 specific disease burdens, resource constraints, and demographic needs. However, funding for research is  
4592 often sparse, and access to state-of-the-art equipment and collaborative networks is limited, hindering local  
4593 professionals from pursuing studies that could improve patient care and safety. Additionally, without strong  
4594 research programs, many talented medical physicists lack career development opportunities, leading some to  
4595 seek positions abroad where they can engage in meaningful scientific work.

### 4596 14.2.9 Technological Obsolescence

4597 The rapid evolution of medical technology means that equipment may become obsolete quickly. Technological  
4598 obsolescence poses a significant challenge for medical physicists in Africa, as outdated equipment limits the  
4599 effectiveness of radiation therapy, diagnostic imaging, and other critical healthcare services. Due to limited  
4600 funding, many healthcare facilities are unable to upgrade essential radiation therapy and medical imaging  
4601 equipment which often operate beyond their recommended lifespan. As a result, these aging technologies  
4602 provide lower-quality images, reduce treatment precision, and frequently break down, causing delays and  
4603 compromising patient outcomes. For medical physicists, working with obsolete equipment restricts the  
4604 ability to apply advanced techniques and stay current with global standards in medical care. Moreover, this  
4605 situation can impede the training of new professionals who miss opportunities to gain experience with modern  
4606 tools. Addressing technological obsolescence through investment in equipment upgrades and maintenance is  
4607 crucial to enhancing treatment quality, supporting professional development, and ensuring that healthcare  
4608 systems across Africa keep pace with advancements in medical physics. Equipment management, and in  
4609 particular budgeting for preventative maintenance, is often only an afterthought, and this can lead to  
4610 extended downtime.

#### 4611 14.2.10 Public Awareness

4612 Public awareness of the role and importance of medical physicists in Africa remains limited, which affects the  
4613 development of the field and its integration into healthcare systems. Many people, including patients and  
4614 even healthcare professionals, are unfamiliar with how medical physicists contribute to the safe and effective  
4615 use of radiation in cancer treatment, diagnostic imaging, and nuclear medicine. This lack of awareness leads  
4616 to underinvestment in medical physics services, as the critical impact of these professionals on patient safety,  
4617 treatment outcomes, and healthcare innovation often goes unrecognized.

4618 Efforts to address these challenges often involve raising awareness through media, community health pro-  
4619 grams, partnerships with hospitals and educational institutions, collaboration between international or-  
4620 ganizations, governments, non-governmental organizations (NGOs), and educational institutions. These  
4621 collaborations can focus on improving education and training opportunities, investing in infrastructure, and  
4622 implementing effective regulatory frameworks to enhance the practice of medical physics in Africa.

### 4623 14.3 Progress, Achievements, Solutions

4624 While challenges exist, there have been notable progress, achievements, and ongoing efforts to address issues  
4625 in the field of medical physics in Africa. Some positive developments are mentioned as follow.

#### 4626 14.3.1 Training Programs

4627 Expansion of educational programs in medical physics: Several African countries have taken steps to establish  
4628 or expand educational programs in medical physics at the postgraduate levels, contributing to a growing pool  
4629 of qualified professionals [5,8]. The International Atomic Energy Agency (IAEA) and the International Centre  
4630 for Theoretical Physics (ICTP) has supported the region with training of medical physicists through long-  
4631 term fellowships and short-term training courses and workshops. The IAEA has developed an Academic and  
4632 Clinical Training syllabus for the region which has been endorsed by the regional Medical Physics Federation  
4633 (FAMPO), and this has largely harmonized the training regimes in Africa. However, access to remunerated  
4634 training posts remains a challenge.

#### 4635 14.3.2 International Collaboration

4636 Collaborative initiatives with international organizations: Partnerships with organizations such as the IAEA,  
4637 World Health Organization (WHO), ICTP, and other international bodies have facilitated capacity-building,  
4638 knowledge exchange, training opportunities, and resource mobilization for African medical physicists. Through  
4639 these collaborations, there have been equipment donations, scholarships, exchange programs, and technical  
4640 assistance, which help bridge resource gaps, provide access to best practices, and empower African medical  
4641 physicists to contribute to and benefit from global advancements.

4642 This is an area that could be expanded on, especially in view of the increased awareness around global health.

### 4643 14.3.3 Capacity Building

4644 Capacity-building projects: Various projects focus on enhancing the capacity of medical physics services.  
4645 These projects often involve the donation or support for acquiring modern equipment and technologies.  
4646 Medical physics capacity building is often part of a much larger national cancer strategy, for example. Other  
4647 capacity building approaches include instituting training programs, workshops, and education initiatives.  
4648 Capacity-building efforts have also led to the establishment of certification and accreditation programs,  
4649 enhancing professional standards and fostering a more skilled and resilient workforce.

### 4650 14.3.4 Research and Innovation

4651 Growing research activities: Some African medical physicists are actively engaged in research, contributing  
4652 to advancements in the field. Research can lead to innovative solutions tailored to the specific needs and  
4653 conditions in the region. Strengthening research support, funding, and partnerships with global institutions  
4654 is essential to enable Africa's medical physicists to innovate and drive progress within the field, fostering  
4655 home-grown solutions and enhancing healthcare quality across the continent.

### 4656 14.3.5 Advancements in Telemedicine

4657 Utilization of telemedicine: Telemedicine applications have been employed to provide remote support,  
4658 consultation, and training for medical physicists in underserved areas, overcoming geographic disparities.  
4659 Through virtual platforms, medical physicists can receive real-time support for complex cases, collaborate  
4660 on treatment planning, and gain insights into the latest technologies and protocols. Additionally, telemedicine  
4661 facilitates ongoing training and professional development, allowing medical physicists to participate in  
4662 webinars, workshops, and mentorship programs without the need for costly travel. These advancements  
4663 are creating a more connected and resource-efficient healthcare network, which is crucial for addressing  
4664 Africa's healthcare needs and advancing the field of medical physics across the continent. The potential  
4665 impact of tools that employ machine learning strategies cannot be overstated. While there are still many  
4666 open questions in this field, there is no doubt that machine learning has the potential to help address some  
4667 of the staffing challenges in the region.

### 4668 14.3.6 Public Awareness and Advocacy

4669 Increasing public awareness: Efforts to raise awareness about the role of medical physicists and the im-  
4670 portance of radiation safety have been made through public health campaigns and educational programs.  
4671 Increased public education on the role of medical physicists have driven more support for training programs,  
4672 funding, and recruitment initiatives.

### 4673 14.3.7 Regulatory Enhancements

4674 Strengthening regulatory frameworks: Some countries are working to enhance and enforce regulatory frame-  
4675 works related to radiation safety and medical physics practices, ensuring compliance with international  
4676 standards. Such strengthened regulatory frameworks of standardized protocols, certification requirements,  
4677 and oversight mechanisms is vital for improving healthcare outcomes and ensuring patient and practitioner  
4678 safety across Africa.

### 4679 14.3.8 Professional Networks

4680 Development of professional networks: Networking opportunities, both within Africa and internationally,  
4681 have facilitated information sharing, collaboration, and mentorship among medical physicists. FAMPO has  
4682 created a network of medical physicists in Africa to raise and maintain practice standards and promote  
4683 collaboration and innovation. The Federation networks with national member organizations, individual  
4684 medical physicists and global professional bodies like the International Organization for Medical Physics  
4685 (IOMP) to promote the application of physics in medicine.

### 4686 14.3.9 Support from NGOs and Foundations

4687 Support from non-governmental organizations (NGOs) and foundations: Various NGOs and philanthropic  
4688 foundations provide financial and technical support to improve medical physics services in Africa. The  
4689 support includes equipment donations, technology upgrades, and funding for research, all of which help  
4690 bridge resource gaps and improve the quality of patient care. The support fosters stronger, more resilient  
4691 healthcare infrastructure in Africa, empowering local medical physicists to deliver high-quality, safe, and  
4692 effective care to communities across the continent.

### 4693 14.3.10 Focus on Sustainable Solutions

4694 Emphasis on sustainable solutions: Initiatives are increasingly focusing on developing sustainable models for  
4695 maintaining and upgrading medical physics infrastructure, considering long-term viability.

4696 While progress has been made, ongoing efforts are necessary to sustain and expand these achievements. Key  
4697 solutions involve continued investment in education and training, infrastructure development, regulatory  
4698 enforcement, and international collaboration. Encouraging local leadership, empowering healthcare profes-  
4699 sionals, and advocating for policy changes are integral parts of fostering sustainable improvements in medical  
4700 physics across the African continent.

## 4701 14.4 High priority needs

4702 As medical physics in Africa continues to evolve, several high-priority future needs have been identified to  
4703 address challenges and enhance the quality of healthcare services. Some of these needs include increased the  
4704 awareness and recognition of role of medical physicists in medical imaging, in addition to the following.

### 4705 14.4.1 Capacity building for medical physicists in imaging

- 4706 • Implement and extend the educational to reach across the continent to new Members who have  
4707 requested assistance to move forward with national cancer control plans.
- 4708 • Increase the frequency of teaching and formal training activities in the centers and abroad.
- 4709 • Establishment an education and training programme in Zones and affiliated to the university to promote  
4710 the education and training programme.
- 4711 • training of the existing qualified therapy medical physicists to support Diagnostic Radiology and  
4712 Nuclear Medicine.
- 4713 • E-learning platform for training [5]
- 4714 • Regional guidelines for academic education and training programs for imaging physicists e-learning  
4715 [10].

### 4716 14.4.2 Establish diagnostic reference levels (DRLs) for nuclear medicine(NM) 4717 and diagnostic radiology (DR)

- 4718 • DRLs are considered a useful dose optimization tool, and medical physicists are an integral part of the  
4719 team to determine DRLs and further optimize these
- 4720 • Standardizing the procedures and optimizing the parameters affecting the dose delivered to patients.
- 4721 • Focus on pediatric imaging by way of examination of a certain number of criteria linked to these  
4722 practices.

### 4723 14.4.3 Expansion of Training Programs

- 4724 • Establish and expand educational programs in medical physics at postgraduate level, as recommended  
4725 by the IOMP and IAEA, to meet the increasing demand for qualified professionals.

### 4726 14.4.4 Continued Professional Development

- 4727 • Develop ongoing training and professional development opportunities to ensure that medical physicists  
4728 stay abreast of advancements in technology and best practices.

#### 4729 14.4.5 Research and Innovation

- 4730 • Foster a culture of research and innovation within the field of medical physics to address local challenges  
4731 and contribute to the global body of knowledge.

#### 4732 14.4.6 Infrastructure Development

- 4733 • Invest in the development and maintenance of modern infrastructure, including upgrading existing  
4734 equipment and acquiring new technologies for diagnosis and treatment.
- 4735 • Harmonization of quality assurance/quality control programme in medical imaging in Africa [9].
- 4736 • Facilities and technical equipment for quality control as well as radiology and nuclear medicine.
- 4737 • Training on QA/QC in nuclear medicine and diagnostic radiology. Implement & develop QA Pro-  
4738 gramme.

#### 4739 14.4.7 International Collaboration

- 4740 • Strengthen and expand collaborations with international organizations, institutions, and professionals  
4741 to facilitate knowledge exchange, training, and resource mobilization.
- 4742 • Collaboration among African member states will be elevated regional guidelines for academic education  
4743 and training programmes.

#### 4744 14.4.8 Telemedicine Integration

- 4745 • Promote the integration of telemedicine solutions to provide remote support, consultation, and training,  
4746 especially in under-served and remote areas.

#### 4747 14.4.9 Patient Safety and Quality Assurance

- 4748 • Emphasize patient safety through the implementation and enforcement of rigorous quality assurance  
4749 programs in medical physics practices.
- 4750 • Training workshop on the acceptance testing and commissioning of diagnostic/interventional radiology  
4751 machine used for pediatric patients.
- 4752 • Increase the awareness about the radiosensitivity of pediatric patients by educating or having workshops  
4753 with hospital managers, government policy makers and recruiters, radiologist, radiographers, clinicians  
4754 about the need and role of the medical physicist.

#### 4755 14.4.10 Standardization and Certification

- 4756 • Work towards standardizing medical physics practices and certifications across the region to ensure  
4757 consistency and adherence to international standards.

#### 4758 14.4.11 Regulatory Framework Strengthening

- 4759 • Strengthen regulatory frameworks related to radiation safety and medical physics practices to ensure  
4760 compliance with international guidelines and standards.

#### 4761 14.4.12 Application for the official accreditation

- 4762 • Implement registration of Medical Physicists by a national Health Professions Council or appropriate  
4763 body to ensure that minimum training requirements are applied.

#### 4764 14.4.13 Public Awareness Campaigns

- 4765 • Conduct public awareness campaigns to educate the public, healthcare providers, and policymakers  
4766 about the critical role of medical physicists in healthcare and the importance of radiation safety.

#### 4767 14.4.14 Networking and Collaboration

- 4768 • • Encourage the establishment of professional networks and collaboration platforms to facilitate infor-  
4769 mation sharing, mentorship, and collaborative research initiatives.

#### 4770 14.4.15 Improve the quality of the service provided

- 4771 • Continue to develop and implement quality procedures; request to the IAEA to support with manual  
4772 and ICT material on the quality management system.

#### 4773 14.4.16 Sustainable Funding Models

- 4774 • Develop sustainable funding models for medical physics services to ensure consistent access to resources  
4775 for education, infrastructure development, and ongoing operations.

#### 4776 14.4.17 Local Leadership Empowerment

- 4777 • Empower local leadership within the field of medical physics to take ownership of initiatives, advocate  
4778 for policy changes, and drive sustainable improvements.

#### 4779 14.4.18 Capacity Building for Healthcare Providers

- 4780 • Provide training and capacity-building programs for healthcare providers to enhance their understand-  
4781 ing of medical physics concepts and the safe use of radiation in medical procedures.

#### 4782 14.4.19 Adaptation to Technological Advances

- 4783 • Prepare for and adapt to technological advances in medical physics by incorporating new equipment,  
4784 treatment techniques, and imaging modalities. By addressing these high-priority needs, stakeholders  
4785 can contribute to the growth and sustainability of medical physics in Africa, ultimately improving  
4786 patient care, enhancing safety, and advancing the field.
- 4787 • Collaboration among governments, healthcare institutions, educational bodies, and international part-  
4788 ners is essential to successfully meet these needs.

### 4789 14.5 Conclusion

4790 The field of medical physics in Africa presents both challenges and promising opportunities for improvement  
4791 in healthcare delivery. Despite facing issues such as limited resources, a shortage of qualified personnel, and  
4792 disparities in infrastructure, there are ongoing efforts to address these challenges.

4793 Key solutions involve the expansion of training programs, international collaborations, infrastructure develop-  
4794 ment, continuous professional development, and research support. Prioritizing capacity building, regulatory  
4795 compliance, and public engagement are crucial for the sustainable growth of medical physics services across  
4796 the continent.

4797 As Africa works towards strengthening its medical physics capabilities, the concerted efforts of governments,  
4798 healthcare institutions, educational bodies, and international partners will play a pivotal role in shaping  
4799 a future where quality and safe medical physics practices contribute significantly to the advancement of  
4800 healthcare in the region. Through these endeavors, the potential for positive impact on patient care,  
4801 technological advancements, and overall healthcare infrastructure in Africa remains promising.

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# Nuclear Physics Working Group

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## 4832 **15.1 Introduction and Motivation**

4833 Nuclear science, technology and research represent the underlying foundation of all nuclear applications.  
4834 Nuclear applications contribute in many ways to health, development and security worldwide. They are  
4835 used in a broad range of areas, from power production to medicine, agriculture, food safety, environment,  
4836 forensics, industry, and the analysis of artefacts. Continuous research efforts and knowledge expansion in  
4837 nuclear physics is necessary to further technological innovation, which in turn brings about new benefits  
4838 for society. There are university level nuclear training facilities in many countries in at least 40 of the  
4839 55 countries in Africa. There are 432 clinical Linacs and throughout the continent and 5 countries have  
4840 Accelerator facilities. Two countries have viable nuclear regulators, 8 have research reactors, and a total  
4841 of 10 have or are seriously considering nuclear power. One would therefore imagine Africa should have a  
4842 healthy platform from which to grow its capacity in nuclear related training, research and technological  
4843 capacity. The IAEA is an important player in developing the nuclear science and technological capacity in  
4844 Africa. It runs a nuclear science program through AFCONE and AFRA to help its Member States to benefit  
4845 from the various existing radiation applications. It also assists and advises them on their needs for capacity-  
4846 building, research and development in the nuclear sciences, for instance with regard to the utilization of  
4847 particle accelerators, research reactors and nuclear instrumentation, including nuclear fusion research and

4848 technology, for the full suite of applications, including energy, medicine, agriculture and manufacturing  
4849 industry. However, the existing capacity and facilities do not cover sufficiently the required opportunities for  
4850 the African population. The absence of technological development needed for running nuclear facilities are  
4851 still very insufficient excepted in very few cases. Therefore, future upgrade plans as well as their role in the  
4852 socioeconomic development in Africa must be addressed. The nuclear physics research field is relatively old  
4853 but very important research field with several journals dedicated to both the theoretical and experimental  
4854 findings. It is a fundamental field from which many other fields of research have emanated and with very  
4855 many spin-off applications.

## 4856 15.2 Overview of Nuclear training in Africa

4857 The countries in Africa which have nuclear training programmes include Algeria, Angola, Benin, Burundi,  
4858 Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Egypt, Equatorial Guinea,  
4859 Ethiopia, Gabon, Ghana, Ivory Coast, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauri-  
4860 tania, Mauritius, Morocco, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa,  
4861 Sudan, Swaziland, Tanzania, The Gambia, Togo, Tunisia, Uganda, Zambia and Zimbabwe. This has been  
4862 estimated from the participation in the AFRA-NEST programme and also via participation in the IAEA  
4863 and its activities. AFRA-NEST was established by AFRA [2] in 2007 to support nuclear training and  
4864 also nuclear knowledge management. The footprint of nuclear training is therefore the majority of African  
4865 countries. This can be considered a good platform, and the AFCONE, AFRA and AFRA-NEST progammes  
4866 already forming a good level of co-ordination for nuclear training.

4867 Recently, The IAEA and South Africa's Laboratory for Accelerator Based Sciences, NRF-iThemba LABS,  
4868 have signed a major agreement to collaborate on achieving major goals regarding accelerator-based sciences  
4869 and training. But due to bad South African immigration policy, access to this facility is limited to only few  
4870 nuclear researchers in Africa.

## 4871 15.3 Overview of nuclear related facilities in Africa

4872 The nuclear related facilities extend from Particle Accelerators, Nuclear Reactors, medical Clinical facilities  
4873 that use radiation, Laboratories with smaller nuclear facilities and instrumentation, such as various nuclear  
4874 radiation sources and detectors, and then implementations of the same in applications in other areas such  
4875 as Agriculture and manufacturing industries.

### 4876 15.3.1 Particle Accelerators : Research facilities and Medical Facilities

4877 The following nuclear related research facilities exist, with their countries and also links to the facilities.

- 4878 • Ghana:  
4879 The Accelerator Laboratory at the Obafemi Awolowo University has a 1.7MV Pelletron Tandem  
4880 Accelerator [3]
- 4881 • Nigeria:  
4882 Centre for Energy Research and Development (CERD)



Figure 15-1: The iThemba LABS has a 200 MeV separated-sector cyclotron (SSC) with two injector cyclotrons in South Africa [7].

4883 Centre for Energy Research and Training(CERT)  
 4884 The Accelerator Laboratory at the Obafemi Awolowo University has a 1.7MV Pelletron Tandem  
 4885 Accelerator [4].

4886 • Egypt:

4887 The Nuclear Research Centre (NRC) has a MGC-20 cyclotron and a 3 MV Tandetron [5].

4888 • Algiers:

4889 The Nuclear Research Centre of Algiers (CRNA) has a 3.75 MV Van de Graaff accelerator [6].

4890 • South Africa:

4891 The iThemba LABS has a 200 MeV separated-sector cyclotron (SSC) with two injector cyclotrons, 6  
 4892 MV Tandem accelerator, 3 MV Tandetron. The main campus view of the SSC is shown in figure 2  
 4893 below [7].

4894 The Nuclear Energy Corporation of South Africa (Necsa) has a Van de Graaff accelerator, capable of  
 4895 going up to a terminal potential 4 MV and a Radio Frequency Quadrupole (RFQ) accelerator, capable  
 4896 of accelerating deuterons up to energies between 3.7 MeV and 5.1 MeV or protons between 1.8 and 2.5  
 4897 MeV [8].

4898 The University of Pretoria as a 2 MV Van de Graaff Accelerator [9].

4899 National Metreological Institute South Africa:(NMISA).

4900 The medical facilities make extensive use of electron linacs for clinical treatments. An audit has been  
 4901 performed by the IAEA and is available at the Directory of Radiotherapy Centres (DIRAC) [10] summarised  
 4902 graphically in figure 15-2 [1]. The total number found is 432. The literature on this topic indicates that Africa  
 4903 is in dire need of technical experts and increased investment to keep them many of them in an appropriate  
 4904 state of operation. Nonetheless, this can be considered a proxy for data indicating the penetration of nuclear  
 4905 medical technology in Africa. Most especially, in the use of modern facilities to validate and provide improved  
 4906 experimental information on nuclei across the periodic table, as well as providing new and balanced scientific  
 4907 interpretation for experimental observations. Researchers in nuclear field across Africa are few, despite the  
 4908 long historical development of nuclear technology in South Africa. Know nuclear facilities are:

4909 In the present configuration, the accelerator facilities are organized into 5 main categories:

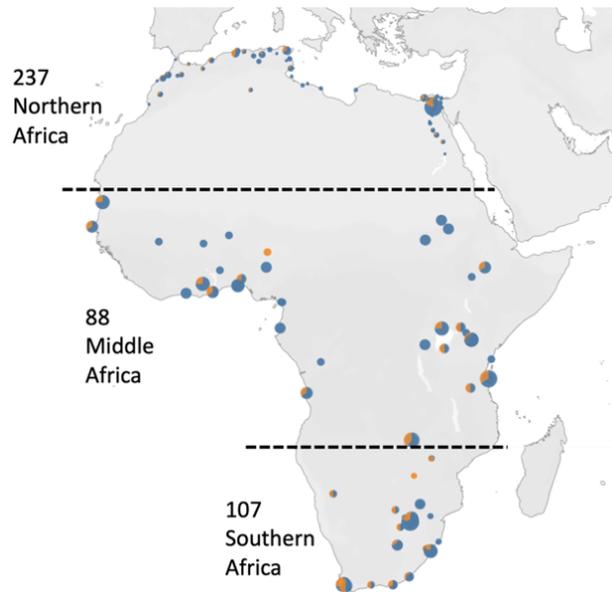


Figure 15-2: The footprint of medical LINACs in Africa from the Directory of Radiotherapy Centres (DIRAC)[1].

- 4910 • Accelerator-Based Neutron Sources: Blue (146 with 3 in Africa)
- 4911 • Boron Neutron Capture Therapy (BNCT) facilities: Orange (29 with 0 in Africa)
- 4912 • Electrostatic Accelerators: Red (322 with 7 in Africa)
- 4913 • Synchrotron Light Sources: Light Blue (60 with 0 in Africa)
- 4914 • X-ray Free Electron Laser Sources: Yellow (14 with 0 in Africa)

### 4915 15.3.2 Nuclear Reactors

4916 Nuclear reactors are categorised into reactors for power generation and research reactors or so-called Materials  
 4917 Test Reactors (MTR). Eleven (11) research reactors currently exist across the African continent, covering  
 4918 a wide power range, from 0.1 kW to 22 MW. Common designs include General Atomics' TRIGA model  
 4919 and the miniature neutron source reactor (MNSR). The countries with Research Reactors include Ghana,  
 4920 Nigeria, Algeria, Egypt, Libya, Morocco, DRC and South Africa.

## 4921 15.4 ASFAP related Activities for the Nuclear Working Group

4922 The first mini-workshop organised by the ASFAP Nuclear Physics group took place on 2nd March 2022  
 4923 with four contributions: i) "ASFAP introduction"; ii) "Nuclear Physics Activities at BIUST"; iii) "The Pan  
 4924 African Virtual Nuclear University"; and, iv) report from a student "Tanzania: challenges facing nuclear

<https://nucleus.iaea.org/sites/accelerators/Pages/Interactive-Map-of-Accelerators.aspx>



Figure 15-3: Accelerator-Based Neutron Sources: Blue (146 with 3 in Africa) [10]

4925 physics research (lack of suitable and qualified personnel, laboratory equipment for nuclear research, etc.)”.  
 4926 It followed with a discussion session in which few relevant aspects were brought-up, such as the need for a  
 4927 training session on Geant4 program (a nuclear and particle physics simulation software). So far, 4 LOIs have  
 4928 been received: three on experimental facilities and one about education and training.

#### 4929 15.4.1 Major challenges

4930 South Africa is facing challenges with energy generation and everyone has to work around load shedding.  
 4931 This ongoing load shedding is negatively affecting nuclear physics research because the main instrument  
 4932 required to conduct experiments and collect data must be turned off during periods of high load shedding  
 4933 implemented by Eskom. For the past year or so, experiments have been postponed at iThemba LABS  
 4934 due to load-shedding. This is the major challenges facing African countries in the running of nuclear  
 4935 physics experiments without power interruption. The International Thermonuclear Experimental Reactor  
 4936 (ITER), is “arguably the most complex machine ever designed,” according to Laban Coblenz, head of  
 4937 communication at the ITER Organization. More than 30 nations are working together to build the world’s  
 4938 largest tokamak to demonstrate the feasibility of harnessing fusion at an industrial scale. However, no  
 4939 African countries were among those involved. In order to meet up with the evolving fusion research, we need  
 4940 to take more responsibilities in the ongoing fusion research activities, and not left behind. Other challenges  
 4941 that can be considered are intensive Outreach Activities through sponsorship by non-governmental and  
 4942 private organisations in Africa, Sustainability and Continuity of nuclear projects and research facilities across  
 4943 African countries, Effective communication through international collaborative projects, Hashtag “Physicists  
 4944 Without Borders initiative”, Facilitation of exchange program among researchers, educational partnerships,  
 4945 workshop, seminars and training of Suitably Qualified and Experienced Personnel (SQEP) in nuclear science  
 4946 and technology to overcome aged workforce in African countries.

## 4947 15.5 High-priority future needs

- 4948 • Establishment of Regional Centres for Nuclear Physics Research Facility
- 4949 • Development of Nuclear Physics Educational Program
- 4950 • Human Recourses Capacity Development in Nuclear Science and Technology in Africa due to aged  
4951 workforces and transfer of knowledge
- 4952 • Outreach and Community Engagements/Interventions
- 4953 • International collaborations
- 4954 • Establishment of theoretical nuclear physics centre similar to ICTP-EAIFR Rwanda for each region in  
4955 Africa for easy access and dissemination of information
- 4956 • Government supports and funding towards Nuclear Education, Training and Research- From Policy  
4957 Management to Implementation.

## 4958 15.6 Synergies with neighbouring fields

4959 While the direct impact on other fields might be less pronounced, the foundational knowledge generated  
4960 through nuclear research can have interdisciplinary/multidisciplinary applications in fields such as materials  
4961 science, astrophysics, and nuclear medicine and engineering.

## 4962 15.7 Environmental and societal impact

4963 Understandably, the foundational knowledge and advancements made in understanding nuclear structure  
4964 can potentially have long-term implications. Some of these may include applications in nuclear energy  
4965 development, materials science for radiation shielding, and fundamental insights into nuclear processes with  
4966 implications for Astrophysics, medical imaging and treatments. While the immediate societal impacts might  
4967 not be directly evident, the foundational knowledge generated holds promise for potential future applications.  
4968 Majorly, the impact of nuclear physics research on the society lies majorly in fundamental and applied  
4969 knowledge contribution and in training future generations for sustainable human capital development. That  
4970 is, the production of new knowledge that will improve our understanding of the atomic nucleus and materials  
4971 in general, and the training of those who will sustain the continued existence of the nuclear power industry,  
4972 nuclear waste management and other allied nuclear industries. The COP28 climate conference has ended  
4973 with a final agreement that highlights a need to transition away from fossil fuels and toward clean energy.  
4974 The conference included a promise by more than 20 countries to triple nuclear capacity worldwide by mid-  
4975 century. "The final COP28 text acknowledges the key role that carbon-free nuclear energy plays in putting  
4976 the brakes on climate change," American Nuclear Society CEO Craig Piercy says. "We can only meet our  
4977 net-zero emissions target by 2050 with a swift, large-scale deployment of new reactors worldwide." In the  
4978 area of environmental impact, evidenced from the recently concluded COP28 where historic pledges and  
4979 agreements considering nuclear energy as a viable solution to climate change were created towards achieving  
4980 net-zero carbon, included Nuclear as part of global energy mix for sustainable development focussing on the  
4981 deployment of Small Modular Reactors (SMRs) in African countries. The project aims to demonstrate a  
4982 safe, clean and reliable nuclear source that operates autonomously for decades and generate stable energy  
4983 for African grids.

## 4984 15.8 Letters of Interests received

4985 Meeting to discuss the ASFAP Nuclear Physics Letters of Interest (LOIs) was held on the 6th of July 2022  
4986 (Online). Below are the points raised on the 3 LOIs during the meeting:

### 4987 15.8.1 NUPHAPHA-Nuclear Photonics Accelerated Physics for Africa

4988 Kalambuka Angeyo (University of Nairobi, Kenya) presented the LOI on Nuclear Photonics using pulse  
4989 lasers and novel sources based on African Union Agenda 2023. He further explained that similar facilities  
4990 mostly in advanced developmental stage are taking place at ELI-NP in Bucharest Romania, MEGaRay at  
4991 Lawrence Livermore USA, Nuclotron Based Ion Collider Facility NICA at Dubna Russia. Paving way out  
4992 on how best African countries can benefited from this technology, suggestion was made that this initiative  
4993 can be coordinated through African Laser Centre and iThemba LABS in South Africa.

### 4994 15.8.2 The use of Am-Be neutron source for teaching and applied research

4995 Sunday Jonah (Ahmadu Bello University, Nigeria) presented on the use of Am-Be neutron source for Physics  
4996 education teaching, training and applied nuclear research purposes. He mentioned that similar set-up have  
4997 been developed at Ghana Atomic Energy Commission (GAEC) through the financial supports from IAEA.  
4998 Emphasis was placed that other African countries can benefited from this project through ASFAP education  
4999 organising committee. There was a question raised by Mark on the actual cost implication and technical  
5000 requirements for installation of this equipment at other African countries. This will include shielding, safety  
5001 aspects as well as security of sources. The actual cost implication will be provided by Sunday Jonah and  
5002 sent to the Nuclear Physics Committee. In terms of running expenses, there will be available training of  
5003 technician through seminars and workshop to be organised via the IAEA regional training courses. In terms  
5004 of communication and outreach, there was a suggestion that the committee should develop pamphlets for  
5005 distribution to other African countries who might be interested in setting up similar training facility in their  
5006 institutions regionally within the country.

### 5007 15.8.3 Unique Research Facilities at the SSC Laboratory in South Africa

5008 Iyabo Usman (University of the Witwatersrand, South Africa) presented on the updates about the South  
5009 African Isotope Facility (SAIF) project taking place at iThemba LABS. New IBA cyclotron has been brought  
5010 to complement the SSC and dedicate to the medical isotope production at iThemba LABS, Cape Town South  
5011 Africa. Also, on the nuclear education and training activities, SAINTS program have been implemented  
5012 whereby several training activities for undergraduate and postgraduate students are been organised. This  
5013 includes training workshops on radiation protection, accelerators, radiation biophysics, nuclear metrology,  
5014 detectors and GEANT4 simulations. More information on future workshops will be announced through  
5015 ASFAP for participation by students from other African countries.

#### 5016 15.8.4 Challenges

5017 : One of the attendee pointed out about challenges in accessing Am-Be training facilities in the northern  
5018 part of Nigeria, and suggested if regional facility of the same kind can be implemented due to a very large  
5019 geographical area of the country. Sunday Jonah and Moji Usikalu will prepare a proposal for six regional  
5020 centres in Nigeria, and encourages all other countries to emulate this strategy.

5021 Another challenge is the funding to set-up this training facility in African countries. A suggestion about  
5022 approaching IAEA funding through AFRA technical cooperation research as alternative source of funding  
5023 can be implemented vi National Liaison Officers of each member states in Africa.

5024 Finally, challenges of getting more members signing up for the ASFAP Nuclear Physics group was mentioned  
5025 in the discussion. Conveners and committee members should develop a strategic way to get more researchers  
5026 involved. This can be achieved through nominating country representatives into the ASFAP Nuclear Physics  
5027 working group.

### 5028 15.9 Electron Ion Collider (EIC) Nuclear Physics Research Con- 5029 tributions in Africa

5030 The Electron Ion Collider (EIC) is a new and powerful accelerator being built by the Department of  
5031 Energy (DoE)'s Brookhaven National Laboratory (BNL) in collaboration with Thomas Jefferson National  
5032 Accelerator Facility in the United States [11, 12]. The EIC is the next quantum chromodynamic (QCD)  
5033 frontier designed to understand the force that binds all matter in the Universe. QCD is a quantum-field  
5034 theory described in terms of strong interactions between quarks with gluons as mediators. While significant  
5035 advancements have been made in various regions worldwide, African nations have yet to harness the full  
5036 potential of nuclear physics and the EIC. The community is vibrant, currently comprising an international  
5037 community whose user group now stands at 1,400+ physicists in over 290 institutions. Of these institutions,  
5038 ten (10) are from the African Continent namely: University Mohammed V in Rabat (Morocco), University  
5039 Mohammed First in Oujda (Morocco), University Ibn-Tofail (Morocco), Egyptian Center for Theoretical  
5040 Physics (Egypt), University Cheikh Anta Diop (Senegal), American University in Cairo (Egypt), University  
5041 of M'sila (Algeria), University of Cape Town (South Africa), Faculty of Sciences of Monastir (Tunisia),  
5042 and University of Zambia (Zambia). These African institutions are committed to the success of the science  
5043 program for the EIC.

#### 5044 15.9.1 Prospects

5045 The prospects of engaging in nuclear physics such as EIC-related research from Africa are promising.  
5046 Increased collaboration with international research teams could position African scientists at the forefront of  
5047 global discoveries in the field. Participation in large-scale experiments such as at the EIC and sPHENIX could  
5048 foster a generation of African physicists who are well-versed in advanced nuclear research methodologies,  
5049 influencing their countries' scientific agendas and policies [13]. Furthermore, understanding the properties  
5050 of matter at fundamental levels can be highly beneficial in various applications, including materials science,  
5051 medical technology, and energy production[14]. These prospects underscore the importance of establishing  
5052 a vibrant nuclear physics research community in Africa.

## 15.10 Contribution to Knowledge through research and innovation

What is the percentages of nuclear physics research publications in international high impact journals such as Physical Review C, Physical Review Letters, Nuclear Physics A, Physical Review Accelerators and Beams, European Nuclear Physics Journal, Physical Review X, and Reviews of Modern Physics? According to APS, Published by APS Physical Review Journals,

- Since 1980, over 1,500 articles by authors in Africa have been published in the APS Physical Review Journals.
- Over 110 articles published Physical Review Journals in 2020 were from authors in Africa.

In general, some of the problems facing nuclear physics communities in Africa include:

- Lack of experimental setups in many African countries
- Problems of maintenance due to lack/absence of technical services
- Affordability to purchase new equipment
- Bureaucracy in laboratory governance and management
- No funds to support students (Master, Ph.D students) and postdocs
- Students are not trained during their Bachelor/Master to use the experimental setup
- Cannot easily access equipment in other institutions in the same country
- Acquisition of equipment is subject to time-consuming bureaucratic procedure
- Lack of high performance computing centres for theoretical projects
- Problems with internet connection to use HPC in other institutes
- Lack of affordable and powerful workstations
- Lack of commercial software licenses for nuclear physics simulations
- No training within schools and workshops
- Lack of suitable student exchange programs /projects among African countries
- Despite the potential benefits, numerous challenges remain for African researchers wishing to engage in EIC-related nuclear physics research.
- There is a shortage of skilled scientists and personnel who are trained in nuclear physics, specifically in areas related to the EIC.

Statistics on the use of radioisotopes, uranium mining, movement of nuclear waste from power plant to the repository waste disposal. Link to the future of the need for power sources to reduce climate change. Therefore, the future is nuclear fusion.

## 15.11 Recommendations

Based on the identified challenges and prospects, the following recommendations can be made to enhance the involvement of African researchers in nuclear physics related research:

- **Increase Funding:** Advocate for increased investment in nuclear physics research from both government and private sectors to ensure adequate resources for EIC related research studies.
- **Strengthen Collaborations:** Foster strong partnerships with international research organizations and institutions involved in EIC research for mutual benefit and knowledge exchange. Collaborations with established global institutions are essential to foster knowledge transfer and expertise development [15]. As the construction of the EIC progresses at Brookhaven National Laboratory in the USA, there are significant opportunities for African scientists to engage in international collaborations and contribute to the scientific knowledge base surrounding this innovative facility.
- **Develop Infrastructure:** Advocate for the establishment of regional-research facilities equipped for nuclear-physics research, including proton and ion-beam technology.
- **Enhance Education and Training:** Invest in educational programs and workshops that focus on advanced nuclear-physics topics, targeting students and early-career researchers.
- **Promote Networking:** Encourage the formation of regional-research networks to improve collaboration between institutions and promote collective-research efforts.
- **Engage the Youth:** Implement outreach initiatives aimed at inspiring high school students and undergraduates to consider careers in nuclear physics and related fields.
- **Interdisciplinary approaches:** Universities and research institutions in Africa must develop interdisciplinary approaches that combine nuclear physics with other scientific domains to maximize research outputs.
- **Public engagement:** Promoting public engagement and awareness surrounding the importance of nuclear physics research could also harness broader support for funding and collaboration [16].

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# High Energy Physics Working Group

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## 5143 16.1 Overview

5144 High energy physics is unique in the sense that it encompasses a broad range of explorations, spearheaded by  
5145 probing what happens at smallest length scale with the highest energy and most complex scientific experiment  
5146 ever built. However stress-testing the well established Standard Model of Particle Physics or searching for  
5147 beyond the Standard Model phenomenon at the Large Hadron Collider (LHC) and other experiments is only  
5148 a part of the story. The field spans complex theoretical endeavours such as string theory, to the current hot  
5149 topic of machine learning, which has possibly been used in this field the longest. While high energy physics  
5150 by nature is global and collaborative, African researchers have been involved in all of the above, while making  
5151 their mark in the worldwide endeavour. However, this chapter is more focused on experimental explorations  
5152 and related phenomenological work, building on previous works along this direction [1].

## 5153 16.2 LHC Physics

5154 The particle physics programme at the LHC is based on four major experiments, ALICE, ATLAS, CMS and  
5155 LHCb. It has to be noted that becoming part of any of the collaborations implies long term commitment  
5156 from the funding agency, and by extension the national government. Considering that the economic  
5157 and political situation in many African countries is far from stable, this presents a substantial challenge.  
5158 So it is indeed remarkable that five countries, Egypt, Morocco, Nigeria, South Africa and Tunisia have  
5159 varying levels of participation in ALICE, ATLAS, and CMS experiments, while Algeria was associated with  
5160 ATLAS in a limited technical capacity. These groups are supported by phenomenologists working alongside  
5161 experimentalists in Egypt, Morocco and South Africa.

5162 The LHC started in 2009, first at a collision energy of 900 GeV, and then moving up to 7 TeV, concluding  
5163 its Run 1 in 2013. The discovery of the long postulated Higgs boson [16, 17] was a highlight of this run,  
5164 where the African groups contributed. After two years of maintenance and upgrade, it restarted in 2015 at  
5165 a collision energy of 13 TeV, concluding the Run 2 in 2018. Another long pause allowed more upgrade to all  
5166 the detectors and accelerator itself, and Run 3 started in 2022, with a slightly increased collision energy of  
5167 13.6 TeV. The Run 3 is supposed to go on till 2026. Then a long shutdown will allow for the preparation for  
5168 high luminosity phase, known as HL-LHC. This includes installation of new key equipment on the accelerator  
5169 side, and replacing critical detector and electronics components for the experiments. The start-up of the  
5170 HL-LHC (Run 4 and Run 5) is now planned for June 2030 till 2041, including a short stop in 2034-35. As no  
5171 new energy frontier experiment after that is still not decided, this is the data this and the next generation  
5172 of particle physicists will see, trying to unravel critical mysteries like dark matter.

5173 Morocco and South Africa participates in ATLAS experiment [2] as clusters, where a number of institutes  
5174 from each country have a common voice in the collaboration matters. This allowed the groups to develop  
5175 without having a critical mass of physicists in a particular university.

5176 The Moroccan cluster started in 1996, and consists of:

- 5177 1. Universite Hassan II (Casablanca)
- 5178 2. Mohammed VI Polytechnic University
- 5179 3. Université Cadi Ayyad (Marrakech)
- 5180 4. University Mohammed V (Rabat)
- 5181 5. Mohammed 1st University (Oujda)
- 5182 6. Ibn-Tofail University (Kenitra)

5183 The South African cluster started in 2010, and consists of:

- 5184 1. iThemba Labs (iTl)
- 5185 2. University of Cape Town (UCT)
- 5186 3. University of Johannesburg (UJ)
- 5187 4. University of South Africa (UNISA)
- 5188 5. University of Witwatersrand (Wits, with University of the Philippines Diliman as an associate institute)
- 5189 6. University of Zululand (UniZulu, which is classified as a historical black university, exemplifying the  
5190 inclusivity of the SA-CERN programme).

5191 *Ecole nationale Supérieure d'Informatique in Algiers is unfortunately not active any more, having started in*  
5192 *2019 and continued till 2023.*

5193 Moroccan and South African clusters collectively have about fifty authors now, and an ever expanding  
5194 number of post-graduate students. The South African hardware activities span detector maintenance and  
5195 upgrade. They include:

- 5196 1. Silicon detector developments on both the SCT and ITk detector systems, including, data acquisition  
 5197 electronics development, evaporative cooling systems, material description in simulation, firmware and  
 5198 test quality control for readout cards, polymoderator design, procurement, and fabrication. CFD  
 5199 simulations for temperature and humidity distributions inside the detector ITk volume was also  
 5200 performed.
- 5201 2. On Muon New Small Wheel, including, material description in simulation, manufacturing and assembly  
 5202 of components and installation tools as well as commissioning.
- 5203 3. Assembly, quality checks and installation of the gap scintillator counters.
- 5204 4. Phase-II upgrade of the Tile Calorimeter, 50% of the production of the Low Voltage Power Supplies  
 5205 (LVPS), 24% of the production of the Tile Preprocessor (PPr) and participation in TileCal November  
 5206 2021 Test-beam.

5207 Moroccan groups work on Transition Radiation Tracker, Liquid-Argon Calorimeter and High Granularity  
 5208 Timing Detector. Moroccan researchers playing a pivotal role in the construction, testing, and commissioning  
 5209 of the ATLAS Electromagnetic Calorimeter Presampler from 1998 to 2003. The groups also have actively  
 5210 engage in distributed data analysis through grid computing, by coordination of the ATLAS Distributed  
 5211 Analysis Support Team. UMP6 is poised to serve as a crucial Moroccan Tier-3 center supporting ATLAS  
 5212 research, with aspirations to evolve into an ATLAS Tier-2 center.

5213 As the interests of the group members and group compositions change over time, any description of the  
 5214 physics analyses the groups currently involved in will be incomplete, but here is a snapshot for the South  
 5215 African institutes:

- 5216 • Part of the Wits group has been invested in searching for new physics in final states with Higgs boson,  
 5217 with or without significant missing energy. Some of the final states probed or being probed recently  
 5218 include photons and multi-leptons, having previously contributed to exploring the  $WW$  decays of the  
 5219 Higgs boson.
- 5220 • Another part of Wits group has contributed to measurements sensitive to internal structure of jets, and  
 5221 searching for new physics in novel final states, including boosted heavy neutrino signature resulting in  
 5222 a lepton inside a jet, semi-visible jets, and dark photons decaying to lepton jets.
- 5223 • The UJ group has for a long term focussed on new physics showing up in four lepton final state,  
 5224 including decays of hypothetical dark  $Z$  boson or additional new scalars. The group also led the Run  
 5225 2 BSM Higgs Physics Report from ATLAS.
- 5226 • The UCT group has focussed on top physics, such as measurement of top mass utilising leptonic  $J/\psi$   
 5227 decays, top quark coupling and charge asymmetry and also on new physics searches via the study of  
 5228 top electro-weak couplings in rare electroweak processes.

5229 Similarly, a possibly incomplete snapshot of the Moroccan groups follows:

- 5230 • The Kenitra group has been involved different di-Higgs as well as in charged Higgs searches.
- 5231 • The Casablanca group is also involved in di-Higgs searches, mostly focussing on  $bbll$  final state, but  
 5232 also have members contributing to hypothetical  $Z'$  to  $\mu\mu$  search and search for new physics in events  
 5233 with leptons and missing energy.

- 5234 • The Rabat group is mostly focussed on searches in final states with additional scalars or dark photons  
5235 or charged Higgs bosons decaying to leptons with or without missing energy. They also look at rare  
5236 light-by-light scattering events in lead-lead collisions.
  
- 5237 • The Oujda group looks for signs for super-symmetry in electroweak-production processes, including  
5238 signatures of displaced tracks.

5239 This shows the diverse interest of both the countries in ATLAS. Some of the recent achievements will  
5240 include a collaboration wide thesis-award winner, ATLAS PhD grant winner, featuring the first semi-visible  
5241 jets search result in ATLAS briefing, and multiple leadership positions in different levels of the collaboration,  
5242 including as a chair of tile calorimeter institutional board, memberships in collaboration board chair advisory  
5243 group, appointment as a contact on Diversity and Inclusion, memberships in early career scientist board,  
5244 and leaderships of different physics sub-groups. The collaboration week was successfully organised in in  
5245 Marrakesh in 2013, showing the impact of the Moroccan cluster to ATLAS already then.

5246 ALICE experiment [6] is more focussed on studying ultra-relativistic heavy-ion collisions in which extreme  
5247 conditions of energy density and temperature occur, and a new state of matter, termed the quark-gluon  
5248 plasma is formed. The groups based in iThemba Labs and in the University of Witwatersrand and Cape  
5249 Town are active. They contribute to upgrade projects towards a common read out unit for the muon identifier,  
5250 the Low-Voltage System for muon tracking, and online data processing for the Transition Radiation Detector.  
5251 In terms p physics analyses, the groups work on  $W$  and  $Z$  boson tests of the Standard Model via the study  
5252 of the cross-sections in lead-lead and proton-lead collisions.

5253 A major focus have been student training. As South Africa is the leading country in Physics research in sub-  
5254 Saharan Africa, students from all over the continent have worked on ATLAS and ALICE experiments over  
5255 the years, some prominent examples being students from Nigeria, Zambia, Zimbabwe, Cameroon, Botswana,  
5256 Madagascar, Lesotho, eSwatini. Some of these students have continued to excel overseas.

5257 The South African community organised annual High Energy Particle Physics workshop, where students  
5258 presented their work along with tutorials on selected topic. This has not restarted after the pandemic, but  
5259 in 2024 January, a school on computing in High Energy Physics, termed Chacal hosted about forty students  
5260 from across the continent and leading experts from all over the world for two weeks in Johannesburg. This  
5261 was funded by French CNRS. The biannual Kruger conference on discovery physics, organised in the vicinity  
5262 of the popular national park, has grown to be a major international meeting in the field. The Moroccan  
5263 community organised the first African Conference on High Energy Physics in 2023. Additionally, the ever  
5264 popular African School and Conference of Physics, always has strong component covering particle physics.

5265 The South African effort is generously supported by the National Research Foundation and Department of  
5266 Science and Industry under a common SA-CERN consortium. It also provides bursaries for postgraduate  
5267 students and support for postdoctoral researchers, which is critical for the growth of the programme. The  
5268 establishment of the Moroccan High Energy Physics Cluster (RUPHE) in 1996 epitomises the nation's  
5269 commitment to advancing science, technology, and innovation. It serves as a hub of collaborating institutes  
5270 in ATLAS. In September 2020, the Moroccan Foundation for Advanced Science, Innovation, and Research  
5271 (MAScIR) achieved recognition as an Associated Technical Institute within the ATLAS experiment. The  
5272 Moroccan Academic and Research Wide Area Network (MARWAN) stands as the national computer network  
5273 dedicated to education, training, and research, supported by Minister of Higher Education, Research, and  
5274 Innovation and the National Center for Scientific and Technical Research (CNRST).

5275 The CMS [3] effort in the continent is led by Academy of Scientific Research and Technology (Cairo) and by  
5276 Center for High Energy Physics (CHEP-FU), Fayoum University (Al Fayoum) in Egypt, and coordinated by  
5277 the Egyptian Network of High Energy Physics (ENHEP). From the detector side, the groups are involved in

5278 the assembly and testing of gaseous muon detectors, including both GEM and RPC gas detectors. In addition  
5279 to detector development, Egyptian researchers contribute to the physics performance of these sub-detectors,  
5280 ensuring their proper functioning in particle detection. On the analysis side, the contributions span diHiggs  
5281 production studies, probing Higgs boson decay to dimuon channels and searches for dark matter. Egyptian  
5282 groups are involved in the MATHUSLA experiment, which focuses on detecting long-lived particles beyond  
5283 the Standard Model.

5284 University of Benin in Nigeria is working on establishing a High-Performance Computing (HPC) as a  
5285 technical part of CMS collaboration. Along with that, the group has contributed to the development and  
5286 Operation of the CMS online system administration, Development and Operation of the CMS Online System  
5287 Administration, unified web-page management, static code analysis, and deployment with GitLab-CI for the  
5288 CMS Tier-0 sites.

5289 Just like Morocco and South Africa, Egypt is also leveraging its active contribution in CMS to encourage  
5290 the next generation of HEP researchers. Several universities, such as Zewail City of Science and Technology  
5291 in Giza, have established programs specifically designed for this. These educational programs, together with  
5292 research initiatives at other institutions, demonstrate Egypt's commitment to developing HEP expertise at  
5293 the academic level and preparing students for advanced research in the field. Egypt has also significantly  
5294 benefited from international training opportunities, such as the Erasmus Mundus program, and collaborations  
5295 coordinated by the Academy of Scientific Research and Technology (ASRT) in Cairo. These partnerships,  
5296 which involve funding agencies from different countries around the world, provide crucial support for capacity  
5297 building, enabling students and young researchers to gain valuable experience and expand their knowledge  
5298 through global collaborations.

5299 The primary objective of the HPC initiative in Nigeria as well is to enhance Nigeria's and Africa's overall  
5300 computational capacity. The center is expected to allocate 20% of its total capacity to functioning as a CMS  
5301 computing center within the Worldwide LHC Computing Grid (WLCG), supporting high-energy physics  
5302 research. The remaining 80% will be utilized for computational tasks in other critical research areas such as  
5303 agriculture, healthcare, and climate change.

5304 While the impact in the LHC physics programme by Africa-based collaborators is undeniable, it is worth  
5305 mentioning the recent interest in machine learning aspects that came about. High energy physics in some  
5306 ways has been the original test-bed of these algorithms, so this has made particle physics attractive to funding  
5307 agencies and even for students pursuing a career beyond physics. In this context, the close connection with  
5308 the African Institute for Mathematical Sciences, which is a pan-African institution (with centres in South  
5309 Africa, Cameroon, Senegal, Ghana, Tanzania and Rwanda) offering a MSc degree in mathematical sciences  
5310 must be mentioned. Even though they are not directly part of the CERN programme, ATLAS members have  
5311 supervised projects, and ran courses focussed mostly on data science. The connection is further strengthened  
5312 by their connection with Quantum Leap Africa (QLA), an organisation supporting students and researchers  
5313 in the quantum science domain. Recently QLA has agreed to support a doctoral student working in ATLAS,  
5314 exemplifying the increasing connection.

## 5315 16.3 Neutrino Experiments

5316 Groups from Morocco and Madagascar are involved in the state-of-the-art neutrino experiments. Having  
5317 previously been part of the ANTARES experiment [8], three universities (Mohammed V, Cadi Ayyad, and  
5318 Mohammed 1) are part of the KM3NeT1 Collaboration [9]. It is a research infrastructure consisting of a  
5319 network of deep-sea neutrino telescopes in the Mediterranean Sea with the main objectives being the discovery  
5320 and subsequent observation of high-energy neutrino sources in the Universe and the determination of the

5321 mass hierarchy of neutrinos. The groups are actively participating in the production line of optical modules  
 5322 in a national site located in Rabat. Besides, the Moroccan team is also involved in the physics analysis of  
 5323 many topics, essentially related to search for magnetic monopoles, search for nuclearites, and study of the  
 5324 neutrino mass hierarchy.

5325 As of November 2024, Madagascar is currently the only African country member of the Deep Underground  
 5326 Neutrino Collaboration or DUNE [13], having joined in 2016. Madagascar is represented by the Neutrino  
 5327 Experimental group of from the University of Antananarivo. The group unfortunately does not have any  
 5328 supports from the University or the Government yet of now but rely on alumna and collaborators from  
 5329 abroad. Three Universities in the US and two national labs have offered and continue to support the  
 5330 university research initiative. (The University of Pittsburgh, Stony Brook University, South Dakota School  
 5331 of Mines, Brookhaven National Laboratory via the African School of Physics and Fermilab). The Neutrino  
 5332 Experimental group of Madagascar have contributed in the Detector Conceptual design report to the System  
 5333 for on-Axis Neutrino Detector and in a project involved cold electronics specifically LArASIC lifetime study  
 5334 at cryogenic temperature.

5335 The ongoing collaborative contributions of Madagascar along with Stony Brook University is a contribution  
 5336 on the ProtoDUNE data analysis and the FD3 simulation and reconstruction. A study of neutrino energy  
 5337 reconstruction using light in the GeV and MeV ranges. Madagascar has a vision to increase the numbers of  
 5338 experts in neutrino event generators in the country as well. One project among many that is worth special  
 5339 note is implementation new cross sections for hadron transport models in the GENIE Monte Carlo event  
 5340 generator, a tool widely used in neutrino experiments. The group have developed a theoretical code that  
 5341 calculates total and differential cross sections for interactions involving  $\pi N$ ,  $\eta N$ ,  $\kappa\lambda$ , and  $\kappa\sigma$  utilizing the  
 5342 DCC facility in ANL-Osaka. The impact in joining DUNE is a tremendous expansion of knowledge in term  
 5343 of experimental high energy physics which was non-existent in the island prior joining DUNE.

## 5344 16.4 Future Experiments

5345 The HL-LHC is expected to run for the next decade, but so far it is not clear what the next big collider  
 5346 facility will be. CERN is strongly advocating for the Future Circular Collider (FCC), starting with an  
 5347 electron–positron collider for precision measurements offering a 15-year research programme from the mid-  
 5348 2040s. Subsequently it will be upgraded to an hadron collider, aiming to reach collision energies of 100 TeV,  
 5349 colliding protons and also heavy-ions, and running until the end of the 21st century. A competing proposal  
 5350 is the Circular Electron Positron Collider (CEPC) in China, for probing the Higgs boson physics in great  
 5351 detail. Many colleagues are involved in feasibility study of different physics scenarios in these proposed  
 5352 colliders.

5353 While neither of these have been approved, the Electron Ion Collider (EIC) [14] is being constructed at  
 5354 Brookhaven National Laboratory (BNL) in partnership with Jefferson Lab (JLab) in USA. The EIC will  
 5355 be a particle accelerator that collides electrons with protons and nuclei to produce snapshots of internal  
 5356 structure of those particles, like a CT scanner for atoms. The following African institutes have joined:

- 5357 1. University Mohammed V (Rabat), Morocco
- 5358 2. University Mohammed I (Oujda), Morocco
- 5359 3. American University (Cairo), Egypt
- 5360 4. Egyptian Centre for Theoretical Physics, Egypt

- 5361 5. University Mohamed Boudiaf (M'sila), Algeria
- 5362 6. University of Monastir (Monastir), Tunisia
- 5363 7. University Cheikh (Anta Diop), Senegal
- 5364 8. University of Cape Town (Cape Town), South Africa
- 5365 9. University of Witwatersrand (Johannesburg), South Africa
- 5366 10. University of Zambia (Lusaka), Zambia

5367 The groups aim to contribute to EIC detector design, simulations and development of the experimental data-  
5368 analysis software kit. They intend to contribute to the study of generalized parton distributions (GPDs),  
5369 study of factorization, jet broadening and parton energy loss in electron-proton (ep) and electron-nucleus (eA)  
5370 collisions, final state particle production mechanisms via spin asymmetries following initial state electron-  
5371 proton (ep), electron-nuclei (eA) particle collisions. Additionally, the extension of comprehensiveness of  
5372 high-dimensional phase space integration taking into account radiations from the initial and final states  
5373 occurring in electron-ion collisions using Monte Carlo integration method is also foreseen.

## 5374 16.5 Phenomenology

5375 The searches and measurement at the experimental facilities are intricately connected to phenomenological  
5376 explorations. This is exemplified by the fact that some of the so-called experimentalists have published such  
5377 papers, and went on to pursue that direction in the experiments. Acknowledging this unique synergy, the  
5378 South African CERN consortium includes theory as an integral part, which has massively contributed to  
5379 the growth of the field in South Africa and beyond. The contributions span exploration of a wide range of  
5380 beyond the Standard Model scenarios, at LHC to future colliders, focussing on LHC multilepton, diphoton,  
5381 and top-quark excesses, models with extra dimensions, dark-QCD and other dark matter scenarios and use  
5382 of machine learning. Additionally, more formal aspects of QCD are also explored, including jets in heavy ion  
5383 collisions, and various aspects of the quark-gluon plasma. The efforts are led by University of Witwatersrand,  
5384 Johannesburg and Cape Town.

5385 The Moroccan and Egyptian groups similarly are involved in studies of super-symmetry (SUSY) phenomenol-  
5386 ogy, Higgs physics, theoretical and EW precision constraints on scalar sectors in various extensions of the  
5387 SM like models with massive gravitons, various extensions of 2HDM, dark photons, Laser-assisted particle  
5388 decays, and astro-Particle Physics. The Moroccan effort is mostly concentrated in Cadi Ayyad University  
5389 in Marrakech and Safi, Rabat University, Tanger University, Ibn Zohr University, Ibn Tofail University,  
5390 Abdelmalek Essaadi University and CPM, Rabat, not in any particular order. The Egyptian effort is led  
5391 by Zewail City of Science, Technology and Innovation, Ain Shams University, Cairo University, Alexandria  
5392 University, Egyptian Center for Theoretical Physics, Cairo, and Assiut University, again not in any specific  
5393 order. Various new physics scenarios such as heavy neutrino, semivisible dark photon, additional Higgs  
5394 bosons, as well as aspects of QCD are studied.

5395 The East African Institute for Fundamental Research (EAIFR), at the University of Rwanda has research  
5396 interest in fundamental physics with a focus on collider physics, physics beyond the Standard Model, cosmic  
5397 inflation, Dark Matter and Dark Energy. EAIFR has produced results on the impact of additional Higgs  
5398 bosons on signal rates and study of possible deviations from the SM. The group from Madagascar, based  
5399 in Institute of High-Energy Physics, is specialist of non perturbative methods in strong interactions. More  
5400 precisely, they use QCD sum rules to predict hadron properties, such as masses and coupling constants.

## 16.6 Challenges Hindering the Growth of HEP in Africa

Growing particle physics in Africa faces numerous significant challenges that must be addressed to cultivate a thriving and sustainable research environment. Let's delve into some key considerations:

- **Infrastructure and Funding:** One of the foremost hurdles is the absence of adequate infrastructure and funding for particle physics research across many African countries. Constructing and maintaining particle accelerators, detectors, and other critical facilities demand substantial financial investment. The scarcity of funds inhibits the establishment of top-tier research centers and the acquisition of state-of-the-art equipment, thereby impeding the ability to compete globally.
- **Education and Expertise:** Nurturing a proficient workforce in particle physics necessitates a robust educational framework. Unfortunately, several African nations encounter difficulties in providing quality education in physics and related disciplines. Targeted programs are imperative to train scientists, engineers, and technicians equipped with the specialized knowledge essential for particle physics research. Moreover, attracting and retaining skilled researchers poses a challenge amidst global competition for talent.
- **International Collaboration:** Collaboration with international institutions is pivotal for the advancement of particle physics in Africa. However, navigating logistical, bureaucratic, and communication barriers can pose challenges in establishing and sustaining such partnerships. Fostering collaborations with established research institutions can grant access to expertise, resources, and collaborative prospects, thereby assisting African researchers in overcoming local constraints.
- **Political Stability and Support:** Political stability and governmental backing are indispensable for the enduring viability of particle physics endeavors. Political unrest and fluctuating climates can disrupt research endeavors, jeopardizing progress and investments. It is imperative to advocate for stable political environments and underscore the significance of particle physics research for the scientific and technological progression of the continent.
- **Public Awareness and Engagement:** Heightening awareness about the significance and potential impact of particle physics research is pivotal for garnering public support and securing funding. Educating both the public and policymakers about the contributions of particle physics to technological innovation, medical advancements, and our comprehension of the universe can foster a supportive atmosphere for research initiatives.
- **Access to Data and Publications:** Ensuring open access to data and research publications is critical for the growth of particle physics in Africa. Restricted access to scientific literature and data can impede researchers' progress and hinder the dissemination of knowledge. Initiatives promoting open science practices and facilitating information-sharing across borders are essential.

Addressing these challenges necessitates a multifaceted approach involving collaboration among governments, educational institutions, international organizations, and the scientific community. By surmounting these obstacles, Africa can make significant contributions to the global field of particle physics and reap the broader scientific and technological advancements stemming from such research efforts.

## 16.7 Prioritizing Future Imperatives: HEP in Africa

To foster particle physics in Africa effectively, it is imperative to conduct a thorough assessment of the key future requirements necessary to advance the field and nurture a flourishing scientific community across the continent.

- **Infrastructure and Technological Advancements:** Establishing robust infrastructure tailored to the unique demands of particle physics research is paramount. This entails developing and maintaining particle accelerators, detectors, and computational facilities. Adequate investment in infrastructure equips African scientists with the necessary tools to conduct cutting-edge experiments and make substantial contributions to global scientific endeavors.
- **Shared Research Facilities:** Encourage the establishment of shared research facilities that can be accessed by scientists from multiple African nations. This can include shared laboratories, data repositories, and computational resources, enhancing the infrastructure available for particle physics research.
- **Establish Collaborative Research Networks:** Create and support regional networks and consortia dedicated to particle physics research. These networks can facilitate collaboration, information exchange, and joint research projects among institutions and researchers across African countries.
- **Cross-Border Collaborative Research Centers:** Support the establishment of collaborative research centers that span multiple African countries. These centers can serve as hubs for joint research, fostering a culture of collaboration and providing a focal point for researchers to converge and exchange ideas.
- **Promotion of International Collaboration:** Facilitating robust collaboration with esteemed research institutions worldwide is indispensable for driving innovation and knowledge exchange in particle physics. By fostering strategic partnerships and participating in collaborative projects, African researchers can leverage resources, expertise, and cutting-edge technologies to advance scientific discovery on a global scale.
- **Research Support and Funding:** Sustained investment in research and development is crucial for nurturing a conducive research environment. Governments, funding agencies, and private sector entities must prioritize funding for particle physics research initiatives, enabling scientists to explore new frontiers and address fundamental questions in the field. Adequate research support fuels innovation, drives technological advancements, and positions Africa as a key player in the global scientific community.
- **Capacity Building and Education:** Investment in education and capacity-building initiatives is fundamental. Enhancing the quality of physics education across all levels, from primary to tertiary institutions, cultivates a pipeline of skilled researchers capable of tackling complex challenges in particle physics. Specialized training programs and collaborations with international institutions bolster expertise within the continent, fostering a dynamic scientific community.
- **Exchange Programs and Fellowships:** Implement exchange programs and fellowships that allow researchers, students, and faculty to spend time at institutions in other African countries. This cross-pollination of ideas and expertise can strengthen research capabilities and foster long-term collaborations.
- **Open Access and Knowledge Dissemination:** Ensuring open access to data, research findings, and scientific publications is vital for fostering collaboration, transparency, and knowledge dissemination within the scientific community. Efforts to promote open science practices and establish accessible

5479 platforms for sharing information empower African researchers to leverage existing knowledge and  
5480 contribute meaningfully to scientific advancements.

- 5481 • **Advocacy for Policy Reform:** Advocating for policies that prioritize scientific research, innovation,  
5482 and technological development is critical. Governments and policymakers must recognize the strategic  
5483 importance of investing in scientific infrastructure, supporting research initiatives, and fostering a  
5484 conducive regulatory framework. By advocating for policy reform, stakeholders can create an enabling  
5485 environment that stimulates scientific inquiry, drives economic growth, and enhances global competi-  
5486 tiveness.

5487 In conclusion, addressing the high-priority future needs for HEP in Africa demands a collaborative and  
5488 multifaceted approach. By investing in infrastructure, capacity building, international collaboration, re-  
5489 search support, and advocacy for policy reform, Africa can harness its scientific potential, contribute to  
5490 groundbreaking discoveries, and shape the future of particle physics on the global stage.

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# Multidisciplinary Science at Paarl Africa Underground Laboratory (PAUL)

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## 5548 Abstract

5549 Establishing a deep underground physics laboratory to study, amongst others, double beta decay, geoneutri-  
5550 nos, reactor neutrinos and dark matter has been discussed for more than a decade within the austral African  
5551 physicists' community. PAUL, the Paarl Africa Underground Laboratory, is an initiative foreseeing an open  
5552 international laboratory devoted to the development of competitive science in the austral region. It has the  
5553 advantage that the location, the Huguenot tunnel, exists already and the geology and the environment of  
5554 the site is appropriate for an experimental facility.

## 5555 17.1 Preamble on ASFAP related-project

5556 During the ASFAP process, in December 2021, two authors of this chapter submitted a letter of interest [1]  
5557 on the potentiality of setting up an underground laboratory (UL) in Africa. These laboratories (ULs)

5558 are located in mines and tunnels, and most of the operating laboratories are to be found in the northern  
 5559 hemisphere: Europe, USA, Russia, Canada and Japan. One UL is under commissioning in Australia, and two  
 5560 more are planned: ANDES at the Argentina-Chile border and INO in India. About one hundred experiments  
 5561 are running or are under construction in the ULs currently in operation and roughly 6000 researchers are  
 5562 involved.

5563 Contact have been taken by the authors of the LoI to prospect whether there is motivation and potential  
 5564 engagement in Africa. An interest was expressed by physicists from South Africa and the first contacts and  
 5565 discussions were established by end of 2022. On Figure 17-1 The yellow star is the foreseen location of the  
 5566 future Africa underground lab facility, in the Western Cape Province of South Africa, under the 1300 m Du  
 Toitskloof mountain [2].



Figure 17-1: Map of the existing or planned underground laboratories. Green dots: the operating facilities. Orange dot: under commissioning SUPL facility in Australia . Red dots: ANDES at the Argentina-Chile border and INO in India. Yellow star: the future Paarl Africa underground lab facility, in the Western Cape Province of South Africa [2].

5567

## 5568 17.2 The African Context

5569 Neutrinos and the search for dark matter have been big drivers in the field of experimental physics, sitting  
 5570 at the frontier between nuclear physics, particle physics, astroparticle physics and cosmology. These studies  
 5571 are only possible in underground laboratories where the experiments are shielded from cosmic rays by at  
 5572 least about 1,000 m of rock. These laboratories are located in mines and tunnels, and most of the operating  
 5573 laboratories are to be found in the northern hemisphere.

5574 Underground laboratories provide the low-background radioactive environment necessary for astroparticle  
 5575 physics to explore extremely rare phenomena. The underground location naturally guarantees high sup-  
 5576 pression of muons and cosmic-ray particles produced in the atmosphere and, consequently, of cosmogenic  
 5577 by-products.

5578 The foreseen location of the future Paarl Africa underground lab facility or PAUL is inside the Huguenot  
5579 tunnel, Figure 17-2, which is conveniently located between the towns of Paarl and Worcester in the Western  
5580 Cape Province of South Africa. The facility will be under the 1300 m Du Toitskloof mountain with about  
5581 800 m of rock overburden for the Huguenot tunnel itself [3].



Figure 17-2: Inside the Huguenot Tunnel. Photo credit: courtesy JJ Van Zyl/Stellenbosch University.

### 5582 17.3 The science case within the African continent

5583 At high dark matter masses, only detectors using noble liquids (Xenon and Argon) can reach the required  
5584 sensitivity. While the underground site for those experiments is not yet defined, a novel underground site  
5585 that does not surpass the existing ones in terms of depth can hardly be a good choice for them. At small dark  
5586 matter masses, however, there are many new opportunities to which a novel underground laboratory can.  
5587 Dark matter with mass below the proton (sub-GeV) typically lies in a dark sector, which does not interact  
5588 directly with any of the Standard Model forces. Instead, new particles (such as dark photons, scalars,  
5589 or pseudo-scalars) can mediate interactions between the dark matter and the ordinary matter. There is  
5590 nowadays a plethora of experimental techniques that are trying to gain sensitivity to such small signals. In  
5591 this case, the challenge is to develop detectors with very low energy thresholds and excellent control over  
5592 detector backgrounds, rather than to build large detectors that are highly demanding in terms of occupied  
5593 volumes in an underground laboratory. There are many other efforts and plans, and since the hunt for  
5594 low-mass dark matter is relatively young, there is space for new experiments and new underground sites.

5595 The search for light dark matter particle is particularly attractive for these new technologies as significant  
5596 advances can be achieved with kg-scale detector arrays.

5597 One of the most interesting facts about having the possibility to perform an experiment of direct dark matter  
5598 detection in an underground laboratory located in the Southern Hemisphere is to compare the eventual  
5599 systematic errors or modulation with respect to the same detector in the Northern Hemisphere. It also  
5600 opens different regions of parameter space when searching for daily modulations.

5601 The other advantage to build such a facility in South Africa is to combine the direct detection with indirect  
5602 dark matter detection from radio astronomy surveys that South Africa is leading. As is well known,  
5603 South Africa has been leading the world-astronomy collaboration “Square Kilometre Array” (SKA) [4] mid-  
5604 frequency arrays, and has already built 64-dishes precursor “MeerKAT” telescopes in 2018 [5]. The dark  
5605 matter annihilation into standard model particles (e.g.  $b\bar{b}, \tau^+\tau^-, \mu^+\mu^-$ ) can eventually cascade to electron-  
5606 positron pairs, which can lose their energies by inverse Compton-scattering and synchrotron radiation. This  
5607 cascade process can generate fluxes in X-rays and radio wavelength respectively, with detailed variation  
5608 determined by the dark matter mass and the astrophysical environment. Both experiments have South  
5609 Africa’s deep participation and involvement. Therefore, the strong synergy between the astrophysical  
5610 (indirect) probes and Paarl Africa Underground Laboratory (direct probe) can jointly measure and constrain  
5611 dark matter effect, which may shed lights on new physics.

5612 The need for very low radioactive material for dark matter and neutrino underground experiments gave  
5613 birth to the study of new detectors able to measure extremely low radiation levels. These very sensitive  
5614 detectors, able to detect levels of radiation a millionth of the natural radiation of the human body and they  
5615 have to be located deep underground to be shielded from cosmic radiation. The industry has shown interest  
5616 in these techniques to select pure materials with almost no radioactive content. Researchers involved in this  
5617 project can contribute to many needs in South Africa for accurate measurements, such as the detection of  
5618 the radioactive gas radon that has been identified as a major radiation hazard in South African underground  
5619 mines. The scientific work can expand to research projects in multiple fields including biology (radiation  
5620 interaction with cells, microbiology in extreme environments), geosciences, chemistry, mining technology,  
5621 quantum computing etc.

5622 In addition, the underground laboratory will provide a dynamic environment for advances in ultra-sensitive  
5623 detectors and ultra-low radiation techniques and highly trained graduates ready to lead innovation in both  
5624 the global search for rare events and cutting-edge technological development to benefit South Africa industry.

## 5625 17.4 An African facility for Africa

5626 Discussions about an underground research facility in South Africa started in 2011. As one of the world’s  
5627 largest producers of gold, South Africa has a number of the world’s deepest gold mines, including the recently  
5628 closed TauTona Gold Mine with a depth of 3900 m, and Mponeng deeper still. In 1965 the Nobel Prize  
5629 laureate Frederich Reines along with South African Physicist, Friedel Sellschop detected the first atmospheric  
5630 neutrino events in the East Rand mine near Johannesburg, South Africa [6]. Initial focus by the South African  
5631 nuclear physics community was on establishing an underground facility in one of South Africa’s deep gold  
5632 mines. The alternative is to develop such an underground laboratory inside the Huguenot tunnel, located  
5633 between the towns of Paarl and Worcester in the Western Cape Province [7].

5634 The development of the Huguenot tunnel as an underground low-level radiation facility holds a number  
5635 of strategic advantages. Such a facility is located approximately 25 km from Stellenbosch University and  
5636 40 km from the iThemba LABS. It offers a unique possibility to build up a scientific complex suitable for

5637 the detection of events under ultra-low radiation exposure, as required for dark matter and neutrino studies,  
5638 as well as for other areas of research.

5639 The laboratory will consist of a surface facility, located near the road freeway Huguenot tunnel, and  
5640 potentially extensive underground spaces and various connecting tunnels. The experimental hall will be  
5641 covered by about 800 m of rock, under the Du Toitskloof Mountains, protecting the experiments from  
5642 cosmic rays. It will be easily accessible, with the ability to drive to it rather than using mine-shaft elevators,  
5643 similarly to the LSM (Laboratoire Souterrain de Modane, France) [8], LSC (Laboratorio Subterráneo de  
5644 Canfranc, Spain) [9] or LNGS (Laboratori Nazionali del Gran Sasso, Italy) [10] facilities.

5645 In December 2023, South Africa's Department of Science and Innovation (DSI) gave mandate to the PAUL  
5646 collaboration for independent scientific and engineering feasibility studies. The main objective is to explore  
5647 the viability of an underground laboratory of about 10,000 m<sup>3</sup> inside the Huguenot Tunnel and to establish  
5648 a scientific culture of international cooperation, between African countries, and with the international  
5649 community.

5650 The first symposium on Science at PAUL was held on January 2024 at Du Kloof [11]. This event has gathered  
5651 an international community of underground laboratories and led to the official launch of the project [12, 13].

## 5652 17.5 The International collaboration and the development in the 5653 African continent

5654 The tunnel provides quick and easy access to the local research communities. Research programs done at  
5655 such a facility will also support postgraduate training programs at Stellenbosch University, the University of  
5656 the Western Cape, the University of Cape Town and Cape Peninsula University of Technology. Furthermore,  
5657 the research at the PAUL will support national and international research activities in astronomy, nuclear  
5658 and particle physics, as well as many of the research topics already discussed.

5659 More than that, the project will offer the chance to integrate with other worldwide facilities, laboratories  
5660 and experiments and increase the potential of the region by increasing its academic activities, the formation  
5661 of new human resources and the development of new basic research and technologies. This is a unique  
5662 opportunity to build an excellent deep underground laboratory, the only one in Africa, with a strong impact  
5663 on regional integration.

5664 The collaboration has been built from the beginning together with high-level scientists from top-level  
5665 underground laboratories. More importantly, the local leading universities, Stellenbosch University and the  
5666 University of the Western Cape, not only attracted other South-African universities such as Wits, UNWA and  
5667 UNISA but facilitated the participation of physicist from other African countries, such Botswana, Nigeria,  
5668 Kenya and even North Africa. This was made possible thanks to the good relations South-African universities  
5669 kept with their former African students. It is also well-reflected in the authorship of the founding article [2].  
5670 The actual collaboration includes thirteen African universities or research organizations.

## 5671 17.6 Prospects

5672 The preliminary work to be followed during 2024 and 2025 is the design and study of PAUL facility including  
5673 the excavation work. This is accomplished together with SMEC, the tunnel company for the civil engineering  
5674 aspect and SANRAL, South African National Roads Agency, for the more strategic aspect of the work.

5675 At the same time, the radiation measurement inside the tunnel are important to measure to be able to  
5676 establish the specifications of PAUL facility. A muographer has been shipped from France to Cape Town in  
5677 December 2023 and the muon flux scan from inside the tunnel is planned for year 2024 and 2025 [14, 15]. In  
5678 parallel to this, the aspect of gathering the community around the project and discussing the future science  
5679 programme is on-going [16].

5680 PAUL will be a top-level international laboratory and is supported by the international community. The  
5681 founding event [11] where the international attendance was evident, not only from northern hemisphere but  
5682 also the southern including African from Nigeria, Rwanda, Botswana etc. has granted not only support  
5683 but also a budget for the feasibility study. In parallel, new collaborations are being established to build  
5684 the physicists of tomorrow to operate PAUL. These collaborations include hosting African students at  
5685 underground laboratories, Grand Sasso, Modane, Canfranc or SNOLAB [17], to participate to the actual  
5686 experiments and their R&Ds, e.g. Damic-M [18] or Tesseract [19], to acquire the know-how, the skills and  
5687 the technologies and to grow the community of African in science of ULs. Contacts have been made with the  
5688 geophysics community at the Witwatersrand university where the experts are located. A new collaboration  
5689 between austral universities is being set up. Other contacts and workshops have been planned in view of  
5690 creating synergies between biophysicists to explore life science underground, similarly to what is done at  
5691 Canfranc [20].

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# Community Engagement

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5718 Ndeye

## 5719 18.1 Introduction

5720 In 2015, countries adopted the UN 2030 Sustainable Development Goals as a universal call to end poverty.  
5721 Poverty is considered one of the greatest challenges to sustainable development in Africa as approximately  
5722 80% of the people in extreme poverty are located in Sub-Saharan Africa. However, Africa has the potential  
5723 to beat poverty as it has the youngest and fastest-growing population in addition to 60% of the world's  
5724 arable lands and 30% of the world's minerals being located in Africa (Coulibaly and Golubski, 2020).

5725 Factors contributing to poverty in Africa are closely related to Science and Technology education. These  
5726 include among others inadequate infrastructures, inadequate resource management, inadequate or lacking  
5727 long-term policies and strategies for education and human resource development, etc. Africa is lagging far  
5728 behind in technology and its ability to compete at the international level is impeded by poor education  
5729 systems (Heckman, 2004). Thus, adequate STEM science education is essential to unlock Africa's potential  
5730 for sustainable development. We need to address the gaps in science and technology skills in Africa. One  
5731 very important key in science education concerns improving the teaching and learning of Physics (Babalola  
5732 and Folasade, 2022). Physics is considered as the basis of all applied sciences; its adequate education can  
5733 help break the cycle of perpetual poverty in Africa for example by building sustainable clean energy systems  
5734 and finding solutions to social and environmental problems such as water pollution and climate change.

5735 The main problem with Physics education in Africa is that the enrolment in Physical Sciences is low in  
5736 high school and university. To mitigate this, collaboration and communication between all stakeholders  
5737 (local communities, the scientific community, policymakers, regional bodies and international partners) are  
5738 needed (Sa'id et al. 2020). It is in this context that community engagement initiatives have emerged  
5739 as a transformative approach to enhancing STEM education in Africa. These initiatives are driven by  
5740 a deep understanding of the critical role education plays in shaping Africa's future by empowering its  
5741 youth. Traditional class teaching and learning is vital but community engagement adds a layer of real-  
5742 world experience and application to STEM concepts. This makes STEM subjects more tangible, accessible,  
5743 and interesting for students (Sa'id et al. 2020).

5744 In November 2020, the African Strategy for Fundamental and Applied Physics (ASFAP) initiative was  
5745 launched by African Physicists (Pan-African and Diaspora) and was mandated by the African Physical  
5746 Society (AfPS) with a mission to develop a strategy to increase Physics education and research capabilities  
5747 in Africa and improve collaborations between all stakeholders to help Africa take its due place as a co-leader in  
5748 the global scientific process. This report will explore the advantages of community engagement initiatives in  
5749 Physics education in Africa, highlighting the thoughts, ideas, and recommendations from different meetings

5750 conducted by the ASFAP Community Engagement Working group members. By embracing these initiatives,  
5751 African countries can forge a strong bond between educational institutions and their communities which will  
5752 contribute towards scientific progress and sustainable development across the continent.

5753 *“Communities count, they are key to improving everything from education and economic development to*  
5754 *health care and race relations”* (Matthews, 2008)

## 5755 18.2 Principles and Definitions

5756 Before delving into the work of the ASFAP Community Engagement Working group, it is important to try  
5757 to understand what community engagement is and why it is important for Physics education in Africa. We  
5758 will also look at the principles of a successful community engagement initiative.

### 5759 *Definitions*

5760 Community engagement can be defined as “the process of working collaboratively with and through groups  
5761 of people affiliated by geographic proximity, special interest, or similar situations to address issues affecting  
5762 the well-being of those people” (Centers for Disease Control and Prevention, 1997). Thus, community  
5763 engagement is a powerful vehicle for bringing about environmental and behavioral changes that will improve  
5764 “the understanding and practice of Physics” by the physics community, its members and the public at large.  
5765 Community engagement initiatives “involves partnerships and coalitions that help mobilize resources and  
5766 influence systems,... and serve as catalysts for changing policies, programs, and practices” (Centers for  
5767 Disease Control and Prevention, 1997).

### 5768 *Why does community engagement matter?*

5769 Community engagement initiatives matter as they increase the likelihood that projects or solutions will be  
5770 widely accepted, they will create more effective solutions, help to improve people’s knowledge and skills  
5771 in problem-solving, empower and integrate people from different backgrounds, help create local networks  
5772 of community members as well as opportunities for discussing community problems before they get out of  
5773 control (Bassler et al. 2008).

### 5774 *Principles of a successful community engagement initiative*

5775 To be successful, each community engagement initiative should be guided by clear principles including the  
5776 following:

- 5777 1. Careful planning and Preparation (adequate and inclusive)
- 5778 2. Inclusion and Demographic Diversity (people, voices, ideas, and information)
- 5779 3. Collaboration and Shared Purpose (work together to advance the common good)
- 5780 4. Openness and Learning (listen to each other, explore new ideas)
- 5781 5. Transparency and Trust (clear and open process)
- 5782 6. Impact and Action (ensure that each effort has the potential to make a difference)
- 5783 7. Sustained Engagement and Participatory Culture (programs and institutions that support continuous  
5784 quality engagement) (Matthews, 2008).

## 18.3 Relationship between Community Engagement and Capacity Building

Each community engagement initiative often involves capacity building of the concerned community. How are the two concepts related? The concepts of “community engagement and capacity building” are closely interconnected and reinforce each other in various ways. Let’s see how they complement each other in various ways to develop sustainable education in a community.

- *Empowerment and Skill Development:* Community engagement initiatives often focus on empowering individuals within the community, including students, educators, and local residents. Through active participation in these initiatives, individuals can acquire new skills, knowledge, and competencies. Capacity building, on the other hand, aims to enhance the abilities and potential of individuals, organizations, or communities. By engaging with the community, capacity-building efforts become more effective as they are tailored to address the specific needs and aspirations of the people involved.
- *Collaboration and networking:* Both community engagement and capacity building foster collaboration and networking among various stakeholders. Community engagement initiatives often bring together educators, students, local leaders, non-profit organizations, and government agencies. These collaborations create a supportive ecosystem where capacity-building efforts can be shared, expanded, and sustained, leading to a more comprehensive and lasting impact (Beegle and Christiaensen, 2019).
- *Sustainability:* When individuals are involved in the decision-making process and take ownership of their educational and developmental goals, they are more likely to sustain the outcomes of capacity-building efforts. This sense of ownership and responsibility drives a culture of continuous learning and improvement within the community.
- *Knowledge transfer and sharing:* Community engagement provides a platform for the exchange of knowledge and experiences. Capacity-building initiatives can leverage this shared knowledge to design programs that are inclusive, culturally sensitive, and locally appropriate. In turn, capacity-building activities enhance the expertise and resources available within the community, contributing to its overall growth and development.
- *Developing community-driven solutions:* Community engagement allows for a bottom-up approach, where solutions are developed based on the specific needs and priorities of the community. Capacity-building efforts can then be tailored to address these unique challenges, making them more effective and sustainable in the long run.

In summary, community engagement and capacity building are intertwined in their efforts to empower individuals, promote collaborative learning, and foster sustainable development. By combining these two approaches, communities can harness their collective potential and drive positive change in various aspects of Physics education in Africa. Improved Physics education in Africa can significantly contribute to improved health care, agriculture, natural resources conservation, etc.

Thus, community engagement is an important topic to consider for any attempt to uplift Physics in Africa. As the ASFAP Community Engagement Working Group, we have considered various leads without exhausting them. It is also a topic at the intersection of various other subgroups like Education, Outreach, Young physicists, and women in physics. There is also a need to introduce ASFAP goals and scope of activities to the community members first. This can be done by the representatives of ASFAP in each county. By doing so, we shall be in a position to interact directly with society and get different feedback on common areas of interest. The ASFAP Community Engagement Working Group is made of four active members, and

5827 co-conveners from different countries (Rwanda, Algeria, Senegal, and Nigeria). We have met several times  
5828 and we were able to identify seven potential areas of possible common action:

- 5829 1. Physics communication and outreach.
- 5830 2. Technology transfer; Internet connectivity/ internet start-up resources; Applications and industry.
- 5831 3. E-lab and e-learning.
- 5832 4. Business development and entrepreneurship
- 5833 5. Public education and outreach; Diversity and inclusion and equity.
- 5834 6. Government engagement and public policy.
- 5835 7. Career pipelines and development; Retention; Capacity development.

## 5836 18.4 Outreach Goals and community needs

5837 We present below some actions worth engaging the community with which delineate the importance of using  
5838 physics in solving societal problems.

### 5839 1. *Physics and Environmental Pollution:*

5840 How can we use Physics to resolve the problem of environmental pollution? To raise awareness  
5841 of the local community on subjects that matter to their everyday life. In the cases of plastic and  
5842 pharmaceutical waste:

- 5843 • Recycling methods for plastics
- 5844 • Waste burning (e.g., incineration of pharmaceuticals wastes)
- 5845 • Pharmaceuticals return to pharmacists or clinics
- 5846 • Special collection programs for pharmaceutical waste (old and unused)
- 5847 • Education and Awareness campaigns on the safe disposal of pharmaceuticals and plastic waste  
5848 (e.g., School visits; Radio Talks; Podcasts; website; etc.)

### 5849 2. *Physics outreach and Education:*

5850 To create awareness and broaden the community's understanding of Physics

- 5851 • Survey on the views of Physics teachers in Africa;
- 5852 • Periodic Training of Physics teachers in Africa;
- 5853 • Virtual Physics laboratories: for those schools where there is no access to laboratories (+ internet  
5854 access): classroom demonstrations for teachers and students;
- 5855 • Annual Physics community fairs: to show the local community how Physics can help them in  
5856 everyday life and introduce children to the fun of Physics;
- 5857 • Organise campus visits for high school children to observe some fun Physics experiments;
- 5858 • Weekend and holidays science classes (for example the University of Johannesburg SOWETO  
5859 Science Centre in South Africa).

5860 3. *Astronomy at the service of physics:*

5861 The Cosmos is after all the largest laboratory in the World... by definition and it is a great stage to  
5862 use various physics branches to illustrate its cognitive.

5863 4. *Introduce the ASFAP initiative to local governments through the African Union (AU):* There could  
5864 have been a part in the blueprint engaging with various physicist bodies or governmental ones at the  
5865 level of each country. This task needs strong connections and we did not attempt to engage with those  
5866 important actors as it needs members in these various countries and regions that we did not have  
5867 (Possibly taking India's engagement with it as a showcase).

5868 **18.5 Community Goals and Priorities**

5869 Among the submitted letters of intent (LOIs) we have noticed that some of them are related to our proposed  
5870 topics. Most of them underline several community goals and priorities crucial for promoting scientific literacy,  
5871 fostering interest in Physics, and building a strong foundation for scientific development. As goals and  
5872 priorities vary across different regions and countries in Africa, some common ones are shown here:

5873 1. *Accessible and Inclusive Education:* Making Physics education accessible to all students, regardless  
5874 of their socioeconomic background, gender, or geographical location, is a key community goal. This  
5875 includes providing resources, facilities, and opportunities for underprivileged communities to engage in  
5876 Physics learning (Makarova, Aeschlimann and Herzog,2019).

5877 2. *Local Relevance:* Emphasizing the relevance of Physics education to the local context and challenges  
5878 is vital. Aligning the curriculum with real-world problems faced by African communities can motivate  
5879 students and demonstrate the practical applications of Physics in their daily lives (Heckam, 2004; Sa'id  
5880 et al. 2020).

5881 3. *Teacher Training and Professional Development:* Prioritizing the training and professional development  
5882 of Physics teachers is essential to ensure they have the necessary skills and knowledge to deliver quality  
5883 education (Heckman, 2004). Thus, continuous support and capacity building for Physics educators  
5884 in Africa can help improve teaching methodologies and inspire effective learning experiences for the  
5885 students.

5886 4. *Gender Equity and Inclusion:* Promoting gender equity and inclusion in Physics education in African  
5887 countries is critical as women form a large percentage of the African population. Thus, encouraging girls  
5888 and women to pursue Physics as a field of study and research can help bridge the gender gap in STEM  
5889 (Science, Technology, Engineering, and Mathematics) fields and contribute to increased development  
5890 in Africa (Jolly, 2009; Beegle, and Christiaensen, 2019).

5891 5. *Practical Learning and Laboratories:* Establishing well-equipped Physics laboratories will allow stu-  
5892 dents to engage in hands-on experiments and practical applications of theoretical concepts. Practical  
5893 learning experiences enhance understanding and stimulate curiosity in the subject (Jolly, 2009).

5894 6. *Collaboration with Local Industries:* Fostering partnerships between educational institutions and local  
5895 industries can provide students with exposure to real-world applications of Physics principles. This  
5896 collaboration can also lead to research opportunities and internships, preparing students for future  
5897 careers in scientific fields.

5898 7. *Public Awareness and Outreach activities:* Increasing public awareness of the importance of Physics  
5899 education and its role in societal development is essential. Community engagement programs, public

- 5900 lectures, and outreach events can help generate interest in Physics and inspire the next generation of  
5901 scientists.
- 5902 8. *Scholarships and Financial Support*: Providing scholarships and financial support for students pursuing  
5903 Physics education can alleviate financial barriers and encourage talented individuals to pursue careers  
5904 in scientific research and innovation.
- 5905 9. *Research and Innovation*: Encouraging research and innovation in Physics within the African context  
5906 can lead to solutions for local challenges (health care, agriculture, clean energy, etc) and contribute to  
5907 global scientific advancements.
- 5908 10. *Sustainable Development*: Integrating concepts of sustainable development and environmental aware-  
5909 ness within Physics education can create environmentally responsible scientists who contribute to  
5910 sustainable solutions for Africa's development.
- 5911 11. *Stopping the Brain drain*: Creating interesting and satisfying jobs for African graduates and making  
5912 sure that they do not immigrate to developed countries will help boost African development.

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# Physics Education Working Group

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## 5951 19.1 Abstract

5952 The African Strategy for Fundamental and Applied Physics (ASFAP) initiative brought together physicists  
5953 from Africa and beyond to address critical issues in physics education across the continent. Through a series  
5954 of meetings held within the physics education group, Letters of Intent (LOIs) were submitted, highlighting  
5955 key challenges such as inadequate infrastructure, outdated curricula, insufficient funding, and a lack of  
5956 collaboration. These issues hinder the development of robust physics education and research capabilities  
5957 across Africa. In response, several strategic proposals emerged from discussions and LOIs, including the  
5958 use of microelectronics to enhance theoretical teaching, the establishment of regional physics experiment  
5959 centers to foster practical learning and research, and the creation of a Pan-African science foundation to  
5960 support sustainable funding and collaboration. This report synthesizes the insights from the LOIs and online  
5961 workshops, outlining a roadmap for addressing the systemic challenges in physics education in Africa and  
5962 advancing the field through collaborative efforts. The proposed initiatives aim to build stronger educational  
5963 frameworks, increase access to resources, and promote innovation in teaching and research, ultimately  
5964 contributing to the growth of physics education and scientific advancement on the continent.

## 5965 19.2 Physics education goals

5966 The African Strategy for Fundamental and Applied Physics (ASFAP) sets forth a vision to harness the trans-  
5967 formative power of physics education to foster scientific progress, technological innovation, and sustainable  
5968 development across the African continent. Physics is a fundamental discipline that drives advancements in  
5969 various fields such as engineering, medicine, energy, and information technology, making it a key pillar for  
5970 Africa's future growth. In alignment with this vision, ASFAP outlines the following core goals for physics  
5971 education:

### 5972 **19.2.1 Cultivating Scientific and Technological Literacy**

5973 One of the primary goals of ASFAP is to promote widespread scientific literacy across Africa, empowering  
5974 citizens to make informed decisions in an increasingly technology-driven world. Physics education must equip  
5975 students with the ability to understand and engage with the scientific principles that underlie everyday phe-  
5976 nomena, from energy generation to telecommunications. By fostering a solid foundation in physics, students  
5977 will develop critical thinking skills that enable them to evaluate scientific and technological developments,  
5978 contributing to a society that is more innovative and better prepared to tackle global challenges such as  
5979 climate change, health crises, and resource management.

### 5980 **19.2.2 Developing 21st-Century Skills**

5981 Physics education must go beyond theoretical knowledge to nurture 21st-century skills that are essential for  
5982 success in modern economies. These include problem-solving, analytical reasoning, creativity, collaboration,  
5983 and digital literacy [1]. ASFAP envisions a physics education system that engages students in inquiry-  
5984 based learning, hands-on experimentation, and interdisciplinary projects that encourage critical thinking  
5985 and innovation. By embedding these skills into physics curricula, students will not only excel in science but  
5986 also become adaptable and resilient individuals capable of addressing complex societal challenges and seizing  
5987 new opportunities.

### 5988 **19.2.3 Enhancing Africa’s Capacity for Innovation**

5989 A central goal of ASFAP is to build Africa’s capacity for scientific and technological innovation. Physics  
5990 education plays a crucial role in laying the groundwork for research and development in fields such as  
5991 renewable energy, space exploration, and healthcare technologies [2]. Through a strong physics education,  
5992 Africa can cultivate a generation of researchers, engineers, and technologists who will drive innovation  
5993 and contribute to the continent’s industrialization and economic diversification. This goal also involves  
5994 establishing pathways from education to industry, ensuring that physics graduates have the skills and  
5995 opportunities to engage in applied research and entrepreneurship.

### 5996 **19.2.4 Promoting Sustainable Development**

5997 ASFAP aligns physics education with Africa’s broader goals for sustainable development, as outlined in the  
5998 African Union’s Agenda 2063 and the United Nations’ Sustainable Development Goals (SDGs). Physics  
5999 education must contribute to solving pressing environmental, energy, and health challenges. For instance,  
6000 physics can offer solutions to Africa’s energy needs by fostering expertise in renewable energy technologies  
6001 such as solar, wind, and geothermal power [3]. Similarly, physics education can play a pivotal role in  
6002 addressing issues related to water purification, sustainable agriculture, and medical technologies, thereby  
6003 improving the quality of life for millions of Africans [4].

### 6004 19.2.5 Addressing the STEM Gender Gap

6005 ASFAP emphasizes the importance of gender equity in physics education. Women remain underrepresented in  
6006 science, technology, engineering, and mathematics (STEM) fields, particularly in physics [5]. To address this,  
6007 ASFAP seeks to create inclusive learning environments that encourage female students to pursue physics and  
6008 other STEM careers. This includes developing mentorship programs, offering scholarships, and promoting  
6009 role models who inspire girls to engage with physics from an early age. By fostering a more diverse and  
6010 inclusive STEM community, Africa can tap into the full potential of its population to drive scientific and  
6011 technological advancements.

### 6012 19.2.6 Supporting Teacher Training and Professional Development

6013 Recognizing the critical role of educators in achieving these goals, ASFAP prioritizes the professional devel-  
6014 opment of physics teachers. Well-trained, motivated teachers are essential for delivering high-quality physics  
6015 education [6]. The strategy aims to enhance teacher preparation programs, provide ongoing professional  
6016 development, and create networks for physics educators across Africa. This support will enable teachers to  
6017 adopt innovative pedagogical approaches, integrate technology into their teaching, and create engaging,  
6018 inquiry-based learning environments. By investing in teachers, ASFAP ensures that physics education  
6019 remains dynamic and responsive to both local and global developments.

### 6020 19.2.7 Fostering International Collaboration and Knowledge Exchange

6021 ASFAP recognizes the value of international collaboration in strengthening Africa's physics education and  
6022 research capabilities. The strategy encourages partnerships between African institutions and global scientific  
6023 communities to facilitate knowledge exchange, joint research projects, and access to cutting-edge technologies.  
6024 This collaboration will not only enrich the learning experience for African students but also position African  
6025 physicists as active contributors to the global scientific community. Additionally, ASFAP seeks to establish  
6026 centers of excellence in physics education and research across the continent, creating hubs for innovation and  
6027 leadership in fundamental and applied physics.

### 6028 19.2.8 Bridging the Gap Between Education and Industry

6029 ASFAP aims to bridge the gap between physics education and industry needs, ensuring that graduates  
6030 are prepared for the workforce and can contribute to Africa's economic growth. This requires aligning  
6031 physics curricula with the skills demanded by emerging industries such as telecommunications, energy, and  
6032 aerospace. By fostering partnerships between educational institutions and the private sector, ASFAP seeks  
6033 to create pathways for students to transition from education into careers that apply their physics knowledge  
6034 in practical, impactful ways. This alignment will also drive the creation of new industries, contributing to  
6035 job creation and economic resilience.

### 19.2.9 Leveraging Technology for Inclusive Education

ASFAP envisions a physics education system that leverages technology to ensure inclusivity and equitable access to learning resources. Many African schools, particularly in rural areas, face challenges related to infrastructure and resource shortages [7]. By incorporating digital learning tools such as virtual laboratories, simulations, and online platforms, ASFAP aims to democratize access to high-quality physics education. These tools can provide students with interactive, immersive learning experiences, even in the absence of physical laboratory facilities. Moreover, digital tools can help overcome geographical barriers, allowing students from across the continent to access the same high-quality education and connect with global learning networks [8].

**Physics as a Catalyst for Africa's Future** The African Strategy for Fundamental and Applied Physics envisions physics education as a catalyst for Africa's scientific, technological, and economic future. By cultivating scientific literacy, promoting innovation, and addressing societal challenges through sustainable development, physics education will play a transformative role in achieving the continent's long-term goals. ASFAP calls for a concerted effort to reform physics education, address structural challenges, and ensure that every African student can engage with and excel in the subject. With the right investments in education, infrastructure, and international partnerships, Africa is poised to become a global leader in fundamental and applied physics, driving innovation and progress for generations to come.

## 19.3 Learning Approach and Challenges for Physics Education

Physics education across Africa holds the potential to significantly contribute to scientific innovation, technological advancement, and socioeconomic development. However, achieving this potential requires a comprehensive and contextually relevant approach to teaching and learning, combined with strategies to address the unique challenges faced by educators and learners on the continent. The African Strategy for Fundamental and Applied Physics (ASFAP) aims to provide a roadmap for strengthening physics education by aligning pedagogical methods with the realities and aspirations of African societies.

*Contextualized and Culturally Relevant Pedagogy:* One of the key pillars of the ASFAP is the development of a learning approach that resonates with the African context. Physics education must move beyond the rote memorization of abstract concepts to one that incorporates real-life applications drawn from local environments and cultures [9]. This involves integrating indigenous knowledge systems and using culturally relevant examples, such as African innovations in engineering, agriculture, and energy, to make learning more relatable and meaningful. Contextualized learning empowers students to see the relevance of physics in solving everyday problems, from water purification to renewable energy solutions [9].

*Inquiry-Based Learning and Hands-On Experiments:* A fundamental goal of ASFAP is to emphasize active learning approaches, such as inquiry-based learning (IBL), where students engage in experimentation, exploration, and discovery. This method fosters curiosity and critical thinking, allowing students to develop problem-solving skills by conducting hands-on experiments and working collaboratively [10]. Physics, being an experimental science, benefits from a learning approach that encourages students to pose questions, test hypotheses, and refine their understanding through practical experience. Inquiry-based methods also foster a deeper conceptual understanding and retention of knowledge [11].

*Leveraging Technology for Physics Education:* The integration of technology into physics education is essential to modernize learning and bridge resource gaps. E-learning platforms, virtual laboratories, and simulation tools such as PhET and GeoGebra can help students visualize complex concepts, even in resource-

6077 limited settings [12]. Technology not only enhances the learning experience but also enables educators to  
6078 reach students in remote areas who may lack access to fully equipped laboratories [13]. ASFAP supports  
6079 the expansion of digital tools to complement traditional teaching methods, ensuring that learners across the  
6080 continent have access to high-quality education.

6081 *Collaboration and Professional Development for Educators:* To implement effective physics education, AS-  
6082 FAP emphasizes continuous professional development for teachers. Educators need support in adopting  
6083 innovative teaching strategies, incorporating research-based practices, and mastering emerging technologies  
6084 [14]. Collaborative networks that connect African teachers with global counterparts are crucial for sharing  
6085 best practices and resources. Initiatives such as cohort-based professional development and teacher exchange  
6086 programs can help build capacity and ensure that educators are well-equipped to deliver high-quality  
6087 instruction.

### 6088 19.3.1 Challenges

6089 While the goals of the African Strategy for Fundamental and Applied Physics are ambitious, several chal-  
6090 lenges must be addressed to realize the transformative potential of physics education.

6091 *Resource Constraints and Infrastructure Deficits:* One of the most significant challenges is the lack of  
6092 adequate resources and infrastructure. Many schools in Africa face shortages of textbooks, laboratory  
6093 equipment, and basic teaching aids [15]. Physics, being an experiment-driven subject, requires hands-on  
6094 learning, but many schools are unable to provide students with access to functioning laboratories. This lack  
6095 of resources impedes students' ability to engage with the subject matter deeply and hinders the development  
6096 of critical scientific skills.

6097 *Teacher Shortages and Capacity Building:* Africa experiences a shortage of qualified physics teachers,  
6098 particularly in rural and underserved areas. This teacher shortage exacerbates the difficulty in delivering  
6099 effective physics education. Many teachers lack the necessary background in physics or sufficient training in  
6100 modern pedagogical approaches [16]. Continuous professional development is needed to bridge these gaps,  
6101 but resource constraints and heavy teaching workloads often limit opportunities for teacher growth.

6102 *Gender Disparities in STEM Education:* The underrepresentation of girls and women in physics remains a  
6103 pressing challenge across Africa. Cultural biases, societal expectations, and gender stereotypes discourage  
6104 many female students from pursuing careers in STEM fields, particularly physics [17]. ASFAP recognizes  
6105 the need to create more inclusive and supportive learning environments that encourage gender equity in  
6106 physics education. Addressing this challenge requires targeted interventions such as mentorship programs,  
6107 scholarships, and awareness campaigns that inspire young women to pursue physics and other STEM  
6108 disciplines.

6109 *Curriculum Rigidities and Examination Pressures:* The current curricula in many African countries are often  
6110 rigid, with an overemphasis on content memorization rather than conceptual understanding and critical  
6111 thinking [18]. This approach can stifle creativity and discourage students from developing a deeper interest  
6112 in physics. Additionally, the pressure to perform well in high-stakes exams often forces teachers to "teach to  
6113 the test," focusing on examination preparation rather than fostering genuine inquiry and exploration [19].  
6114 ASFAP advocates for a curriculum reform that emphasizes conceptual learning, real-world applications, and  
6115 creativity over rote memorization.

6116 *Language Barriers and Cognitive Load:* Many African students study physics in a language that is not their  
6117 first language, which can significantly increase cognitive load and hinder their comprehension of complex

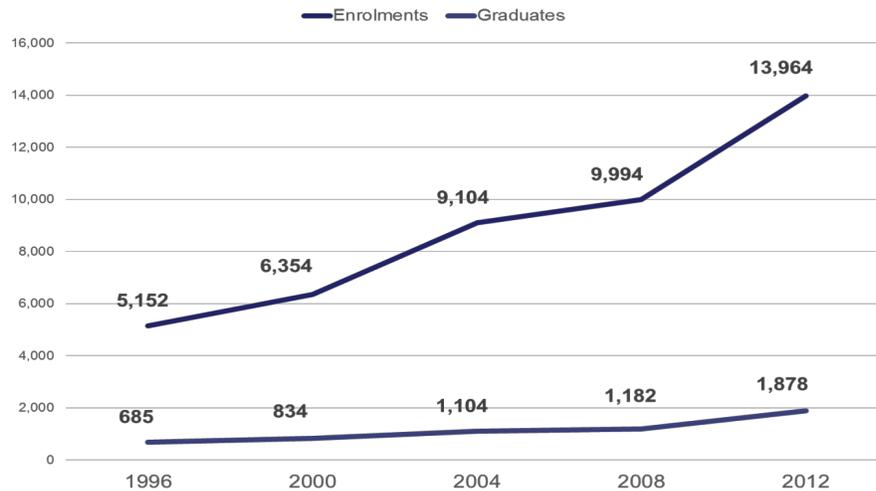


Figure 19-1: PhD enrolments and graduates in South Africa: 1996–2012 [41].

6118 physics concepts [20]. This language barrier often results in a shallow understanding of physics, as students  
 6119 focus more on language comprehension than on engaging with the scientific content. Implementing bilingual  
 6120 or multilingual teaching strategies, including code-switching where appropriate, can help students grasp key  
 6121 concepts while gradually developing their language proficiency [21].

6122 *Inequitable Access to Technology:* While technology has the potential to revolutionize physics education,  
 6123 unequal access to digital tools and resources remains a challenge. Internet connectivity, access to computers,  
 6124 and reliable electricity are often limited in rural and underserved areas [8]. This digital divide must  
 6125 be addressed through policies that prioritize infrastructure development and the provision of affordable,  
 6126 accessible technology for all students.

6127 Figure 19-1 presents a longitudinal analysis of PhD enrolments and graduates in South Africa from 1996  
 6128 to 2012, as reported by the Department of Higher Education and Training (DHET) in 2013 [41]. The data  
 6129 indicates a steady increase in PhD enrollments over the 16-year period, highlighting a growing demand for  
 6130 advanced academic qualifications. This growth is likely a result of national policies aimed at expanding post-  
 6131 graduate education and research capacity to address skills shortages and drive innovation in the knowledge  
 6132 economy.

6133 Figure 19-1 reveals two distinct trends: one related to PhD enrollments and the other to PhD graduates. The  
 6134 increase in enrollments suggests that more individuals are pursuing doctoral degrees, reflecting a broader  
 6135 recognition of the importance of doctoral-level education for both personal and professional development.  
 6136 However, the gap between enrolments and graduates is also evident, underscoring the challenges students  
 6137 face in completing their PhD programmes.

6138 A key observation is the gradual but slower increase in PhD graduates compared to enrollments. This  
 6139 discrepancy may be attributed to several factors, including the time-intensive nature of doctoral studies,  
 6140 financial constraints, academic preparedness, and the availability of adequate supervisory capacity. The latter  
 6141 issue has been identified as a significant barrier in South Africa, where a shortage of qualified supervisors  
 6142 has impeded timely PhD completions.

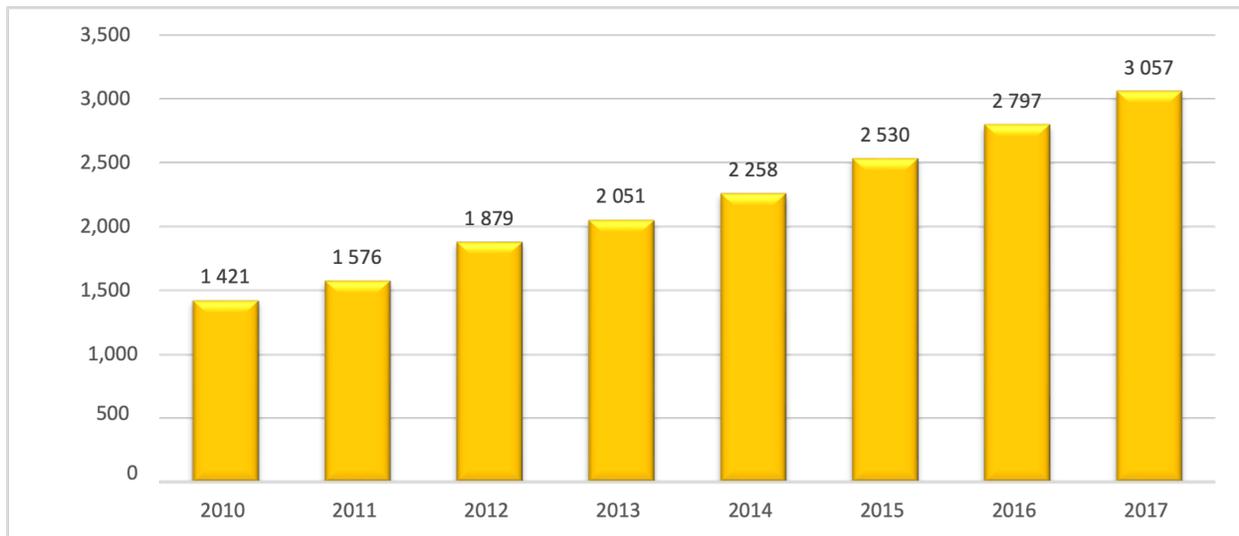


Figure 19-2: Number of doctoral degree graduates in South African universities, 2010–2017 [42].

6143 The data further suggests that while the growth in enrollments signals progress in addressing the country’s  
 6144 need for highly skilled researchers, the system still faces obstacles in ensuring that a higher proportion of  
 6145 enrolled PhD candidates complete their studies. Addressing these barriers is critical to achieving the national  
 6146 target of producing more PhD graduates, which is essential for South Africa’s research output and its global  
 6147 academic standing.

6148 In summary, Figure 19-1 highlights both the opportunities and challenges in the South African higher edu-  
 6149 cation system concerning PhD education. While significant strides have been made in increasing enrolments,  
 6150 further efforts are required to improve throughput rates and enhance the overall success of PhD programmes  
 6151 in the country.

6152 Figure 19-2 presents the number of doctoral degree graduates from South African universities between 2010  
 6153 and 2017, as reported in the Statistics on Post-School Education and Training in South Africa [42]. The  
 6154 data illustrates a consistent upward trend in doctoral graduates over this eight-year period, reflecting positive  
 6155 progress in the country’s efforts to enhance its research capacity and produce more highly qualified scholars.

6156 From 2010 to 2017, the number of PhD graduates increased significantly, with universities producing more  
 6157 doctoral candidates each year. This rise can be attributed to various national initiatives, such as the  
 6158 Department of Higher Education and Training’s (DHET) drive to increase research output and capacity,  
 6159 as well as targeted funding programs aimed at supporting postgraduate students. The government has  
 6160 placed a strong emphasis on doctoral education as part of its broader strategy to strengthen South Africa’s  
 6161 global competitiveness in research, innovation, and the knowledge economy.

6162 Despite this positive trajectory, the number of doctoral graduates remains modest when compared to  
 6163 international standards. This suggests that while there has been notable growth, challenges remain in  
 6164 achieving the desired scale of doctoral production. These challenges may include limitations in supervisory  
 6165 capacity, high dropout rates, and the financial burden on students, which could hinder their ability to  
 6166 complete their degrees.

6167 The increase in PhD graduates over time can also be linked to efforts by universities to improve their research  
 6168 output and reputation. As many institutions seek to climb global university rankings, the production of

6169 PhD graduates has become a key performance indicator. Additionally, policies encouraging the enrolment  
6170 of underrepresented groups in postgraduate studies, including women and Black South Africans, have  
6171 contributed to diversifying the profile of doctoral graduates.

6172 However, the data also highlights the uneven distribution of PhD graduates across different universities.  
6173 While some institutions have significantly boosted their doctoral outputs, others continue to struggle,  
6174 reflecting disparities in resources, research infrastructure, and academic support. Addressing these disparities  
6175 will be crucial for South Africa to meet its long-term goals for higher education transformation and equity.

6176 In summary, Figure 19-2 demonstrates encouraging progress in the production of doctoral graduates in South  
6177 Africa between 2010 and 2017. Although the numbers reflect a growing pool of highly skilled researchers,  
6178 further efforts are required to ensure that all universities can contribute to this national priority, and that the  
6179 growth in PhD graduates continues to align with the country's broader socio-economic development goals.

6180 **A Collective Vision** The African Strategy for Fundamental and Applied Physics envisions a future where  
6181 every African student has access to high-quality physics education that equips them with the knowledge and  
6182 skills to contribute to their societies. Overcoming the challenges in physics education requires a collaborative  
6183 approach, bringing together governments, educational institutions, non-governmental organizations, and  
6184 international partners. Investments in teacher training, infrastructure, curriculum reform, and gender equity  
6185 are essential to transforming physics education across the continent. By addressing these challenges head-  
6186 on and implementing innovative learning approaches, Africa can cultivate a new generation of physicists,  
6187 engineers, and problem solvers who will drive the continent's scientific and technological progress. Physics  
6188 education, when aligned with African realities and opportunities, has the potential to unlock transformative  
6189 solutions for energy, health, agriculture, and sustainable development, positioning Africa as a global leader  
6190 in science and innovation.

## 6191 19.4 Physics Education on an International Level

6192 In the global context, physics education serves as a critical foundation for technological advancement,  
6193 scientific inquiry, and economic development. Internationally, it plays a significant role in addressing  
6194 pressing global challenges, from energy sustainability and climate change to healthcare innovations and space  
6195 exploration. For the African continent, aligning with global physics education trends and participating in  
6196 international collaboration is pivotal in realizing the goals of ASFAP. By engaging with the international  
6197 physics education community, Africa can both contribute to and benefit from the collective progress of global  
6198 science, ensuring that African students, educators, and researchers have the tools and opportunities to thrive  
6199 in a competitive, interconnected world.

6200 Figure 3 presents a comparative analysis of the number of doctoral degree graduates across various countries  
6201 in 2015, based on data from the UNESCO Institute for Statistics [43]. This figure offers insight into the global  
6202 landscape of PhD production, highlighting significant differences in the output of highly trained researchers  
6203 among nations.

6204 The data reveals those countries with advanced research infrastructures and well-established higher education  
6205 systems, such as the United States, China, and Germany, lead in the production of PhD graduates. These  
6206 nations consistently invest heavily in research and development (R&D), with strong governmental support  
6207 and robust institutional frameworks that facilitate high levels of postgraduate education. The high number  
6208 of doctoral graduates in these countries reflects their capacity to generate knowledge and drive innovation  
6209 on a global scale.

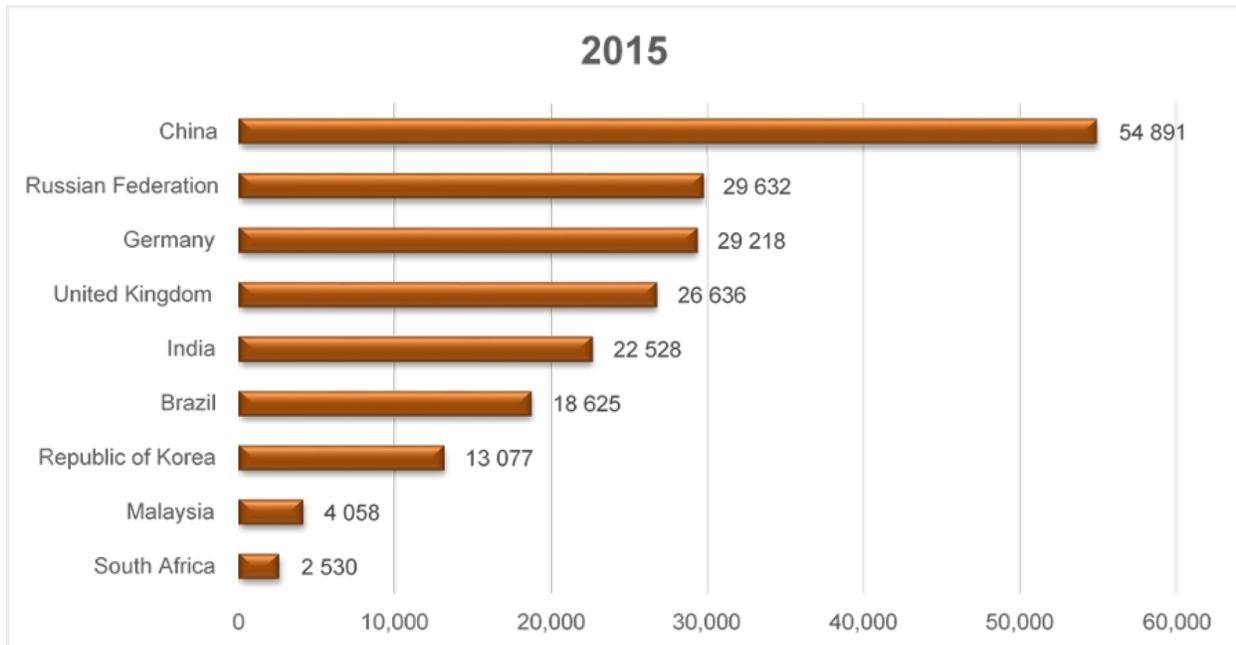


Figure 19-3: Number of doctoral degree graduates by country, 2015 [43].

6210 In contrast, many developing countries, including South Africa, produce significantly fewer PhD graduates.  
 6211 South Africa's position in the figure, though modest compared to larger economies, reflects its growing  
 6212 commitment to enhancing research capacity and doctoral education. However, the gap between South  
 6213 Africa and leading nations points to persistent challenges, such as limited funding, insufficient supervision  
 6214 capacity, and infrastructural constraints, which impede the country's ability to scale up doctoral production  
 6215 to the levels seen in more developed countries.

6216 It is also notable that emerging economies like China and India are rapidly increasing their PhD outputs,  
 6217 driven by targeted national strategies aimed at boosting innovation and research to support economic  
 6218 development. For instance, China's exponential rise in doctoral graduates reflects its strategic focus on  
 6219 becoming a global leader in science, technology, and innovation. This trend underscores the critical role of  
 6220 national policies and investment in higher education and research to drive PhD production.

6221 European countries such as the United Kingdom and Germany are also prominently featured in the figure,  
 6222 reflecting their longstanding tradition of academic excellence and their role as global hubs for research. These  
 6223 countries benefit from well-funded higher education systems, high levels of international collaboration, and  
 6224 strong research outputs, which contribute to their ability to produce many doctoral graduates annually.

6225 In summary, Figure 19-3 highlights the stark disparities in PhD production between developed and developing  
 6226 countries in 2015. While leading economies continue to dominate the global doctoral landscape, countries  
 6227 like South Africa show signs of progress, though challenges remain in scaling up doctoral education to meet  
 6228 global standards. The data emphasizes the importance of sustained investment in higher education, research  
 6229 infrastructure, and supervisory capacity to close the gap between nations and fully leverage the potential of  
 6230 doctoral education for societal and economic development.

### 19.4.1 Leveraging Global Best Practices in Physics Education

Physics education at the international level has evolved significantly with advancements in pedagogy, technology, and research methodologies. The global physics education community emphasizes inquiry-based learning, active engagement, and the integration of technology to make physics more accessible and relevant to students. ASFAP aims to adopt and localize these global best practices to ensure that African students receive a world-class physics education. By aligning curricula with international standards and incorporating emerging trends such as computational thinking, robotics, and interdisciplinary learning, Africa can prepare its students to compete on the global stage and engage in cutting-edge scientific endeavors.

### 19.4.2 Fostering International Collaboration and Research Partnerships

International collaboration is essential for the advancement of physics education and research. ASFAP emphasizes the importance of building global networks that link African institutions with leading research centers, universities, and international organizations in physics education. These partnerships will enable knowledge exchange, joint research projects, and access to cutting-edge laboratory facilities and technologies. Furthermore, collaborative efforts can support the development of African centers of excellence in physics education and research, attracting global talent and positioning Africa as a key player in the international scientific community. Participation in global initiatives such as the International Centre for Theoretical Physics (ICTP) and the European Organization for Nuclear Research (CERN) will also provide African students and researchers with invaluable opportunities to contribute to and learn from international scientific advancements.

### 19.4.3 Addressing Global Challenges through Physics Education

Physics is at the heart of many global challenges, including energy sustainability, environmental protection, and public health. On an international level, physics education prepares students to tackle these challenges by equipping them with the necessary scientific knowledge, problem-solving skills, and innovative thinking. For Africa, participation in international efforts to address these issues is essential. ASFAP envisions a physics education system that not only responds to local needs but also contributes to global scientific solutions. For instance, African physicists and researchers can engage in international collaborations on renewable energy projects, space research, and medical physics initiatives, helping to address both African and global challenges. This cross-border collaboration will enhance the visibility of African contributions to science and foster a global community of learners and researchers working toward common goals.

Figure 19-4 presents data on the share of academic staff holding PhDs in South African universities between 2010 and 2017, as reported by the DHET HEMIS database [42]. Over this period, the figure shows a clear upward trend, reflecting a growing emphasis on the professional development of academic personnel and a broader national push to enhance the qualifications of university staff.

In 2010, a relatively small percentage of academic staff in South African universities held PhD qualifications. However, from 2010 to 2017, this share increased steadily, highlighting the sector's focus on improving academic quality and research output. The rise in PhD-qualified staff is in line with national priorities, particularly the Department of Higher Education and Training's initiatives to strengthen research capacity, improve postgraduate supervision, and enhance the quality of higher education.

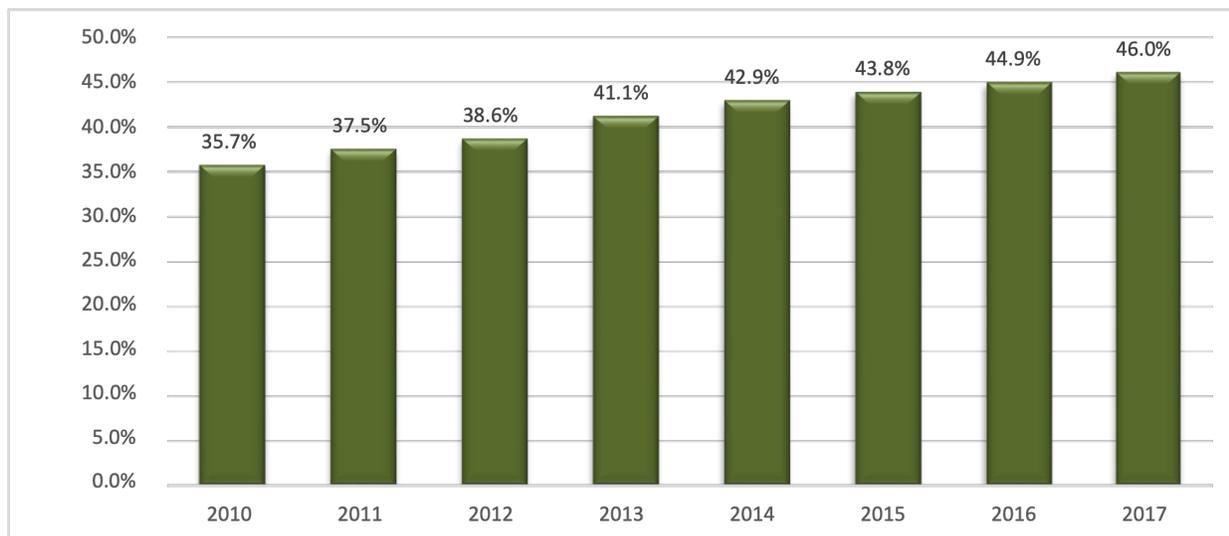


Figure 19-4: Share of academic staff with a PhD in South African universities, 2010–2017 [42].

6269 Several factors have driven this positive trend. One key factor is the government’s push to professionalize  
 6270 the academic workforce. DHET has implemented various funding programs, such as research grants and  
 6271 incentives for PhD completion, to support academic staff in obtaining doctoral qualifications. Additionally,  
 6272 universities themselves have recognized the need to boost the number of PhD-qualified staff to meet institu-  
 6273 tional goals for research output, rankings, and global competitiveness. As a result, many institutions have  
 6274 prioritized hiring academics with PhDs and supporting existing staff in their doctoral studies.

6275 This increase in PhD-qualified staff is particularly important for postgraduate education. As more staff  
 6276 members hold doctoral qualifications, universities are better equipped to provide high-quality supervision  
 6277 to postgraduate students, which is crucial for improving completion rates and the production of master’s  
 6278 and doctoral graduates. It also strengthens the research culture within universities, leading to greater  
 6279 contributions to knowledge generation and innovation.

6280 Despite these gains, the data shows that South Africa still faces challenges in meeting international bench-  
 6281 marks for the share of academic staff with PhDs. While the upward trend is encouraging, the overall  
 6282 percentage of PhD-qualified staff remains lower than that seen in leading research-intensive institutions  
 6283 globally. This suggests that additional efforts are needed to accelerate the pace of transformation and reach  
 6284 international standards.

6285 Furthermore, there are notable disparities across institutions. Historically advantaged universities tend to  
 6286 have a higher proportion of PhD-qualified academic staff, while historically disadvantaged institutions often  
 6287 lag due to resource constraints, lower research funding, and challenges in attracting highly qualified personnel.  
 6288 Addressing these inequities will be critical for ensuring that all universities can benefit from a more qualified  
 6289 academic workforce and for promoting equity in higher education.

6290 In summary, Figure 5 illustrates the steady progress in increasing the share of academic staff with PhDs  
 6291 in South African universities from 2010 to 2017. While this trend is a positive indicator of efforts to  
 6292 enhance academic qualifications and research capacity, further work is needed to address disparities between  
 6293 institutions and to raise the overall percentage of PhD-qualified staff to meet international standards.

6294 Expanding opportunities for academic development and supporting equitable growth across all universities  
6295 will be essential for sustaining this progress.

#### 6296 **19.4.4 Promoting Mobility and Knowledge Exchange**

6297 International mobility for students, educators, and researchers is a key component of global physics education.  
6298 ASFAP prioritizes the mobility of African physics students and scholars, enabling them to study, teach, and  
6299 conduct research abroad, while also attracting international talent to African institutions. This two-way flow  
6300 of knowledge will ensure that African students and researchers are exposed to diverse perspectives, cutting-  
6301 edge technologies, and innovative teaching practices. Programs such as international exchange scholarships,  
6302 joint PhD programs, and visiting professorships will play a crucial role in fostering this knowledge exchange.  
6303 By building these international connections, Africa will enhance its physics education ecosystem, benefiting  
6304 from the expertise and resources of the global community.

#### 6305 **19.4.5 Aligning with Global Standards in Physics Education**

6306 To ensure that African students and researchers can compete on the global stage, ASFAP aims to align  
6307 African physics education systems with international standards in both curriculum design and research  
6308 output. This alignment involves updating curricula to reflect the latest scientific discoveries and integrating  
6309 emerging fields such as quantum computing, nanotechnology, and data science. It also includes adopting  
6310 global best practices in assessment, accreditation, and certification. By doing so, African students will be  
6311 able to seamlessly transition into global scientific and academic communities, ensuring that their education  
6312 is recognized and valued worldwide. Additionally, ensuring compatibility with international standards will  
6313 enable African institutions to collaborate more effectively with global partners and attract international  
6314 funding for research and development projects.

#### 6315 **19.4.6 Enhancing Digital Learning and Open Science Initiatives**

6316 The digital transformation of education has had a profound impact on global physics education, with online  
6317 platforms, virtual laboratories, and open educational resources (OERs) becoming integral components of  
6318 learning. ASFAP seeks to leverage digital technologies to democratize access to physics education across  
6319 Africa and to connect with global learning platforms. By embracing digital learning tools, African students  
6320 can participate in online courses offered by leading global universities, engage in virtual experiments, and  
6321 collaborate with peers worldwide. Additionally, the strategy promotes open science initiatives, encouraging  
6322 the sharing of research findings, data, and educational resources across borders. These initiatives will provide  
6323 African students and researchers with access to global knowledge pools, accelerating scientific discovery and  
6324 innovation.

### 6325 19.4.7 Supporting Teacher Development through Global Professional Networks

6326 The quality of physics education depends on the expertise and dedication of teachers. ASFAP recognizes  
6327 the importance of supporting the professional development of physics educators by connecting them with  
6328 global networks and professional organizations. International collaboration provides African teachers with  
6329 opportunities to attend international conferences, participate in workshops, and engage in online communities  
6330 that focus on innovative teaching practices and educational research. By being part of these networks, African  
6331 physics educators will stay at the forefront of global pedagogical trends and bring innovative practices  
6332 into their classrooms. This continuous development will not only enhance the quality of physics education  
6333 in Africa but also create a generation of educators who are active contributors to the global education  
6334 community.

### 6335 19.4.8 Encouraging International Recognition of African Contributions to Physics

6336 African physicists have made significant contributions to global scientific knowledge, yet these contributions  
6337 are often underrecognized [22]. ASFAP seeks to elevate the visibility of African contributions to physics by  
6338 encouraging more African researchers to publish in international journals, participate in global conferences,  
6339 and collaborate on high-impact projects. By showcasing Africa's scientific achievements on the global stage,  
6340 ASFAP aims to challenge stereotypes about African science and establish Africa as a key contributor to the  
6341 advancement of physics. This increased visibility will also attract international collaborations, investments in  
6342 African research institutions, and opportunities for African students to engage in prestigious global projects.

### 6343 19.4.9 Facilitating Global Engagement in Space and High-Energy Physics

6344 Emerging fields such as space science and high-energy physics offer exciting opportunities for African  
6345 participation in global research efforts. ASFAP envisions the development of programs and partnerships  
6346 that will enable African students and researchers to engage with international space agencies and high-  
6347 energy physics projects, such as those at CERN. Africa's growing interest in space science, exemplified by  
6348 the development of the African Space Agency, aligns with the global push to explore space as the next  
6349 frontier for scientific discovery. By fostering partnerships in these fields, African physicists can contribute  
6350 to cutting-edge research that has global implications while also gaining access to advanced technologies and  
6351 scientific infrastructure.

6352 Figure 19-5 depicts the number of doctoral degree graduates per million of South Africa's population each  
6353 year between 2010 and 2017, based on data from the Department of Higher Education and Training [42].  
6354 This metric provides a per capita perspective on PhD production, allowing for a clearer understanding of  
6355 the country's capacity to produce highly qualified researchers relative to its population size.

6356 The figure shows a gradual increase in the number of doctoral graduates per million people over the observed  
6357 period. This rise reflects ongoing efforts by South Africa to build a more robust research and development  
6358 sector, recognizing that doctoral education is critical for advancing innovation, economic growth, and  
6359 addressing complex societal challenges. The steady growth highlights a national commitment to expanding  
6360 postgraduate education, which aligns with government policies aimed at improving research output and  
6361 fostering a knowledge-driven economy.

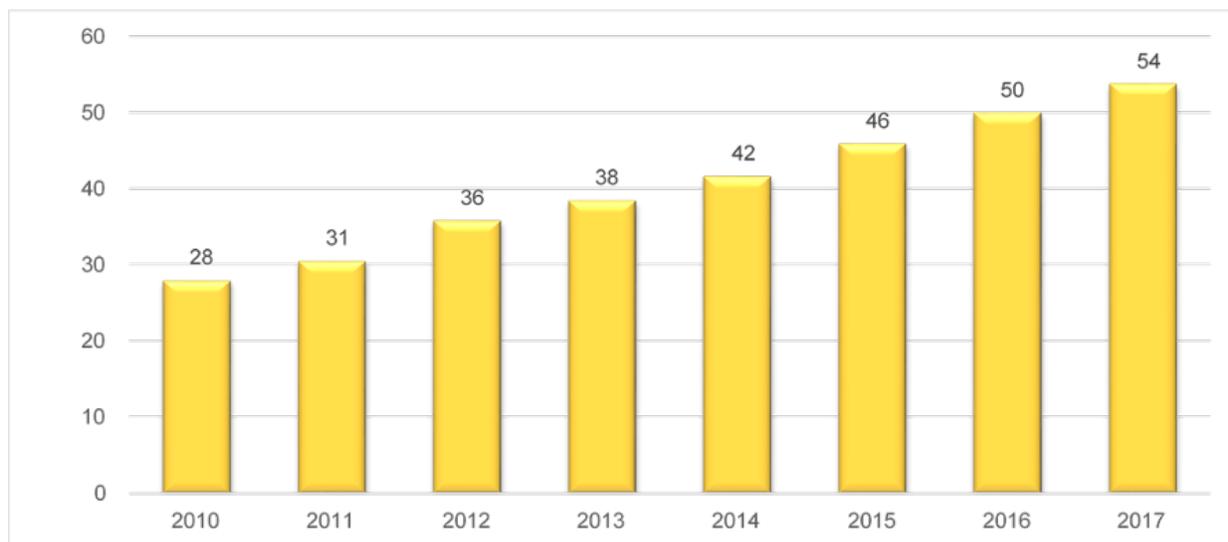


Figure 19-5: Number of doctoral degree graduates per million of population per year, 2010–2017 [42].

6362 Despite this positive trend, the number of doctoral graduates per capita in South Africa remains relatively  
6363 low when compared to global benchmarks, especially in comparison to developed countries with advanced  
6364 research ecosystems. This suggests that while South Africa is making progress, the country still has  
6365 substantial ground to cover to achieve parity with global leaders in doctoral production. Factors such as  
6366 limited funding, supervision capacity, and challenges in student retention continue to constrain the potential  
6367 for large-scale PhD output.

6368 However, while the figure shows progress in increasing doctoral graduates relative to the population, there  
6369 are still structural challenges that need to be addressed. For instance, South Africa faces disparities in  
6370 PhD production across its universities and academic disciplines. Certain institutions and fields, particularly  
6371 in the natural sciences and engineering, are more successful in producing PhDs than others. This uneven  
6372 distribution limits the overall capacity of the country to leverage doctoral education for widespread socio-  
6373 economic development.

6374 In summary, Figure 19-5 highlights South Africa’s strides in boosting the number of doctoral graduates per  
6375 million of the population between 2010 and 2017. Although the data shows a positive trajectory, the country  
6376 must address existing challenges, such as enhancing supervision, increasing funding, and ensuring equitable  
6377 PhD production across all institutions and fields. Achieving these goals will be essential for South Africa to  
6378 fully realize the benefits of doctoral education on a national and global scale.

#### 6379 19.4.10 Addressing the Global STEM Gender Gap

6380 Globally, women remain underrepresented in STEM fields, including physics [23]. ASFAP aligns with  
6381 international efforts to address this gender gap by creating policies and programs that encourage more  
6382 women to pursue careers in physics and related fields. International collaborations can provide mentorship,  
6383 scholarships, and networking opportunities for African women in physics, helping to break down barriers  
6384 and inspire future generations. By drawing on global best practices and success stories from other regions,

6385 Africa can develop a more inclusive and equitable physics education system that supports gender diversity  
6386 in STEM at both the national and international levels.

6387 **Africa as a Global Contributor to Physics Education** The African Strategy for Fundamental and  
6388 Applied Physics envisions a future where Africa is an active participant in the global physics community,  
6389 contributing to and benefiting from international advancements in science and education. By aligning physics  
6390 education with international standards, fostering collaboration, and encouraging the mobility of students and  
6391 researchers, ASFAP seeks to position Africa as a key player in the global scientific arena. Through these  
6392 efforts, African students, educators, and researchers will not only gain access to the world's best educational  
6393 resources and technologies but also contribute to solving global challenges through the power of physics.

## 6394 19.5 Major Challenges Facing Public Schools

6395 Public schools across Africa face significant challenges that hinder the delivery of quality physics education  
6396 [24]. For the African Strategy for Fundamental and Applied Physics (ASFAP) to be successful, these obstacles  
6397 must be addressed to ensure that students receive the foundation needed to thrive in both fundamental and  
6398 applied physics. Some of the major challenges include:

### 6399 19.5.1 Lack of Qualified Physics Teachers

6400 One of the most pressing issues facing public schools is the shortage of qualified physics teachers. Many  
6401 teachers in African public schools either lack formal qualifications in physics or are not adequately trained  
6402 to teach the subject [25]. This shortage is exacerbated by the fact that physics is often viewed as a difficult  
6403 subject, deterring both teachers and students. Without properly trained educators, students struggle to  
6404 grasp foundational physics concepts, limiting their ability to pursue further studies in the subject. The  
6405 ASFAP needs to prioritize teacher training programs and continuous professional development to ensure  
6406 that teachers are equipped to deliver high-quality physics instruction.

### 6407 19.5.2 Inadequate Infrastructure and Laboratory Facilities

6408 Public schools in many African countries suffer from inadequate infrastructure, particularly when it comes to  
6409 laboratories and science equipment. Physics, as a subject, requires practical, hands-on learning experiences  
6410 that are often difficult to provide without well-equipped laboratories. Many schools lack basic laboratory  
6411 equipment such as electrical circuits, measuring instruments, and experimental setups [26]. This prevents  
6412 students from engaging in practical experiments, which are crucial for understanding physics concepts and  
6413 developing scientific thinking. Addressing this challenge requires significant investment in school infrastruc-  
6414 ture to create environments where students can experiment and apply theoretical knowledge.

### 6415 19.5.3 Overcrowded Classrooms

6416 Overcrowding is a widespread issue in many African public schools, where student-to-teacher ratios are  
6417 often extremely high [27]. In such settings, it is challenging for teachers to provide individualized attention

6418 or manage the class effectively, especially in subjects like physics that require complex explanations and  
6419 experimentation. Overcrowded classrooms lead to lower student engagement, poor academic performance,  
6420 and a lack of in-depth understanding of physics concepts [28]. To counteract this, the ASFAP must advocate  
6421 for policies that reduce classroom sizes and ensure a more conducive learning environment for both students  
6422 and teachers.

#### 6423 **19.5.4 Inconsistent Curriculum and Assessment Standards**

6424 Many African countries face challenges related to the lack of consistency in curriculum design and assessment  
6425 standards in physics education. In some public schools, the curriculum may not be aligned with international  
6426 standards, leading to a disparity in the level of physics knowledge imparted to students [29]. Inconsistent  
6427 assessments further exacerbate this issue, with students in different regions being tested on varying levels  
6428 of content difficulty. This inconsistency hinders the development of a cohesive physics education framework  
6429 across the continent. The ASFAP must promote the development of a standardized, yet contextually relevant,  
6430 curriculum that ensures all students receive a comprehensive and rigorous education in physics.

#### 6431 **19.5.5 Limited Access to Educational Technology**

6432 While educational technology plays an increasingly important role in modern physics education, many public  
6433 schools in Africa lack access to digital tools and resources. In developed countries, students can engage with  
6434 virtual labs, simulations, and digital learning platforms that make physics more accessible and engaging.  
6435 In contrast, many African public schools lack the infrastructure to support such technologies, including  
6436 reliable internet access and electricity [30]. This technological divide limits students' exposure to modern  
6437 physics applications and global advancements. ASFAP should prioritize digital inclusion by advocating for  
6438 investment in educational technologies, ensuring that all students have access to the tools necessary for  
6439 21st-century learning.

#### 6440 **19.5.6 Language Barriers and Code-Switching**

6441 In many African countries, students are taught in a language that is not their first language, particularly  
6442 in the sciences. This language barrier complicates the learning of complex physics concepts and leads to  
6443 code-switching—where teachers and students alternate between languages to facilitate understanding [31].  
6444 However, this practice can cause confusion and hinder the development of a strong foundation in scientific  
6445 terminology and conceptual thinking. Addressing language barriers through the development of localized  
6446 teaching resources and improved language training for teachers is critical for enhancing physics education  
6447 outcomes in public schools.

#### 6448 **19.5.7 Socio-Economic Disparities**

6449 Many public schools serve students from low-income households, where poverty significantly affects students'  
6450 ability to engage fully with their education. Limited access to resources such as textbooks, learning materials,

6451 and even transportation to school creates barriers to consistent attendance and academic performance  
6452 [32]. Additionally, students from disadvantaged backgrounds may need to prioritize economic survival over  
6453 education, leading to high dropout rates and lower academic achievement. For the ASFAP to succeed, it  
6454 must address the socio-economic challenges that impact students' access to quality education, particularly  
6455 in physics, which often requires additional resources for effective learning.

### 6456 19.5.8 Gender Disparities in Physics Education

6457 Across Africa, gender disparities remain a significant challenge in physics education. Physics is often  
6458 perceived as a male-dominated subject, leading to lower participation rates among girls. Cultural stereotypes,  
6459 societal expectations, and a lack of female role models in science contribute to this gender gap [33]. As a  
6460 result, girls are often underrepresented in physics classes, and those who do participate may face additional  
6461 challenges in receiving support or encouragement. The ASFAP should promote gender-inclusive policies  
6462 and initiatives that encourage more girls to engage with physics from an early age, providing mentorship  
6463 programs and creating awareness to break down gender biases.

### 6464 19.5.9 Inadequate Funding for Public Schools

6465 Public schools in many African countries suffer from chronic underfunding, which affects all aspects of  
6466 the education system [34]. Limited budgets mean that schools cannot invest in critical resources such as  
6467 laboratory equipment, teacher training, and student support services. Moreover, underfunding impacts the  
6468 salaries of teachers, leading to low morale and a lack of motivation to improve teaching practices. For the  
6469 ASFAP to achieve its goals, there must be a concerted effort to increase investment in public education  
6470 systems, ensuring that schools have the resources necessary to deliver high-quality physics education.

### 6471 19.5.10 Lack of Emphasis on Physics at the Primary and Secondary Levels

6472 Physics is often introduced too late in students' academic careers, with many students only encountering  
6473 the subject in secondary school. This late introduction contributes to students viewing physics as abstract  
6474 and difficult, as they may not have a solid foundation in basic scientific principles. Moreover, the lack of  
6475 exposure to physics at the primary school level reduces students' interest and confidence in pursuing the  
6476 subject further [35]. ASFAP should advocate for the early introduction of physics concepts in primary  
6477 education to build students' interest and capability in the subject from a young age, laying the groundwork  
6478 for more advanced studies in secondary and higher education.

6479 **Tackling Challenges for a Stronger Physics Education Ecosystem** For the African Strategy for  
6480 Fundamental and Applied Physics to succeed, addressing the challenges facing public schools is critical. By  
6481 focusing on improving teacher training, enhancing infrastructure, standardizing curricula, and addressing  
6482 socio-economic and gender disparities, ASFAP can help build a stronger, more resilient physics education  
6483 system. Overcoming these obstacles will ensure that African students are better prepared to contribute  
6484 to the continent's scientific and technological progress, ultimately positioning Africa as a key player in the  
6485 global scientific community.

## 6486 19.6 Physics Laboratories in High Schools

6487 Physics laboratories play a crucial role in secondary education, serving as the foundation for experiential  
6488 learning and the application of theoretical concepts. For the African Strategy for Fundamental and Applied  
6489 Physics (ASFAP) to realize its goals of advancing both fundamental and applied physics across the continent,  
6490 enhancing the availability and functionality of high school physics laboratories is essential. Well-equipped  
6491 and effectively managed laboratories can significantly improve students' understanding of physics and inspire  
6492 interest in pursuing further studies in the subject.

### 6493 19.6.1 Importance of Laboratories in Physics Education

6494 Physics is an inherently practical subject, where students learn through experimentation and observation.  
6495 Laboratories allow students to directly interact with physical phenomena, helping them grasp concepts like  
6496 motion, electricity, magnetism, and optics [36]. Through hands-on experiments, students can see the real-  
6497 world application of abstract theories, deepening their understanding and retention of scientific principles.  
6498 In addition, laboratory work fosters critical thinking, problem-solving, and analytical skills, which are  
6499 essential for success in physics and other STEM fields [37]. The ASFAP must recognize the central role  
6500 of laboratories in cultivating scientific literacy and encouraging innovation among students. Without access  
6501 to these practical learning experiences, students may struggle to develop the foundational knowledge and  
6502 skills necessary for success in higher-level physics courses or careers in science and technology.

### 6503 19.6.2 Current Challenges Facing High School Physics Laboratories in Africa

6504 Many public high schools across Africa face significant challenges in providing adequate laboratory facilities  
6505 for physics education. Some of the key issues include:

6506 *Limited or Outdated Equipment:* Many schools lack basic physics equipment such as oscilloscopes, voltmeters,  
6507 ammeters, or simple pendulum setups. Even where equipment exists, it is often outdated or in disrepair  
6508 due to a lack of maintenance funds. This scarcity limits the range of experiments students can perform,  
6509 hindering their ability to explore physics concepts thoroughly.

6510 *Inadequate Funding:* The underfunding of public schools across Africa is a major obstacle to the estab-  
6511 lishment and maintenance of functional physics laboratories. Schools often lack the financial resources to  
6512 purchase necessary equipment, chemicals, and safety gear, or to build and maintain proper laboratory spaces.

6513 *Teacher Training:* Many physics teachers in Africa, particularly in rural areas, are not adequately trained  
6514 in conducting laboratory experiments. They may feel unprepared to manage practical sessions, which limits  
6515 the frequency and quality of hands-on learning experiences for students.

6516 *Unequal Access:* Schools in urban areas may have access to better resources than those in rural areas, creating  
6517 disparities in the quality of physics education. Rural schools lack the infrastructure, including electricity  
6518 and water, needed to run laboratories, making it difficult to provide any form of practical learning.

### 19.6.3 Recommendations for Improving Physics Laboratories in High Schools

*Increased Investment in Laboratory Infrastructure:* Governments and stakeholders need to prioritize investment in the construction and refurbishment of physics laboratories in public high schools. This includes providing modern equipment and ensuring that laboratories are safe, functional, and accessible to all students. A dedicated budget for the maintenance and periodic upgrading of laboratory facilities should be a part of national and regional education strategies.

*Provision of Mobile Laboratories:* For schools in remote or rural areas where building permanent laboratories may not be feasible in the short term, mobile laboratories can be an effective solution. These traveling labs, equipped with essential physics tools and materials, can bring practical physics education to underserved regions. Mobile laboratories ensure that students in all regions have access to the same quality of education, bridging the urban-rural divide. *Teacher Training and Professional Development:* Teacher training programs must emphasize laboratory management and practical instruction. Continuous professional development should be offered to physics teachers to help them stay up to date with modern experimental techniques, safety protocols, and best practices for engaging students in hands-on learning. This will not only improve the quality of laboratory sessions but also boost teachers' confidence in using laboratory resources effectively.

*Innovative Teaching Aids and Virtual Labs:* Where traditional laboratories are not available, the use of virtual labs and low-cost teaching aids can offer alternative solutions. Virtual labs allow students to perform simulations of experiments through computers, providing an interactive and immersive learning experience. Similarly, low-cost, locally sourced materials can be used to create physics experiment setups that mimic standard laboratory equipment. ASFAP can support the development and dissemination of such innovative tools to ensure that even underfunded schools can provide meaningful practical experiences.

*Community and Private Sector Involvement:* Engaging the private sector and community organizations in the provision of physics laboratories can complement government efforts. Partnerships with businesses, non-governmental organizations (NGOs), and international donors can help fund laboratory construction, equipment procurement, and teacher training initiatives. These collaborations could also promote the development of internship or mentorship programs, linking high school students with professionals in physics-related fields.

*Standardization of Laboratory Facilities:* Establishing minimum standards for high school physics laboratories across Africa is crucial to ensure consistency in the quality of education. ASFAP should work with national governments to develop a standardized framework that specifies the basic equipment, safety requirements, and infrastructure needed for a functional physics laboratory. This will ensure that all students, regardless of location, have access to laboratories that meet these standards.

### 19.6.4 The Role of Laboratories in Promoting Careers in Physics

Well-equipped and properly utilized physics laboratories can inspire students to pursue careers in science, technology, engineering, and mathematics (STEM). Early exposure to practical physics experiments can spark curiosity, foster creativity, and provide a deeper appreciation for the subject [38]. By making physics more engaging and accessible, laboratories help demystify the subject, encouraging more students to consider physics as a viable and exciting career path. To meet the long-term objectives of the ASFAP, it is critical to cultivate a generation of students who are not only competent in physics but also passionate about its potential applications in fields such as energy, telecommunications, healthcare, and space science. Functional

6559 high school laboratories can play a pivotal role in this mission by providing students with a robust foundation  
6560 in experimental science and critical thinking.

6561 **Building a Strong Physics Education Ecosystem Through Laboratories** For the African Strategy  
6562 for Fundamental and Applied Physics to be successful, high school laboratories must become a priority. By  
6563 addressing the existing challenges and implementing practical, sustainable solutions, ASFAP can ensure that  
6564 African students receive the hands-on, practical experience necessary to excel in physics. This approach will  
6565 not only improve academic outcomes but also help build a stronger physics education ecosystem, fostering  
6566 innovation and scientific advancement across the continent. The investment in high school laboratories today  
6567 will lay the groundwork for Africa’s future leaders in science and technology, empowering them to contribute  
6568 to global knowledge and development.

## 6569 19.7 Promotion of Active Learning

6570 Active learning is a pedagogical approach that encourages students to take an active role in their own  
6571 learning, fostering deeper understanding and engagement with the subject matter [39]. For the African  
6572 Strategy for Fundamental and Applied Physics (ASFAP), promoting active learning in physics education is  
6573 crucial to enhancing the quality of teaching and learning across the continent. Active learning methodologies  
6574 can transform passive, lecture-based teaching into a dynamic process where students interact with physics  
6575 concepts, collaborate with peers, and apply their knowledge to solve real-world problems.

### 6576 19.7.1 The Role of Active Learning in Physics Education

6577 Physics is inherently complex, with abstract theories and principles that can be difficult to grasp through  
6578 traditional lecture methods alone. Active learning, which includes strategies such as peer instruction,  
6579 problem-based learning, interactive simulations, and inquiry-based experiments, engages students in the  
6580 learning process, making them participants rather than passive receivers of information [40].

6581 Active learning supports the development of critical thinking, problem-solving, and collaboration skills, which  
6582 are essential for success in physics. For ASFAP, embedding active learning strategies into physics education  
6583 can lead to:

6584 *Deeper Conceptual Understanding:* By actively engaging with material, students better internalize and  
6585 comprehend difficult physics concepts. They can see how theories apply in practical settings and develop a  
6586 stronger foundation for future studies in both fundamental and applied physics.

6587 *Increased Student Engagement:* Active learning methods make physics more interesting and relevant. Rather  
6588 than merely memorizing formulas, students actively explore the principles of motion, energy, and matter  
6589 through discussions, experiments, and simulations. This can lead to increased interest in physics, higher  
6590 motivation, and improved academic performance.

6591 *Collaboration and Communication Skills:* Many active learning strategies encourage group work and peer  
6592 interaction, helping students develop teamwork and communication skills. These skills are vital in real-world  
6593 scientific and engineering environments where collaboration is key to success.

### 6594 19.7.2 Challenges to Implementing Active Learning in Africa

6595 Despite the clear benefits of active learning, many public schools across Africa face challenges that hinder  
6596 its widespread implementation in physics education. Some of the primary barriers include:

6597 *Large Class Sizes:* Many African public schools have overcrowded classrooms, making it difficult to implement  
6598 active learning techniques that require interaction, discussion, and group work.

6599 *Limited Resources:* Active learning often requires resources such as laboratory equipment, technology (for  
6600 simulations), and teaching aids. Many schools, especially in rural areas, lack access to these resources,  
6601 making it challenging to incorporate hands-on, student-centered learning experiences.

6602 *Teacher Preparedness:* Successful active learning depends on well-trained teachers who are confident in  
6603 facilitating student discussions, guiding experiments, and using technology in the classroom. However, many  
6604 teachers have not received sufficient training in active learning methods and may be more comfortable with  
6605 traditional lecture-based approaches.

6606 *Cultural and Educational Norms:* In some educational systems, there is still a strong focus on rote learning  
6607 and memorization. Shifting towards an active learning paradigm requires a cultural change in how teaching  
6608 and learning are viewed, particularly in high-stakes subjects like physics, where examinations often drive  
6609 instructional approaches.

### 6610 19.7.3 Strategies for Promoting Active Learning in African Physics Classrooms

6611 To promote active learning in alignment with the African Strategy for Fundamental and Applied Physics,  
6612 several key strategies should be implemented to overcome existing challenges and encourage the adoption of  
6613 active learning methodologies:

6614 *Professional Development for Teachers:* Teachers are central to the success of active learning. Providing  
6615 ongoing professional development and training on active learning techniques is critical. This could include  
6616 workshops on problem-based learning, interactive simulations, flipped classroom approaches, and the effective  
6617 use of technology. Teachers need practical strategies for managing large classrooms while fostering an active,  
6618 student-centered learning environment.

6619 *Incorporating Low-Cost, Hands-On Learning Tools:* In resource-limited environments, innovative and low-  
6620 cost teaching aids can be utilized to bring active learning into the classroom. For example, simple materials  
6621 like string, weights, and stopwatches can be used to demonstrate physics concepts like motion and force.  
6622 By embracing creativity in teaching aids, teachers can provide hands-on learning opportunities even when  
6623 formal laboratory equipment is unavailable.

6624 *Leveraging Technology and Virtual Labs:* In schools that have access to technology, the use of interactive  
6625 simulations and virtual labs can be a powerful tool for active learning. These technologies allow students  
6626 to visualize complex physics concepts and experiment with variables in a virtual environment, promoting  
6627 engagement and understanding. ASFAP can support the development and dissemination of these technologies  
6628 across African schools, particularly in under-resourced areas.

6629 *Problem-Based and Inquiry-Based Learning:* These active learning methods involve students working on  
6630 real-world problems or conducting their own experiments to explore physics concepts. Teachers can present  
6631 physics problems relevant to local contexts (such as energy, telecommunications, or transportation) and guide

6632 students through the process of investigating solutions. This approach helps students see the relevance of  
6633 physics to their everyday lives and future careers while building critical thinking and problem-solving skills.

6634 *Peer Instruction and Collaborative Learning:* Involving students in peer teaching is a cost-effective and  
6635 impactful strategy. Techniques like Think-Pair-Share, where students think individually about a question,  
6636 discuss their ideas with a partner, and then share with the larger class, can be easily implemented in most  
6637 classrooms. This encourages active participation and deeper understanding as students explain concepts to  
6638 their peers and engage in collaborative problem-solving.

#### 6639 19.7.4 Active Learning and Gender Inclusivity

6640 Promoting active learning can also address issues of gender inclusivity in physics education. Traditional  
6641 lecture-based instruction can sometimes create environments where girls feel less confident or less likely to  
6642 participate. Active learning strategies that focus on collaboration, discussion, and hands-on experiments  
6643 create more inclusive classrooms where all students, regardless of gender, can engage fully with the material.  
6644 Encouraging girls to take active roles in physics learning through group work and problem-solving can help  
6645 break down gender stereotypes and inspire more young women to pursue physics-related careers.

#### 6646 19.7.5 Institutional and Policy Support for Active Learning

6647 For active learning to thrive in African schools, institutional and policy support is necessary. Ministries of  
6648 education, school administrators, and curriculum developers need to:

6649 *Revise Curricula:* Active learning approaches should be integrated into national physics curricula, shifting  
6650 away from a focus on rote memorization towards deeper understanding and practical applications. This  
6651 requires a rethinking of both the content and the methods of teaching physics.

6652 *Support Classroom Innovation:* Schools and teachers should be encouraged to experiment with innovative  
6653 teaching methods, and there should be mechanisms for sharing best practices and successful active learning  
6654 strategies across the education system.

6655 *Assessment Reform:* Traditional assessments, which often prioritize memorization over conceptual under-  
6656 standing, may discourage active learning. Revising assessment systems to include evaluations of students'  
6657 problem-solving abilities, practical skills, and conceptual understanding can support the adoption of active  
6658 learning methods in the classroom.

6659 **Active Learning as a Catalyst for Physics Education in Africa** The African Strategy for Funda-  
6660 mental and Applied Physics can significantly advance its goals by promoting active learning in physics  
6661 education. Active learning not only improves students' understanding of complex physics concepts but also  
6662 helps them develop the skills needed for innovation, scientific inquiry, and technological advancement. By  
6663 addressing challenges such as large class sizes, resource limitations, and teacher training, ASFAP can foster  
6664 an educational environment where students are actively engaged, inspired, and equipped to become the next  
6665 generation of physicists, engineers, and innovators across the continent. Through strategic investment and  
6666 policy support, active learning can become the cornerstone of a transformative physics education system in  
6667 Africa.

6668 **Active Learning: Steps that can foster growth** Large-scale changes will greatly help to improve the  
6669 physics learning environment in Africa. At the same time, African institutions and educators can take  
6670 steps in the relatively near term that can stimulate the growth of active learning in physics. The first  
6671 of these is for physics research institutions to partner with teachers for both professional development in  
6672 physics and creation of useful materials and activities. This should not be top-down but rather a sharing  
6673 of expertise: physicists offering knowledge and mentorship with teachers offering their knowledge of the  
6674 classroom environment, teaching techniques, and how students learn or fail to do so. While these partnerships  
6675 can be fruitful, networking them across countries, regions, or the whole continent can enable these groups to  
6676 pool experiences to increase their effectiveness. In-person workshops and even one-on-one partnerships are  
6677 very effective; they can be enhanced from local region to local region by means of online collaboration. Models  
6678 of such collaborations which can be modified and adapted for the African context are Netzwerk Teilchenwelt  
6679 [44] in Germany and QuarkNet [45] in the United States. Such groups can emphasize affordable, doable  
6680 solutions for high school from simple, effective, and inexpensive laboratory equipment to online access of  
6681 both simulations and data from actual experiments, including those at the cutting edge. African institutions  
6682 have recently joined International Masterclasses [46] in increasing numbers, giving high school and university  
6683 students opportunities to engage with data from experiments at CERN and other forefront laboratories; as  
6684 this data is from physics research, there are no answers ”in the back of the book” and students, consulting  
6685 with tutors, must make their own judgments and construct results. This sort of activity can be spread by  
6686 means of an African network or networks to engage more students and their teachers, who gain expertise by  
6687 preparing and helping the students. [47] University students can participate as masterclass students or tutors,  
6688 both of which enhance their physics education. As research grows in Africa, it should be possible to create  
6689 masterclasses based on African research, such as current research at iThemba Labs or new opportunities at  
6690 the proposed African Light Source. At the same time, it is possible at the university or laboratory level to  
6691 create opportunities for high school and undergraduate - or even graduate - students to experiment with  
6692 inexpensive, do-it-yourself equipment such as the Cosmic Watch [48] small cosmic ray detector or simple  
6693 cloud chambers. Thus, opportunities to promote active learning at all levels but especially in high school  
6694 exist now and can be embraced by the physics community from research physicists and their students to  
6695 high school teachers and their students.

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# Women in Physics Working Group

6826 Marie Chantal Cyulinyana, Iroka Chidinma Joy

6827 Dephney Mathebula

6828 *"It's important to recognize that intelligence is malleable and can be enhanced through a growth mindset.*  
6829 *This involves embracing challenges, learning from criticism, viewing effort as a journey toward mastery,*  
6830 *persisting in the face of obstacles, and finding inspiration in the achievements of others."*, Dr Cyulinyana.

## 6831 20.1 Introduction and motivation

6832 The status of women scientists in research has evolved over the years, but challenges and disparities still  
6833 exist in many parts of the world. It's important to note that the experiences of women scientists can vary  
6834 widely depending on factors such as geographic location, cultural context, and specific fields of research.

6835 Overall, women account for a minority of the world's researchers. Despite the growing demand for cross-  
6836 nationally-comparable statistics on women in science, national data and their use in policy making often  
6837 remain limited. This fact sheet presents global and regional profiles, pinpointing where women thrive in  
6838 this sector and where they are under-represented. Researchers are professionals engaged in the conception  
6839 or creation of new knowledge. They conduct research and improve or develop concepts, theories, models,  
6840 techniques instrumentation, software or operational methods, in the framework of R and D projects [1].

6841 The persistent under representation of women in traditionally male-dominated fields remains a challenge,  
6842 and despite diverse efforts to eliminate it, breaking the "glass ceiling" for women in the field of science proves  
6843 particularly difficult. While strides have been taken toward achieving gender parity in higher education, the  
6844 disparity is more pronounced in scientific disciplines. UNESCO's 2021 [3] estimate revealed that globally,  
6845 45-55% of students at the master's and bachelor's levels are women. However, in science-related areas like  
6846 engineering and computer science, the proportion of female graduates is significantly lower. This gap widens  
6847 as one ascends the academic career ladder. Presently, women constitute 30% of the world's researchers and  
6848 a mere 12% of members in national science academies, with even smaller percentages in low-income nations.  
6849 This trend is also evident in high-tech sectors such as artificial intelligence (AI). According to a Strathmore  
6850 University study, women make up 29% of the workforce and only 10 % of leadership positions in the AI  
6851 industry across the African continent [5].

6852 This issue extends beyond a mere concern about representation and is not exclusive to women alone—it  
6853 is a challenge that impacts all members of society. Those engaged in science, technology, engineering, and  
6854 mathematics (STEM) bear significant responsibility in devising innovative and enduring solutions to the  
6855 intricate problems facing our world [2],[4]. Without the contributions of women scientists and the distinct

6856 perspectives they offer, scientific possibilities will be constrained, limiting our collective capacity to tackle a  
6857 range of challenges, spanning from diseases and food insecurity to climate change.

6858 In general, the challenge becomes particularly pronounced when applied to the field of physics, as gender  
6859 bias and stereotypes persist. Physics lags behind in addressing these issues, necessitating greater efforts  
6860 to encourage the younger generation both males and females to pursue the subject and shape their future  
6861 careers around it [6], [7] and [8].

## 6862 20.2 Goals, challenges and Solutions

### 6863 20.2.1 Goals

6864 The main goal of a Women in Physics working group in the African context is to promote gender inclusively,  
6865 empower women in physics, and address barriers, aiming to increase representation, provide support, and  
6866 foster a collaborative and supportive community for women pursuing physics careers in Africa.

### 6867 20.2.2 Challenges and Disparities

6868 Women in physics in Africa, like in many other parts of the world, face various challenges that can impact  
6869 their participation, advancement, and retention in the field. While experiences may vary, some common  
6870 challenges include:

6871 **Underrepresentation:** Women are often underrepresented in physics in Africa, both in academic institu-  
6872 tions and research settings. This underrepresentation can lead to a lack of visibility and fewer role models  
6873 for aspiring female physicists.

6874 **Gender Bias:** Gender biases may exist in hiring, promotion, and funding processes. Preconceived notions  
6875 about gender roles can affect how women are perceived in the workplace, potentially hindering their career  
6876 progression.

6877 **Sociocultural Factors:** Cultural and societal norms may discourage or limit women's pursuit of careers in  
6878 physics. Stereotypes about gender roles and expectations may influence career choices and opportunities.

6879 **Access to Education:** Limited access to quality education, especially in rural areas, can disproportionately  
6880 affect girls and women, limiting their entry into physics and related fields.

6881 **Work-Life Balance:** The demanding nature of physics research, with long hours and intense workloads,  
6882 can create challenges for women, especially those balancing family responsibilities. This may contribute to  
6883 difficulties in maintaining a healthy work-life balance.

6884 **Lack of Support Networks:** The absence of strong support networks, mentorship programs, and female  
6885 role models in physics can make it more challenging for women to navigate the academic and professional  
6886 landscape.

6887 **Harassment and Discrimination:** Instances of harassment and discrimination, whether subtle or overt,  
6888 can create hostile work environments, leading to a lack of job satisfaction and hindering career advancement.

6889 **Limited Resources:** Inadequate resources, including funding for research projects and access to modern  
6890 laboratories and equipment, can hinder the ability of women physicists to conduct cutting-edge research.

6891 **Networking Challenges:** Building professional networks is crucial for career advancement, but women  
6892 in physics in Africa may face challenges in networking opportunities, which can impact collaboration and  
6893 visibility in the field.

6894 **Policy and Institutional Barriers:** Institutional policies and practices that are not gender-inclusive  
6895 may create barriers for women in physics. Lack of family-friendly policies and support for maternity  
6896 leave can particularly affect women in their career trajectories. Efforts to address these challenges include  
6897 promoting diversity and inclusion, implementing supportive policies, fostering mentorship programs, and  
6898 raising awareness about the importance of gender equality in physics. Collaborative initiatives at the  
6899 institutional, national, and international levels are essential to creating an environment where women in  
6900 physics in Africa can thrive and contribute fully to the scientific community

6901 **Imposter Syndrome** Women in STEM fields, particularly in Physics, might encounter imposter syndrome,  
6902 a phenomenon where they question their capabilities and sense a lack of belonging, even in the face of their  
6903 achievements and qualifications. This psychological hurdle has the potential to impact self-confidence and  
6904 impede career advancement.

### 6905 20.2.3 Progress, Achievements, Solutions

6906 **Promoting Gender Inclusivity:** Advocate for gender inclusivity and equal opportunities within the field  
6907 of physics in Africa. Work towards dismantling gender biases and stereotypes that may hinder women's  
6908 participation in physics.

6909 **Empowering Women in Physics:** Provide support, mentorship, and resources to women pursuing  
6910 careers in physics. This could involve establishing mentorship programs, organizing workshops, and creating  
6911 networking opportunities.

6912 **Increasing Representation:** Strive to increase the representation of women in physics at all levels,  
6913 including academia, research institutions, and industry. Encourage women to take on leadership roles and  
6914 contribute to decision-making processes within the physics community.

6915 **Educational Outreach:** Engage in educational outreach programs to inspire and encourage young girls  
6916 to pursue physics. This may involve collaborations with schools, organizing science fairs, and conducting  
6917 awareness campaigns to showcase the contributions of women in physics.

6918 **Addressing Barriers:** Identify and address specific barriers that women face in pursuing physics careers  
6919 in the African context. This could involve advocating for supportive policies, addressing cultural norms, and  
6920 ensuring that women have access to educational and professional opportunities.

6921 **Networking and Collaboration:** Foster collaboration and networking among women physicists in Africa.  
6922 Create platforms for sharing experiences, knowledge, and resources to build a supportive community.

6923 **Research and Data Collection:** Conduct research on the status of women in physics in Africa, collecting  
6924 data on representation, challenges, and success stories. This information can be valuable in informing policies  
6925 and initiatives aimed at improving gender equity.

6926 **Partnerships with Institutions:** Collaborate with academic institutions, research organizations, and  
6927 industry partners to create a more inclusive environment for women in physics. This may involve working  
6928 with institutions to develop and implement policies that support gender diversity.

6929 **Advocacy for Policy Changes:** Advocate for policy changes at the national and institutional levels to  
6930 address gender disparities in physics. This could involve lobbying for equal opportunities, fair recruitment  
6931 processes, and family-friendly policies.

6932 **Celebrating Achievements:** Recognize and celebrate the achievements of women in physics in Africa.  
6933 Highlighting success stories can serve as inspiration and motivation for others, helping to create a positive  
6934 and supportive community for women in the field.

## 6935 20.3 Conclusion

6936 It is of utmost importance to enhance the involvement of women in physics and address gender disparities  
6937 in the field to shape a promising future for women in physics. This involves implementing various strategies,  
6938 such as establishing alliances with other working groups within ASFAP to collaboratively devise inclusive  
6939 measures for the physics community. We at ASFAP Women in Physics working group (WPWG) strongly  
6940 support the collection of data through regular surveys to accurately assess the number and status of women  
6941 in physics across Africa. It is essential to include the voices of men in this endeavor to foster a collective and  
6942 united approach. Additionally, at the educational level, efforts should be made to make physics an appealing  
6943 course that attracts the interest and enthusiasm of everyone.

6944 Women in Physics are continually shattering barriers and surmounting daily challenges. Their impactful  
6945 contributions to fields traditionally dominated by men showcase their resilience and expertise. Although  
6946 there remains progress to achieve gender parity in Physics, numerous avenues exist to bolster and champion  
6947 women in this field. Encouraging young girls, championing equal pay and representation, and fostering  
6948 mutual support can collectively cultivate a more inclusive and diverse Physics community.

6949 The Women in Physics Working Group (WPWG) is dedicated to making a significant contribution to society  
6950 by actively mentoring young physicists in Africa. Furthermore, the group is committed to fostering research  
6951 collaborations with underrepresented women physicists on a global scale. In its efforts to advance higher  
6952 education and support local scientific research projects in Africa, the WPWG is eager to collaborate with  
6953 policymakers globally, as well as engage with the private sector and business enterprises.

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# Young Physicists Working Group

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6971 Education and scientific research lead to social, economic, and political development of any country. De-  
6972 veloped societies like the Group of Seven (G7) countries have not only heavily invested in education, but  
6973 also in scientific research in their respective countries. Similarly, for African countries to develop socially,  
6974 economically, and politically, they should follow suit by massively investing in education and local scientific  
6975 research.

## 6976 21.1 Introduction and motivation

6977 In 2009, the United Nations Population Fund announced that the population of Africa had reached the one-  
6978 billion mark and doubled in size in 27 years [1]. Regardless of the size and large pool of the human resource  
6979 that the continent is endowed with, most African countries continue struggling economically. Based on the  
6980 World Bank estimates [2], the proportion of Africans living on less than US\$ 1.90 per day fell from 56% in  
6981 1990 to 43% in 2012. This indicates an improvement of 13% in the living standards of the people in Africa  
6982 though according to the World Bank Report [2], there were still more poor people in Africa in 2012 than in  
6983 1990 estimated to be more than 330 million up from about 280 million due to the rapid population growth [1]  
6984 that the continent has been undergoing over the years. Furthermore, despite poverty being a major problem  
6985 in Africa [2], the continent also experiences deadly diseases such as the Acquired-immunodeficiency syndrome  
6986 (AIDS) caused by the Human-immunodeficiency virus (HIV) believed to have originated from Africa [4, 3];  
6987 Ebola-virus disease [5] whose fatality rate is around 50% with case fatality rates ranging from 25% to 90% in  
6988 past outbreaks [5], and the recent outbreak of the COVID-19 pandemic [6], which has impacted negatively  
6989 on Africa and the rest of the world. The continent also faces challenges in science and technology [7] with  
6990 many African countries technologically dependent on other continents in engineering, education, agricultural  
6991 products, health services, among others. African countries also face inadequate research-output capability  
6992 or interest with Africa noted to generate only less than 1% of the world's research output [8] despite its  
6993 increasing population [1]. Due to all these challenges and other factors, the continent has seen young,  
6994 talented, skilled, and educated Africans leaving the continent in search for better opportunities overseas,  
6995 a trend referred to as brain drain [9]. To address these challenges, African countries can draw inspiration  
6996 from developed societies, particularly the Group of Seven (G7) nations [10], renowned for their massive  
6997 investments in higher education, science, and technology. The establishment of the Young Physicists Forum  
6998 (YPF) [12] in 2021, under the African Strategy on Fundamental and Applied Physics (ASFAP) [11] amid the  
6999 COVID-19 pandemic [6], was meant to identify the major challenges that young physicists face and solutions  
7000 thereof in order to positively contribute to the educational and local-scientific research on the continent, and  
7001 thus, build capacity for Africa.

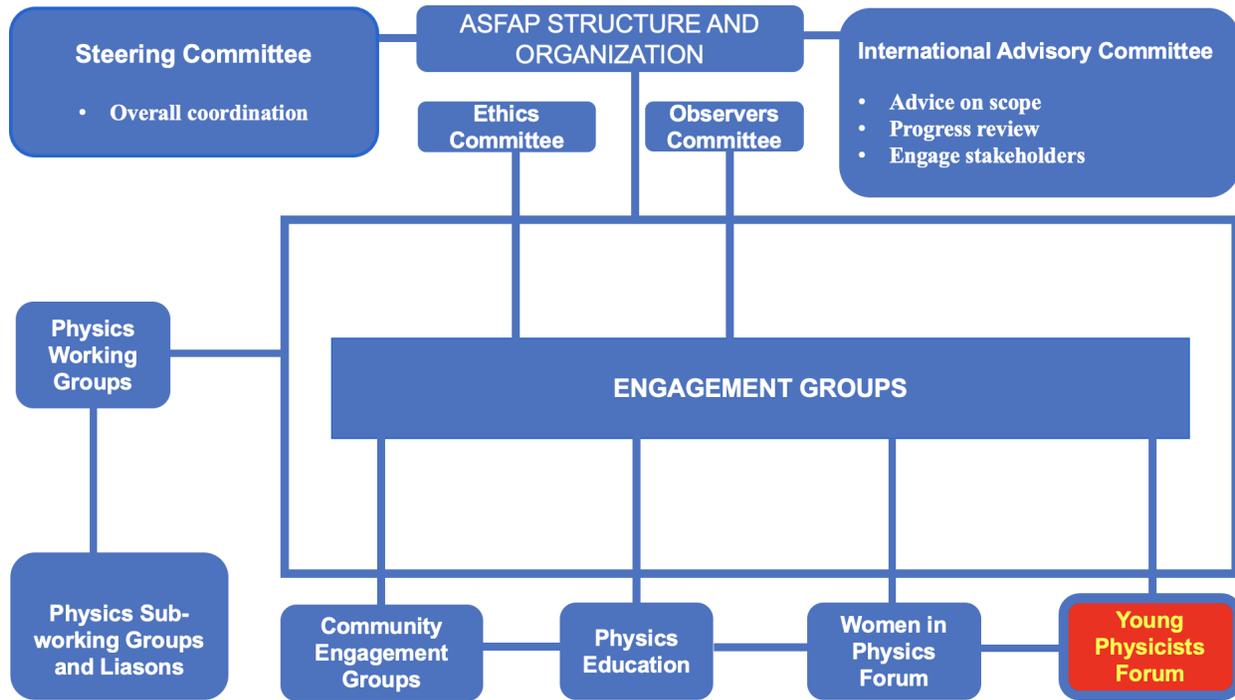


Figure 21-1: Structure and organization of the African Strategy on Fundamental and Applied Physics.

7002 The Young Physicists Forum [12] is one of the engagement and physics working groups (PWG) under the  
 7003 African Strategy on Fundamental and Applied Physics (ASFAP) [11]. The forum is driven by three, young,  
 7004 and vibrant physicists who are co-conveners of the group all in possession of a doctor of philosophy in  
 7005 physics [12]. The co-conveners' mandate is, among other things, to ensure that the group remains sharply  
 7006 focused on its aims and objectives. The forum has a total of 110 active members [12], most of whom are  
 7007 in possession of either a master of science degree or doctor of philosophy in physics. There is, however, no  
 7008 discrimination regarding the highest level of education YPF members [12] should meet and, therefore, all  
 7009 interested individuals within and outside the African continent are eligible to join the forum [12] as long as  
 7010 they sign up [12] and get approved by the steering committee of ASFAP [11]. The group also encourages  
 7011 undergraduate students in various science disciplines, particularly physics, from various African universities  
 7012 to join the YPF [12] and enjoy the mentoring/scholarship benefits that YPF members share within the group,  
 7013 and thus increase their chance of embarking on postgraduate studies either within Africa or overseas. The  
 7014 Young Physicists Forum [12] reports to the steering committee of ASFAP [11] in a well organized structure  
 7015 as shown in Figure 21-1.

## 7016 21.2 Goals, challenges, and solutions

7017 The aims and objectives of the YPF [12] are, among others, to collect ideas, opinions, and experiences on  
 7018 education, physics outlook, careers, workplace environment, and scientific research in Africa. Furthermore,  
 7019 the forum is mandated to clearly identify and raise awareness of the educational challenges and science  
 7020 career opportunities for young physicists in Africa and advocate for change by informing policymakers  
 7021 for action. Last, but not the least, the forum also aims to collect preliminary data for future research.

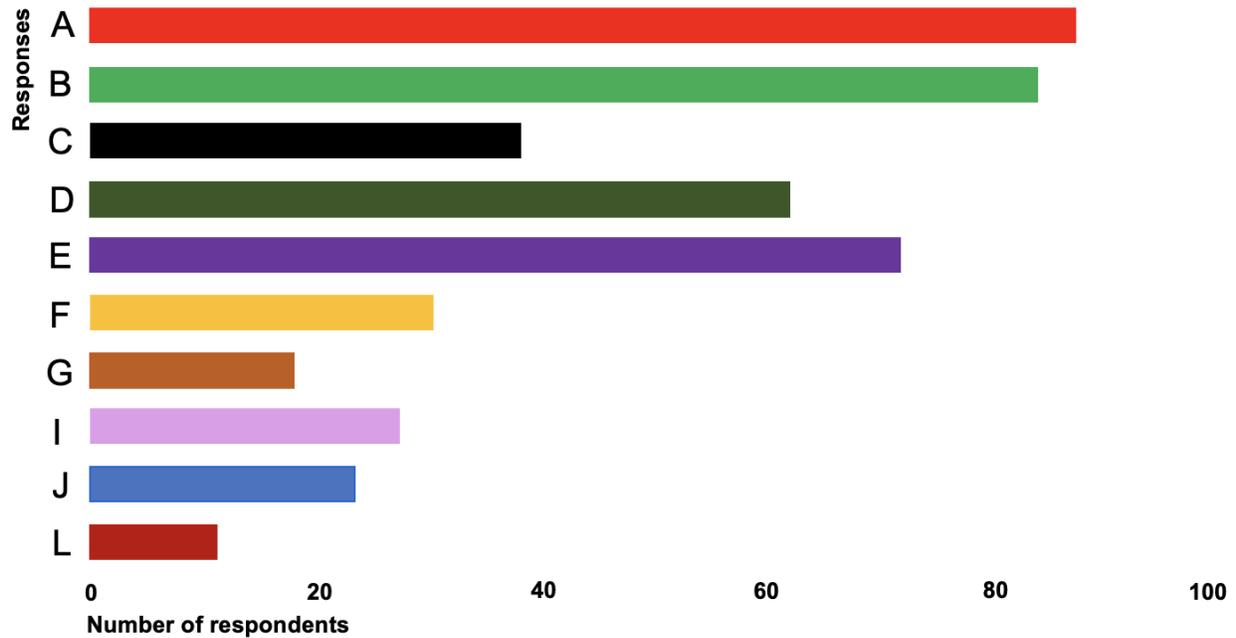


Figure 21-2: Challenges faced by respondents pursuing their highest level of education in African universities.

7022 Since the group's inception in 2021, the Young Physicists Forum [12] has made tremendous progress in  
 7023 meeting its mandate (i.e., its aims and objectives) with the main modes of information dissemination being  
 7024 through scheduled meetings within the group and regular co-conveners' meetings, which are usually held on  
 7025 Wednesday at 5:00 PM, Coordinated Universal Time (UTC). The forum also formulated a survey [15] to  
 7026 solicit for a wider community input of ideas. In addition, the group virtually held a successful workshop  
 7027 with stakeholders within and outside ASFAP [11] on 26<sup>th</sup> January, 2022 tagged *ASFAP: YPF-Challenges and*  
 7028 *Opportunities* [13]. The YPF [12] also actively participated in the second edition of the African Conference on  
 7029 Fundamental and Applied Physics tagged *ACP2021* [17] and contributed three talks under different themes  
 7030 mainly focused on the status and progress the forum has so far made in line with the aims and objectives of  
 7031 the group.

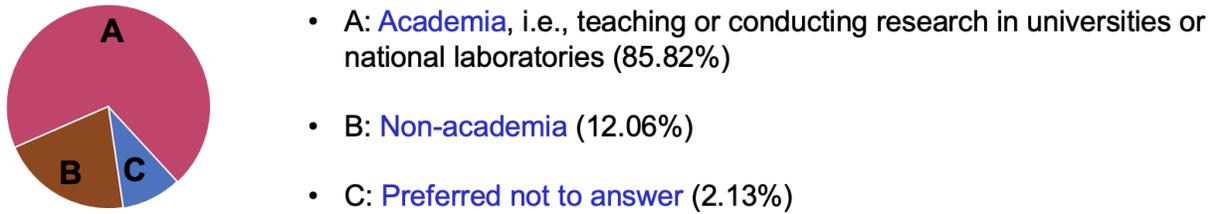
7032 To solicit for a wider community input, the Young Physicists Forum [12] opened a survey [15] to sample  
 7033 African respondents within and overseas, main of whom are alumni of the African School of Physics  
 7034 (ASP) [16]. The survey [15] was aimed at gathering information on the education background, research  
 7035 performance, collaboration opportunities, career development, and workplace environment of the respon-  
 7036 dents. Survey results [15] show that 79.56%, of the respondents pursued their highest level of education  
 7037 within Africa while 20.44% of the respondents attained their highest level of education outside the continent  
 7038 of Africa. The survey [15] has further revealed that of the respondents who attained their highest level of  
 7039 education within Africa normalized to 100%, only 39.42% were satisfied. Factors leading to the educational  
 7040 dissatisfaction rate by respondents are plotted in Figure 21-2 and outlined in Table 21-1. From Figure 21-2  
 7041 and Table 21-1, it is evident that good quality education and research in Africa still remain a huge challenge.  
 7042 Other major obstacles of an African educational system include the lack of mentors, skills training, libraries,  
 7043 job insecurity, and to a lesser extent political instability such as wars, among others. Since education, science,  
 7044 and technology are ingredients that contribute massively to a good life and development of global economies,  
 7045 there is need to solicit for remedies that counter the education and research challenges that many African  
 7046 countries have been grappling with for years.

Table 21-1: Educational challenges faced by respondents pursuing higher education in African institutions

Responses	Challenges	Rate (%)
A	Lack of research funding	20.35
B	Lack of research equipment	19.26
C	Lack of mentoring support	7.88
D	Lack of mobility opportunities	13.57
E	Lack of proper skills training	15.75
F	Lack of access to libraries	6.35
G	Limitation of academic freedom	3.50
H	Imbalance between work and family demands	5.91
I	Job insecurity	4.81
J	Political instability and wars	2.63

7047 According to the survey [15] conducted by the Young Physicists Forum [12], prominent solutions to educa-  
7048 tional challenges include raising awareness to African policymakers and private enterprises on the need to  
7049 fund research through provision of grants, which universities in Africa should utilize to buy experimental  
7050 equipment and conduct research. African governments should also invest in building higher learning in-  
7051 stitutions that are well equipped with research facilities such as modern laboratories where academic staff  
7052 and their students could establish the link between theory and experimental work. This would then help  
7053 reduce over-dependence on foreign research facilities and contribute to meaningful and reliable collaboration  
7054 with other institutions and research facilities overseas. Public and private universities should work together  
7055 and help improve the internet network in universities and research facilities across Africa as a good and  
7056 stable internet connectivity undoubtedly enhances scientific research output and helps improve the quality  
7057 of learning.

7058 Other measures that may help counter educational challenges in Africa include revision of the school  
7059 and university curricula by reducing over-dependence on theoretical work [15], building scientific research  
7060 facilities, and securing laboratory equipment to encourage research skills and knowledge acquisition through  
7061 experimental work among African students. Furthermore, the lack of mentors in science disciplines like  
7062 physics in African universities could be resolved by motivating professors to embark on scientific research  
7063 projects and closely working with their students [15] once research grants are available to them from  
7064 governments and private enterprises. Academic staff should also spend more advisory time with their  
7065 students and try and establish the link between theoretical and experimental work together [15]. Additionally,  
7066 academic staff should offer more structured feedback to students and also establish research collaborations  
7067 within and outside the continent so as to expose their students scientifically [15]. Occupational and career  
7068 guidance should also be provided to students by their advisors in order to motivate them regarding their future  
7069 endeavours in academia within Africa [15]. A career with occupational development is another huge challenge  
7070 being faced by young physicists in Africa [15]. According to the population sampled in the survey [15], it  
7071 is found that roughly 85.82% of the respondents are in the field of academia where they are teaching and  
7072 conducting research in national universities and laboratories while those in non-academia fields accounted to  
7073 about 12.06%, and approximately 2.13% preferred not to reveal their occupation as shown in the pie chart  
7074 in Figure 21-3 by A, B, and C, respectively. Those in academia identified themselves as bachelors, masters,  
7075 and doctoral students including postdocs, engineers, technicians, physicists as well as faculty members.



Occupation and present representation of sample									
Current position	Bachelors students	Masters students	PhD students	Postdocs	Engineers	Technicians	Faculty	Physicists	other
Percent (%)	3.55	10.64	44.68	8.51	0.71	0.71	14.18	9.93	7.09

Figure 21-3: Occupation and percent representation of respondents according to the survey conducted by YPF.

7076 Results of the survey [15] have further revealed that securing an academia position within African universities  
 7077 and national research facilities poses a major challenge and is, at the same time, a huge sacrifice owing to the  
 7078 fact that the workplace environment is mostly not conducive due to lack of experimental facilities, among  
 7079 other challenges, more so in the last two years with the breakout of the COVID-19 pandemic [6]. Based  
 7080 on the results of the survey [15], the Young Physicists Forum [12] has learnt that the combined effect of  
 7081 the nature of an academia workplace environment in Africa and the impact of the COVID-19 [6] has led  
 7082 to a reduction of academic interactions between academic staff and students according to 19.35% of the  
 7083 respondents. Other effects include the reduction of experimental activities (14.52% of the respondents) and  
 7084 research funding according to 12.50% of the respondents. The nature of the workplace environment with  
 7085 the impact of the COVID-19 pandemic [6] has also led to fewer advisor-student interactions according to  
 7086 13.91% of the respondents while other effects include physical and mental health problems as well as financial  
 7087 hardships as described in Figure 21-4. The poor currency-exchange rates of African currencies against major  
 7088 world currencies such as the United States Dollars (\$), Euro (€), and the British Pound (£), among others,  
 7089 is another major challenge [15] of being in the academia field in Africa as this significantly and negatively  
 7090 impacts scientific collaboration work between Africa and other continents as far as international research  
 7091 visits and conferences by students and academic staff are concerned.

7092 The lack of good will and minimal interest in education, science, and technology in Africa [7] have led to a huge  
 7093 challenge over the years where the world has witnessed a large number of skilled manpower leaving Africa for  
 7094 other continents in search of a more conducive workplace environment and an attractive income to support  
 7095 their families, a trend known as brain drain [9]. The survey [15] conducted by the YPF [12] has revealed some  
 7096 instances of brain drain [15, 9] that have been taking place in Africa over the years. These include young and  
 7097 skilled African students studying abroad on scholarships opting to stay and working overseas after completion  
 7098 of their studies [15]. Researchers and postdocs also feel more comfortable working overseas than in African  
 7099 universities where they are either not welcomed or because of the nature of an African academic-workplace  
 7100 environment and meagre salaries [15]. The lack of academic freedom (i.e., students having no choice of what  
 7101 to study due to financial reasons), inadequate funding, and absence of research equipment disfavor Africa as  
 7102 a good destination for good quality education and research work [15]. Political instability such as wars in  
 7103 some countries in Africa drive away academically qualified personnel to other countries outside the continent  
 7104 where they settle down and continue to contribute to science and technology there than in their African

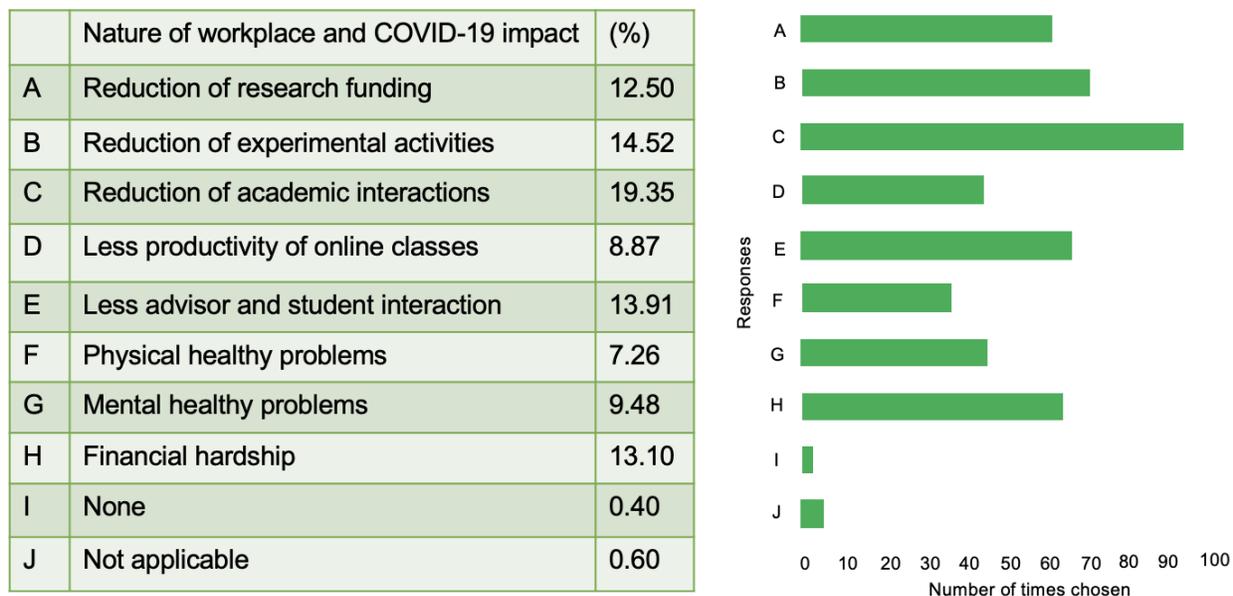


Figure 21-4: Impact of the nature of the workplace and COVID-19 pandemic on research institutions in Africa.

Table 21-2: Measures that may help counter brain drain according to the survey conducted by the YPF

1	Create a school of excellence within Africa for Africans who have obtained their baccalaureate with honors in order to encourage African academic excellence and experience.
2	Policymakers on the continent should partner with private enterprises and work together to improve the research-workplace environment and conditions of service such as salaries to match foreign-based counterparts in academia.
3	Create national research laboratories and more academic positions in African universities and provide research grants to enable academic staff members to embark on a meaningful scientific research experience within the continent.
4	Policymakers should stabilize African currencies to compete favorably with other major world currencies such that the salaries skilled academic staff are earning in Africa are favourably comparable to salaries fellow counterparts earn abroad.
5	Enhance and connect African academic infrastructures with the rest of the world; promote scientific collaborations with international universities, research institutions, and laboratories and allow creative young Africans to present new scientific research projects.
6	Massive investment in African university education is required that will result in an increase in well paying jobs. A marketing campaign should be setup to encourage the youth to stay and work in their respective countries in Africa.

7105 countries of origin [15]. In spite of all these brain-drain challenges [15, 9], the hope for Africa in education,  
7106 science, and technology [7] is still alive. Through the survey [15], the YPF [12] have compiled measures to  
7107 counter the effects of brain drain [9] and hence help keep alive the hope for African countries to develop their  
7108 education and build capacity for Africa. These interventions are summarized and listed in Table 21-2.

## 7109 21.3 Outlook

7110 During the ASFAP process, the Young Physicists Forum has been representing young African physicists  
7111 within the ASFAP community. However, no overarching group exists to provide broad representation for  
7112 young African physicists outside or beyond ASFAP. Therefore, YPF conveners are taking steps to ensure the  
7113 continuity of a field-wide young African physicists representative group within Africa. In this section, the  
7114 main ideas emerging from community feedback, steps taken to form a long-term organization in accordance  
7115 with that feedback, and possible next steps in evolving YPF to become an organization that can serve the  
7116 entire YPF community for the long term in Africa are outlined.

### 7117 21.3.1 YPF at ASFAP Town Hall Meeting

7118 The ASFAP Community Town Hall meeting took place from July 12 to 15, 2021. It was held online to  
7119 discuss the scope and focus of the working groups [18]. The YPF co-conveners served as representatives  
7120 of the YPF. The key points from the community feedback included establishing a representative group for  
7121 the YPF community to lead initiatives beyond the ASFAP process, maintaining the goals of representation  
7122 in the ASFAP and ASFAP—YPF surveys, and enhancing efforts on other key long-term initiatives. The  
7123 community feedback formed around two arms of the organization:

- 7124 1. **ASFAP— YPF Coordination** to coordinate with ASFAP— Physics working groups and help get  
7125 young African physicist members involved in the ASFAP process.
- 7126 2. **ASFAP— YPF Core Initiatives** to assess and initiate ASFAP-YPF critical issues independently.  
7127 The community feedback formed around three key initiatives that will extend beyond the ASFAP  
7128 process as follows:
  - 7129 • **Surveys** to collect ideas, opinions and experiences on careers, physics outlook, workplace culture,  
7130 and scientific research on the African continent.
  - 7131 • **Enrichment** to deal with professional development and building cohesion within the YPF com-  
7132 munity.
  - 7133 • **Long-term organization** to define the long-term structure of the young African physicists  
7134 organization after the ASFAP process.

### 7135 21.3.2 Mission and Goals of the Long-Term Representation

7136 The YPF aims to provide long term young-physicists representation to all members of the fundamental and  
7137 applied physics community in Africa. Toward this mission, the YPF has a goal of fostering a welcoming,  
7138 inclusive, collaborative, and multidisciplinary community. Initiatives that benefit young-physicist members

7139 of the fundamental and applied physics community within the continent will benefit the community at large.  
7140 The creation of an inclusive space that promotes equity, respect, and representation across the discipline is  
7141 of the utmost importance. The YPF community has expressed the necessity of continuing and extending  
7142 the organization and community established during the ASFAP process. The organizational structure and  
7143 community established by the YPF during the ASFAP strategy will serve as a starting point for this long-  
7144 term organization. Based on community feedback, the YPF plans to continue and adapt the *long-term*  
7145 *organization's* key initiatives beyond the ASFAP process and solicit for new key initiatives. The YPF has,  
7146 therefore, put forward the above goals to ensure that its mission not only continues beyond the ASFAP  
7147 process, but also empowers members of the YPF community to function effectively.

## 7148 21.4 Recommendations

7149 The recommendations in this section were prepared by the YPF community and are a supplement to the  
7150 survey recommendations in Sec. 21.2. They include recommendations from contributed white papers and  
7151 community feedback obtained throughout the ASFAP process.

7152 **Recommendation 1: Raise Awareness and Secure Research Funding** - African policymakers and  
7153 private enterprises should be made aware of the importance of funding research in education in Africa.  
7154 The provision of grants could enable universities to purchase experimental equipment and conduct research  
7155 thereby reducing reliance on foreign facilities and fostering collaboration with overseas institutions.

7156 **Recommendation 2: Invest in Higher Learning Institutions** - African governments should invest in  
7157 building well-equipped higher learning institutions with modern research facilities. This includes establishing  
7158 modern laboratories where students and academic staff can bridge the gap between theory and practical  
7159 experimentation.

7160 **Recommendation 3: Improve Internet Connectivity in Higher Learning Institutions** - Reliable  
7161 internet access greatly enhances scientific research output and improves the overall quality of teaching and  
7162 learning. The collaboration between public and private sectors is, therefore, essential in ensuring that internet  
7163 connectivity across African universities and research facilities is enhanced.

7164 **Recommendation 4: Revise Science Curricula and Expand Research Facilities** - Reduce overem-  
7165 phasis on theoretical work by revising school and university curricula. Investing in scientific research facilities  
7166 and securing laboratory equipment can encourage hands-on research among African students, fostering  
7167 valuable skills and knowledge acquisition.

7168 **Recommendation 5: Promote Science Research Projects and Mentorship Programs** - Encourage  
7169 academic staff members to engage in scientific research projects and mentor students closely. The availability  
7170 of research grants from governments and private enterprises can facilitate this process. Establishing a strong  
7171 link between theoretical and experimental work is crucial for student development.

7172 **Recommendation 6: Provide Structured Feedback and Foster Collaboration** - Academic staff  
7173 members should offer structured feedback to students and facilitate research collaborations within and outside  
7174 the continent. Exposure to diverse scientific environments enhances students' scientific understanding and  
7175 skills.

7176 **Recommendation 7: Offer Occupational and Career Guidance** - Faculty staff should provide students  
7177 with guidance on future academic and career paths within Africa, motivating them to pursue their endeavors  
7178 in academia. This guidance plays a crucial role in shaping the future of African students in the global scientific  
7179 community.

**Recommendation 8: Retain Skilled Humanpower within Africa and Minimize Brain Drain -**  
Policymakers should provide a conducive work-place environment that is fairly comparable to workplaces in other scientifically advanced continents. This will greatly help in minimizing the brain-drain syndrome in Africa. Attracting skilled manpower will entail high-quality service delivery within the continent.

## 21.5 Conclusion

The African continent is endowed with abundant natural resources ranging from huge arable land through oil, natural gas, minerals to floras and faunas. It is amazingly puzzling to note that the continent holds a large proportion of the world's natural resources, both renewable and non-renewable and yet, to a large extent, Africa still remains undeveloped with higher poverty levels [2] than other continents. To restrain or minimize these challenges, Africa should heavily invest in higher education and promote local scientific research [15, 7]. Advanced scientific research carried out within Africa would, for example, help find solutions to diseases such as HIV/AIDS [3, 4] that have been ravaging the continent over the years; produce vaccines of its own to cure pandemics such as COVID-19 [6] without having to entirely depend on or solely wait for developed societies [10] to share portions of their vaccines; process its abundant natural resources from raw materials to finished products, and reduce over-dependence on developed countries for finished goods and services [7]. This would, in turn, build an even better relationship between Africa and the rest of the world as far as business is concerned. Since higher education is one of the keys to social, economic, and political independence of any country, it goes without saying that, higher education should be prioritized across Africa. Policymakers should ensure that the educated-human resource is enticed to work within Africa by offering an attractive workplace environment and good conditions of service. These measures would help minimize the brain-drain [15, 9] phenomenon. The YPF [12] is entirely open and solely devoted to identifying the challenges that young physicists face in developing their careers in Africa and finding solutions as well as career opportunities available for young physicists on the continent so as to revamp education and build capacity for Africa. The YPF is also entirely committed to mentor young physicists in Africa and to help promote research collaborations with other young physicists globally [15]. To broaden its impact, the YPF plans to evolve beyond the ASFAP process by leveraging the community it has built to create a permanent structure that offers new opportunities and support to its members. This expanded YPF aims to partner with policymakers, the private sector, and business enterprises globally to advance higher education and local scientific research projects in Africa. The YPF will work closely with various African governments to unite skilled young physicists, find solutions in fundamental and applied physics, and conduct significant research across sectors such as clean energy, medicine, agriculture, transport, and communication. The overarching goal is to improve the quality of life and service delivery across Africa.

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