Africa-UK Physics Partnership Programme Feasibility Study Report

July 2020

Value proposition

Unlocking the potential of the sub-Saharan African physics community through sustainable capacity-building in problem-based physics training, and innovation-focused research, to empower physicists in sub-Saharan Africa to make fundamental discoveries, and significantly contribute to addressing major local and global challenges.

The Association of Commonwealth Universities (ACU)

The ACU is an international organisation dedicated to building a better world through higher education. We believe that international collaboration is central to this ambition. As a membership organisation representing over 500 universities across the Commonwealth, including over 100 in sub-Saharan Africa (SSA), we champion higher education as a cornerstone of stronger societies.

The ACU works with governments, funders, and other international organisations to strengthen the capacity of universities and their researchers, empowering them to tackle global challenges. Our track record includes projects in SSA funded by the UK government, such as Climate Impacts Research Capacity and Leadership Enhancement (CIRCLE) and Development Research Uptake in Sub-Saharan Africa (DRUSSA). CIRCLE aims to strengthen climate change research in SSA through an innovative dual approach, supporting individual academics to undertake research while also working with universities to improve their capacity to support and promote quality research practices. DRUSSA worked with 22 universities in the region to embed research uptake and strengthen the relationship between the production of research and its impact on society.

The ACU has been able to draw on the strength of its networks and delivery track record to collaborate with the Institute of Physics on the feasibility study. Our knowledge and expertise, gained from previous projects and engaged member universities, has informed the process to capture challenges and identify opportunities to take forward in the proposed Africa-UK Physics Partnership Programme.

The Institute of Physics (IOP)

The Institute of Physics is the professional body and learned society for physics in the UK and Ireland. We seek to raise public awareness and understanding of physics and support the development of a diverse and inclusive physics community. As a charity, the IOP's mission is to ensure that physics delivers on its exceptional potential to benefit society.

As a society we face an unprecedented array of challenges. Globally, we need to address a changing climate and a growing population, to decarbonise economies, improve healthcare and ensure water, food, and energy supplies and, develop the next generation of physicists to tackle these challenges. Physics has a vital role to play in this context and in response, the IOP has developed an ambitious strategy to transform the physics landscape for the UK and Ireland and ensure a thriving physics ecosystem that will contribute to innovation, discovery, research, growth and debate in the UK, Ireland and beyond.

Internationally the IOP works with other national scientific bodies, governments and industry, and our membership. As an independent body we are able to play a role as a trusted broker and facilitator of cross-border collaboration. Our relationships and reputation mean we can bring together scientists and organisations from around the world, building the cross-border links that fuel scientific discovery and technological innovation. Leading the Africa-UK Physics Partnership Programme allows us to combine our strengths and ambitions to establish a programme that has the potential to generate long-term, sustainable impact.

Study consultant: BRIAN Masara, CEO, South African Institute of Physics

Report and graphic design: Daniella Bo Ya Hu, ACU

Executive Summary

The fundamental study of physics has played a crucial role in helping us to understand natural phenomena and biological processes throughout history. Research and innovation in the physical sciences have produced some of our most important technological advances ranging from weather forecasting to vital drug developments, and new discoveries continue to drive forward our quest for solutions to global challenges.

However, physics as a discipline has not advanced at an equal pace around the globe. In sub-Saharan Africa (SSA), physics research faces major challenges including gaps in human capital, infrastructural deficits, weaker support systems for innovation and barriers to international collaboration. These factors have limited the advancement of scientific solutions in SSA, and in turn reduced the contributions of the SSA physics community to developmental priorities.

Despite these challenges, in recent decades the shifting landscapes of higher education and policy have produced vibrant research communities with enormous growth potential across the continent. Harnessing this momentum and empowering the SSA physics community to translate science into practice has the potential to position physics as an agent for development. However, a preliminary analysis carried out by the IOP in 2019 found that of over 4,000 relevant projects across SSA, only a small proportion (5.5%) involved physics.

As a response to this gap, a prospective multi-year programme has the potential to improve physics training, research, infrastructure and collaboration in SSA with the overall objective of supporting the SSA physics community to produce world-class research and contribute to developmental priorities. Preceding the design of the Programme proposal, an in-depth, participatory feasibility study was commissioned by the UK Department for Business, Energy and Industrial Strategy (BEIS) to investigate current challenges and identify strategic opportunities for intervention.

Feasibility study

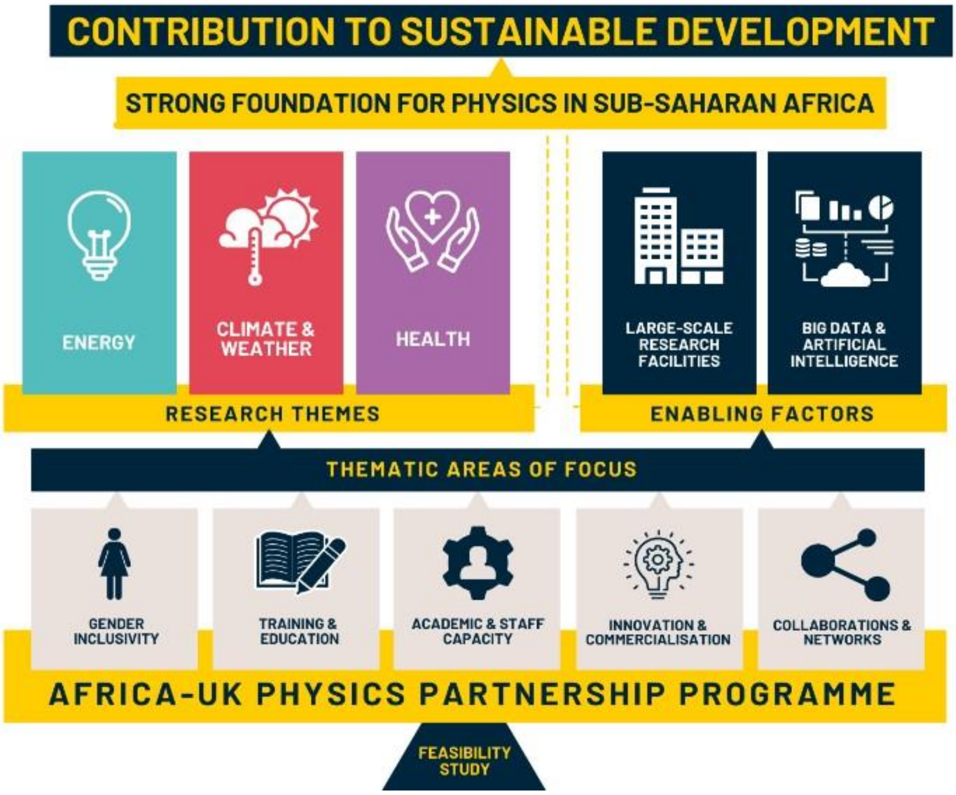
The feasibility study was carried out between March and June 2020 by the ACU and the IOP. To provide an evidence base for the Africa-UK Physics Partnership Programme design, the study investigated five key thematic areas as determined through initial conversations with Programme stakeholders. These areas include the three research themes of energy, climate and weather and health, and access to large- scale research facilities and the advancement of big data and artificial intelligence (AI) as two key enablers. The nine SSA partner countries for the proposed programme are: Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Tanzania and Uganda.

Stakeholders of the Africa-UK Physics Partnership Programme selected these five thematic areas as they are major drivers for physics research and sustainable development, as well as areas where the SSA physics community can play a leading role. Through a survey, a series of consultation meetings and extensive background research, the study gathered the opinions of the physics communities across all participating countries in order to:

1. Measure the current level of physics research and innovation in SSA based on the following dimensions: academic and research staff capacity, physics training and education pipeline, research infrastructure and access to large-scale research facilities, Research and Development (R&D) and innovation platforms, and collaborations and networks;

2. Uncover the major challenges faced by students, academic and research staff and institutions in the discipline of physics in SSA;

3. Recommend opportunities to enhance enabling factors and advance physics across all research themes.



Approach of the feasibility study and prospective Programme

Key study findings

- **Academic and research human capital:** Energy has the highest number of researchers and technicians, followed by climate and weather, with the smallest number for big data and AI. However, big data and AI have higher ratios of early-career staff. There is a consensus amongst academic staff that work overload, insufficient support for staff development and lack of skilled technicians to maintain research equipment are the main hindrances to their research and professional advancement.

- **Physics training and education:** Universities are experiencing challenges in attracting and retaining students in the physics education pipeline at both undergraduate and postgraduate levels. Pipeline issues originate at the school-level, where there is a general lack of encouragement for students to take up physics, a lack of understanding about the importance of the subject, and a lack of awareness about career paths and professional opportunities.

- **Research infrastructure:** State-of-the-art research equipment and the technical skills to repair and service them are not readily available for all research themes. Energy and climate and weather are supported by a reasonable amount of equipment, while health and medical physics equipment often serve both research and clinical purposes. Although equipment for big data and AI is scarce, the study found several advanced big data research centres in South Africa and Kenya.

- **Large-scale research facilities:** Of the institutions surveyed, 91% indicated they would benefit from increased access to large-scale research facilities for multiple reasons, including the opportunity to give young scientists international experience and to collaborate with top scientists. The most significant large-scale research facility available on the African continent is the Square Kilometre Array (SKA), and several significant large-scale African research facilities currently under development have also been identified.

  Several Centres of Excellence (CoEs) were found for all research themes, although the field of medical physics had the fewest number. Most CoEs are country-focused and there is a need to establish ones that encompass multiple countries.

- **Gender inclusivity:** Most PhD holders and academic and research staff are male. The shortage of women in physics is not unique to Africa; however, in the African context, participants reported gender norms, cultural barriers, family responsibilities and workplace harassment as significant barriers for gender inclusivity in physics.

- **R&D and innovation outputs:** Relatively low levels of innovation and commercialisation outputs are attributable to a lack of targeted training, weak industry-academic collaborations, and traditional teaching approaches that value theory over experimental or applied physics.

- **Collaborations and networks:** The main types of existing partnerships are joint-research, co- supervision of students, and staff and student exchanges. Energy research collaborations are particularly prominent followed by collaborations for climate and weather. Less than half of universities undertake consultancy work for industry or have industry-funded research programmes, indicating relatively weak links between the private sector and academia.

Recommendations:

Following an analysis of study findings and inputs from the SSA physics community, the following recommendations can be made to guide the development of future programmes.

1. Provide funding and support to enhance the physics education pipeline beginning at the school-level through to university in order attract and retain more students in physics;

2. Provide encouragement for students, particularly young women and girls, to pursue physics education by clarifying career opportunities, raising awareness about the importance of physics, and promoting the value of academia;

3. Grant financial support for post-graduate students;

4. Develop R&D infrastructure and strengthen commercialisation support systems through strengthening academia-industry ties and increasing placement and opportunities for consultation work;

5. Engage governments on the need to have more academic staff, and to appoint research-only staff in universities;

6. Address gender-based cultural stereotypes and workplace harassment to reduce barriers for women in physics;

7. Improve access to large-scale research facilities and build multilateral Centres of Excellence, particularly in the field of health and medical physics;

8. Enhance opportunities to establish new bilateral and multilateral research collaborations and strengthen existing networks.

Integrating the above recommendations in future programmes will establish a solid foundation of support for the SSA physics community to produce world-class physics research and innovation and foster long-term partnerships with the UK. The study found existing pockets of excellence across all thematic areas as well as willing communities of physicists across all partner countries ready to participate and contribute to Programme objectives. Within this enabling environment, the development of an African-led approach supported by both SSA and UK governments and focused on capacity development, training and education has a strong potential to position physics as a driver of development in SSA.

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1. Introduction

The fundamental study of physics has played a crucial role in helping us understand natural phenomena and biological processes throughout history. Research and innovation in the physical sciences have produced some of our most important technological advances ranging from weather forecasting to vital drug developments, and new discoveries continue to drive forward our quest for solutions to global challenges.

However, physics as a discipline has not advanced at an equal pace around the globe. In sub-Saharan Africa (SSA), physics research faces major challenges including gaps in human capital, infrastructural deficits, weaker support systems for innovation and barriers to international collaboration. These factors have limited the advancement of scientific solutions in SSA, and in turn reduced the contributions of the SSA physics community to developmental priorities.

Despite these challenges, in recent decades the shifting landscapes of higher education and policy have produced vibrant research communities with enormous growth potential across the continent. Harnessing this momentum and empowering the SSA physics community to translate science into practice has the potential to position physics as an agent for development. However, a preliminary analysis carried out by the Institute of Physics (IOP) in 2019 found that of over 4,000 relevant projects across SSA, only a small proportion (5.5%) involved physics.

As a response to this gap, a prospective multi-year programme has the potential to improve physics training, research, infrastructure and collaboration in SSA with the overall objective of supporting the SSA physics community to produce world-class research, foster long-term partnerships with the UK, and contribute to developmental priorities. Preceding the design of the Programme proposal, an in-depth, participatory feasibility study was commissioned by the UK Department for Business, Energy and Industrial Strategy (BEIS) to investigate current challenges and identify strategic opportunities for intervention.

1.1. Purpose of the study

The 2020 feasibility study commissioned by UK BEIS and conducted by the Association of Commonwealth Universities (ACU) and the Institute of Physics (IOP) has provided a strong evidence base to inform the development of future programmes. This report will:

- Present and discuss core findings from the study;
- Suggest recommendations for interventions which adequately address existing challenges and leverage strategic opportunities.

In line with Programme priorities, the study investigated the current level of capacity, challenges and opportunities within five key thematic areas agreed upon through initial conversations with Programme stakeholders. These areas include: three research themes (energy, climate and weather and health) and two enablers (access to large-scale research facilities and the advancement of big data and artificial intelligence (AI)). The research themes have been selected because they are key drivers for development. They also represent ODA priority areas where the SSA physics community can play an important role.

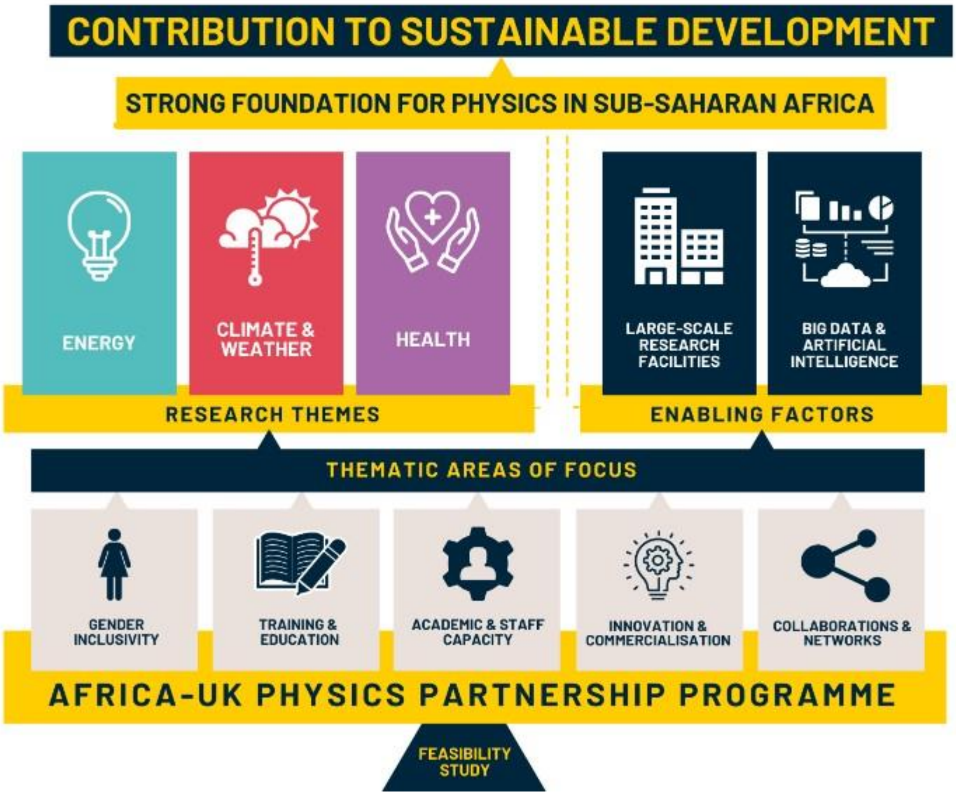

Figure 1: Approach of the feasibility study and prospective Programme

Physics communities in the UK and across all nine SSA partner countries (Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Tanzania and Uganda) were consulted throughout study in order to determine the current level of capacity, challenges and opportunities for physics in SSA. The details of Programme stakeholders and a full list of study participants can be found in Appendix 3.

Within the study, capacity was specifically appraised using the following dimensions:

- Availability and qualifications of academic and research staff
- Quality of the physics training and education pipeline
- Level of gender inclusivity
- Availability and quality of research infrastructure
- Strength of R&D and innovation platforms
- The presence and strength of collaborations and networks

This report presents findings, challenges and opportunities for each of these dimensions in order. The final section discusses the participation potential of partner countries and concludes with a summary of strategic interventions identified through the study.

1.2. Background

Thematic areas

To contextualise physics research within the external operating environment in partner countries, the following section provides key background information for each thematic area.

Energy

Energy is the most robust research theme, with strong existing capabilities in energy materials and renewable energy research and innovation. This area also has the highest number of researchers, postgraduate production, and research facilities, and produces the most reported innovation outputs. Africa is home to 55% of the world's potential renewable energy capacity, presenting an excellent opportunity for the field of energy research on the continent[1]. Strengthening this field will improve clean energy provision and promote industrialisation, education, health, and food security in SSA.

Climate and Weather

SSA's economy is still heavily dependent on agriculture, which is highly vulnerable to climate and weather variability[2]. Available methods of farming are predominantly low-tech, with low irrigated land and widespread dependencies on rain-fed agriculture. The continent is therefore profoundly affected by natural temperature, precipitation, sunlight, and extreme weather events[3]. To ensure food security, there is a need to build capacity and skills in climate and weather forecasting that is location-specific and widely available down to the level of farmers' crop fields.

According to the UNDP's study on disaster recovery in Africa, it is the only continent that has had its share of reported natural disasters in the world increase over the past decade[4]. However, early warning and disaster management systems remain underdeveloped across the continent. There is an urgent need to integrate climate and weather information into decision-making processes, early warning and disaster management systems.

Health

Medical physics in SSA suffers from low human capital development with departments overwhelmingly focused on training students for clinical work as opposed to research. As a result, levels of research and development in medical physics have remained low. There is a need to strengthen capacity and support an African medical physics community, which engages in both clinical work and research. Increasing the number of medical physicists can help address alarming trends in the prevalence of diseases, such as the global increase and burden of cancer[5] reported by the World Health Organization (WHO).

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[1] UKRI (Durham Univ, Engineering) - Developing performance-based design for foundation systems of WIND turbines in AFRICA (WindAfrica) and IEA - Africa Energy Outlook (World Energy Outlook special report) 2019 [IEA; 2019]

[2] IPCC – Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in territorial ecosystems [IPCC; 2019]

[3] Kotir, J.H. Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. (Environment, Development, and Sustainability 13, 587–605 (2011))

[4] UNDP – Baseline Study on Disaster Recovery in Africa: transitioning from relief to recovery [UNDP; 2019] and UNDRR- Global Assessment Report on Disaster Risk Reduction [UNDRR; 2019]

[5] WHO Report on Cancer: setting priorities, investing wisely and providing care for all [WHO; 2020]

Supporting interdisciplinary research teams between medical physics and biological sciences will not only produce more effective solutions to global health challenges, but also presents an opportunity to increase gender inclusivity in physics given higher numbers of female researchers in the biological sciences[6].

The world recently witnessed the contributions of biophysics techniques, such as cryo-electron microscopy (cryoEM), to enhancing our understanding of COVID-19 and potential strategies for treatment[7]. Developing capacity for biophysics research and innovation in SSA, as a matter of urgency, can equip communities with the skills and capital to develop guards against future biological disasters and develop solutions.

Big data and AI

Although big data and AI are in relatively nascent stages of development, they are critical tools for physics research and underpin much of the innovation and research within energy, climate and weather, and health. Among other examples, big data and AI are essential for big science at the Large Hadron Collider, synchrotron science, computational physics modelling, and the data-intensive requirements of the Square Kilometre Array (SKA) project, involving several SSA partner countries.

The 4th Industrial Revolution has rapidly increased demands to build competency in big data and AI across a spectrum of applications ranging from public health to climate science. As a result, various universities in South Africa (e.g. Witwatersrand[8], Stellenbosch[9], Pretoria[10], and Cape Town[11]) have introduced postgraduate degrees in Data Science at Honours and Masters' level. The Inter-University Institute for Data-Intensive Astronomy – a partnership between the Universities of Cape Town, the Western Cape and Pretoria – was recently established to cater for MeerKAT needs, preparing the university communities for the data challenges of the SKA. The African Institute of Mathematical Science (AIMS) has also launched the "African Master's in Machine Intelligence", an AI programme in Rwanda partnering with Google and Facebook[12]. These factors all present opportunities to build big data and AI capacities in physics and to forge multidisciplinary research between physics, engineering, statistics, and computer science.

Large-scale research facilities

There is a lack of engagement with international large-scale research facilities across the majority of SSA partner countries. However, previous studies suggest a strong positive correlation between international collaboration and citation impact[13]. There are ample opportunities to increase the engagement of partner countries with international large-scale research facilities, such as the proposal to establish remote access to large-scale research facilities such as the Diamond Light Source, activities around the African Light Source, and the move towards the establishment of multilateral intra-Africa cooperation agreements by South Africa's National Research Foundation (NRF), among others.

[6] UIS (UNESCO) - Women in Science (Fact Sheet, 55) (June 2019)

[7] COVID-19: How physics is helping the fight against the pandemic – Physics World (19/3/20)

[8] University of the Witwatersrand - BSc Big Data Analytics

[9] Stellenbosch – School for Data Science and Computational Thinking

[10] Pretoria – MIT in Big Data Science

[11] University of Cape Town – Masters programmes in Data Science

[12] AIMS (African Institute of Mathematical Science) and Matekenya, D. et al, Preparing Africa's next generation for leadership in digital data and innovation (WB blog (11/5/20))

[13] Blom, A. et al - Sub-Saharan African Science Technology, Engineering and Mathematics Research: a Decade of Development [World Bank; 2016]

1.3. Key study outcome: Theory of Change

During the study, a Programme Theory of Change was co-produced with stakeholders. The outcome is shown below as Figure 2, and inputs into the Theory of Change are attached to this report as Supporting Document A.

The inception phase of the Programme would encompass consultations with a range of key stakeholders across the UK and SSA partner countries to determine implementation strategies and intermediate outcomes and generate buy-in for the African-led Programme approach.

In the implementation phase, funding, support and technical assistance would be provided to multi-level stakeholders with a view to enhancing school-based education, university-level education, research, industry collaborations, national frameworks and global frameworks for the physical sciences. By promoting human and infrastructural capital, and equipping SSA partners to fully engage with international research, the implementation phase would aim to establish a solid foundation for the Africa-led physics community to meet local demands for science, technology and innovation and contribute to sustainable development.

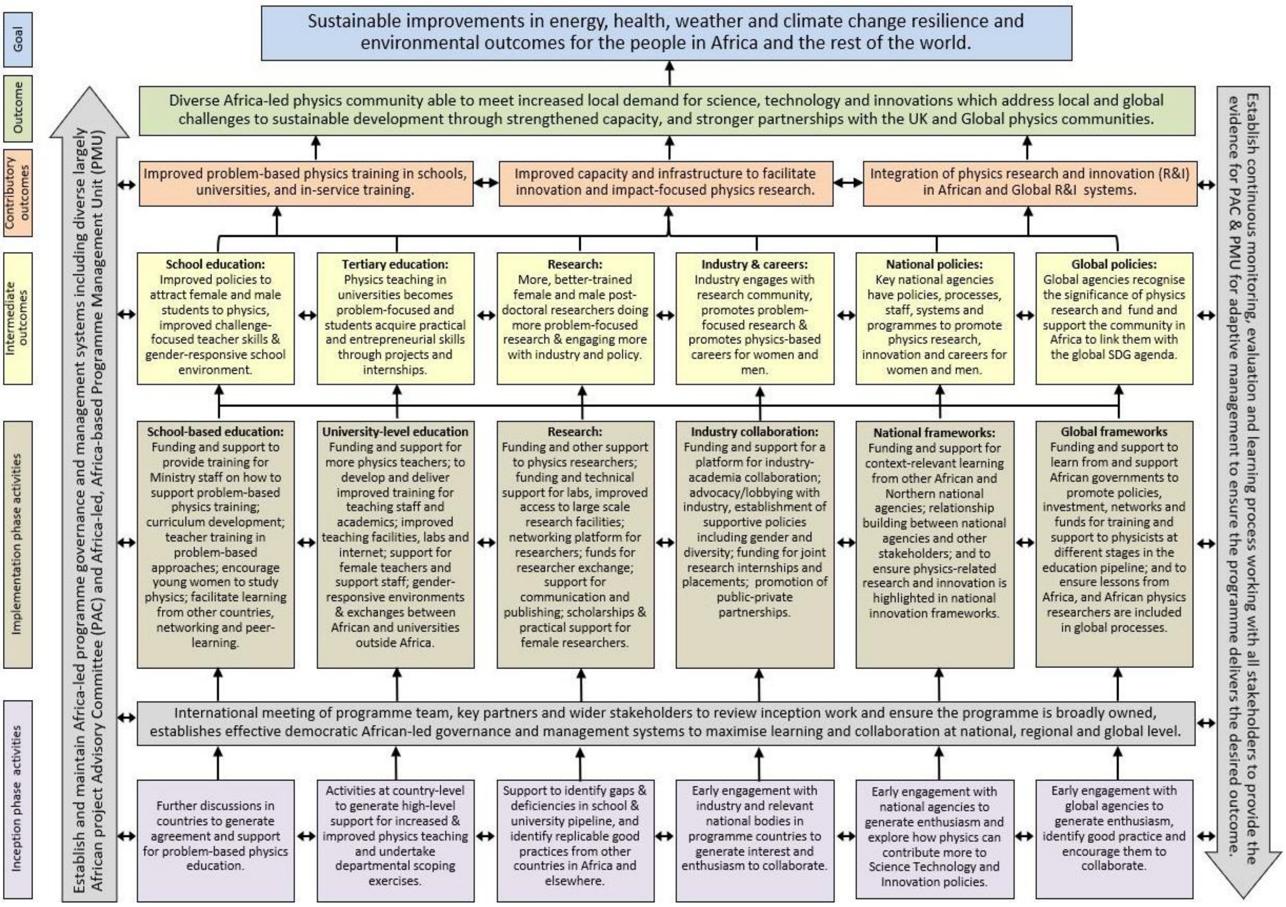


Figure 2: Theory of Change for the proposed Africa-UK Physics Partnership Programme

2. Research methodology

The ACU and IOP worked with the University of the Witwatersrand (South Africa) to identify the consultant Brian Masara (CEO of the South African Institute of Physics (SAIP)) to conduct the study on their behalf.

This feasibility study used a mixed methods concurrent triangulation research approach that combined quantitative and qualitative data. Quantitative data was obtained from online surveys and bibliometric analysis of partner country co-authorship with international large-scale research facilities. Qualitative data was obtained from focus group meetings of physics experts and one-to-one expert interviews with selected physicists from the project partner countries. Validation of the draft report was achieved through peer review by a group of experts. Figure 3 below shows the research method used in the study.

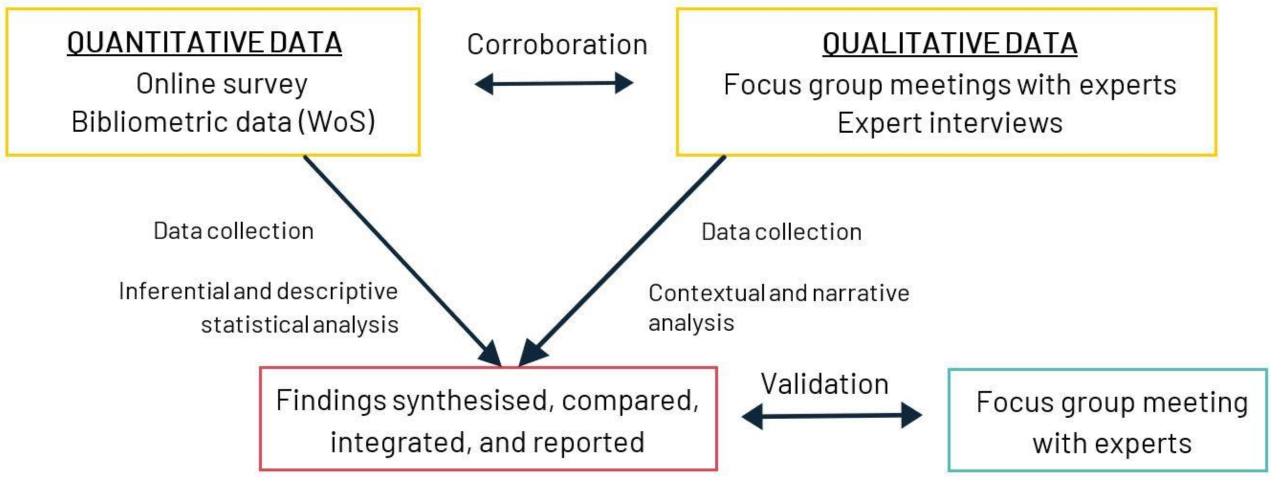


Figure 3: Research method used in the study

The reference group was assembled by selecting physics experts with skills in critical areas such as energy, medical physics, biophysics, climate and weather, big data, AI, gender inclusivity, physics education and large-scale research facilities. All the project partner countries provided experts.

2.1. Survey design

Two questionnaires targeted at universities and research facilities were designed. The questionnaire design was informed by the previous Marine Plastics Research Capacity Audit commissioned by BEIS in 2019 and by the physics expert group.

The survey instrument comprised the following sections:

Section 1: Institutional Demographic Information
Section 2: Human Capital and Skills Available
Section 3: Human Capital Development and Physics Education Pipeline
Section 4: Research and Innovation Infrastructure
Section 5: Research Development and Innovation Outputs
Section 6: Research Collaborations, Partnerships and Networks
Section 7: Africa-UK Physics Partnership Programme Participation Potential

2.2. Data collection and analysis

The survey population consisted of physics-related academic institutions, research facilities and physicists working in the Africa-UK Physics Partnership Programme countries. The sample was selected through the ACU, the IOP and the SAIP contact databases for the partner countries.

A total of 24 physics experts from nine countries were interviewed, including representatives from UK research councils. The most significant amount of data was gathered through survey responses from 50 universities and seven research facilities. Figure 4 below shows the geographical distribution of universities surveyed and experts interviewed.

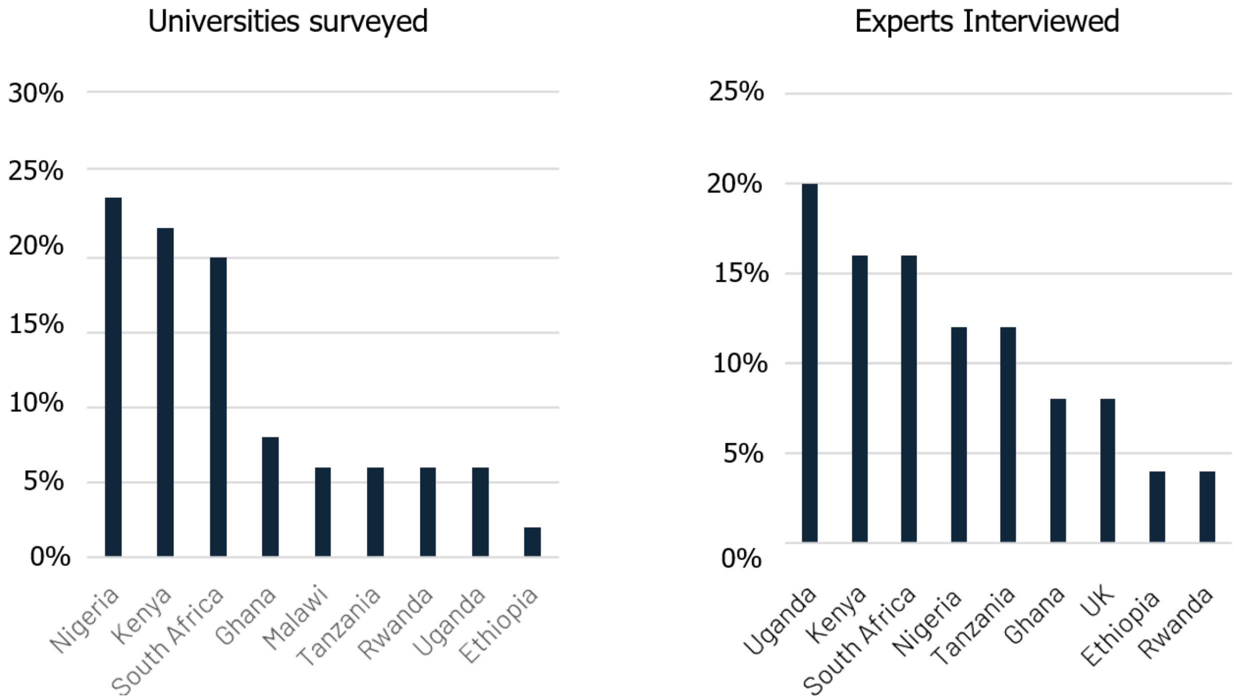


Figure 4: Geographical distribution of study participants

The study was conducted during the COVID-19 pandemic when many university campuses were closed, and travel was not possible. The face-to-face workshops originally planned were therefore moved online and all data was collected virtually.

Quantitative data collection was done via online questionnaires. The survey was open for responses between 16th April and 31st May 2020. The questionnaire links were sent via email to over 100 survey targets, with a follow up email sent two weeks before the survey closed and with personalised follow ups to ACU member universities. Responses were received from 50 organisations, with a response rate of 48%. The survey data was analysed using Statistical Package for the Social Sciences (SPSS) Software. Both descriptive and inferential statistics were used to present results and interpret quantitative data.

Qualitative data was collected through two methods, namely, focus group meetings and one-to-one interviews with subject matter experts from the UK and the Africa-UK Physics Partnership Programme countries. Two consultations were used to develop the survey design and to understand the state, challenges and opportunities for the various areas of interest that include the thematic areas, gender inclusivity, physics education and large-scale research facilities.

The findings of the online survey were followed up through a series of 24 one-to-one interviews with physics experts between 1st – 12th June 2020. Qualitative data was analysed using contextual and narrative analysis, manual analysis and RESOOMER software was utilised.

2.3. Validity and reliability

The questionnaire was informed by two consultations. The first expert group meeting constituted nine thematic area experts from South Africa and the second expert group meeting was made up of 14 experts from east and west Africa. The experts gave inputs on questionnaire design, questionnaire coverage of physics-related capacity development metrics, constructs clarity, and ease of completion of the questionnaire. After these meetings, a second version of the questionnaire was developed, circulated to the experts for inputs and then a pilot survey was created to test and improve the questionnaire before the final version was circulated.

A third focus group meeting was held at which experts from across all the project partner countries came into one meeting to discuss the draft feasibility report. The third focus group meeting aimed to ascertain if the feasibility study had managed to capture the real state of affairs, opportunities and challenges faced by the physics community. The meeting supported the validity of the feasibility report as a true reflection of the status of physics in the SSA partner countries and concurred with suggested recommendations.

A final workshop was held with 29 representatives from partner countries and the UK to develop the Theory of Change, informed by the results of the study. This was facilitated by INASP. Full lists of focus group and workshop participants can be found in Supporting Document A.

Reliability was evaluated in SPSS using Cronbach's alpha. The minimum acceptable value of reliability of 0.7 was satisfied. The entire 96 variable measurement scale has a Cronbach's alpha value of 0.944, which shows a high internal consistency and reliability of the measurement instrument used in the survey.

3. Study findings: available capacity, challenges, and opportunities

3.1. Prevalence of programmes by research theme

The study assessed the availability of training and research programmes across 50 universities for each of the key research themes.

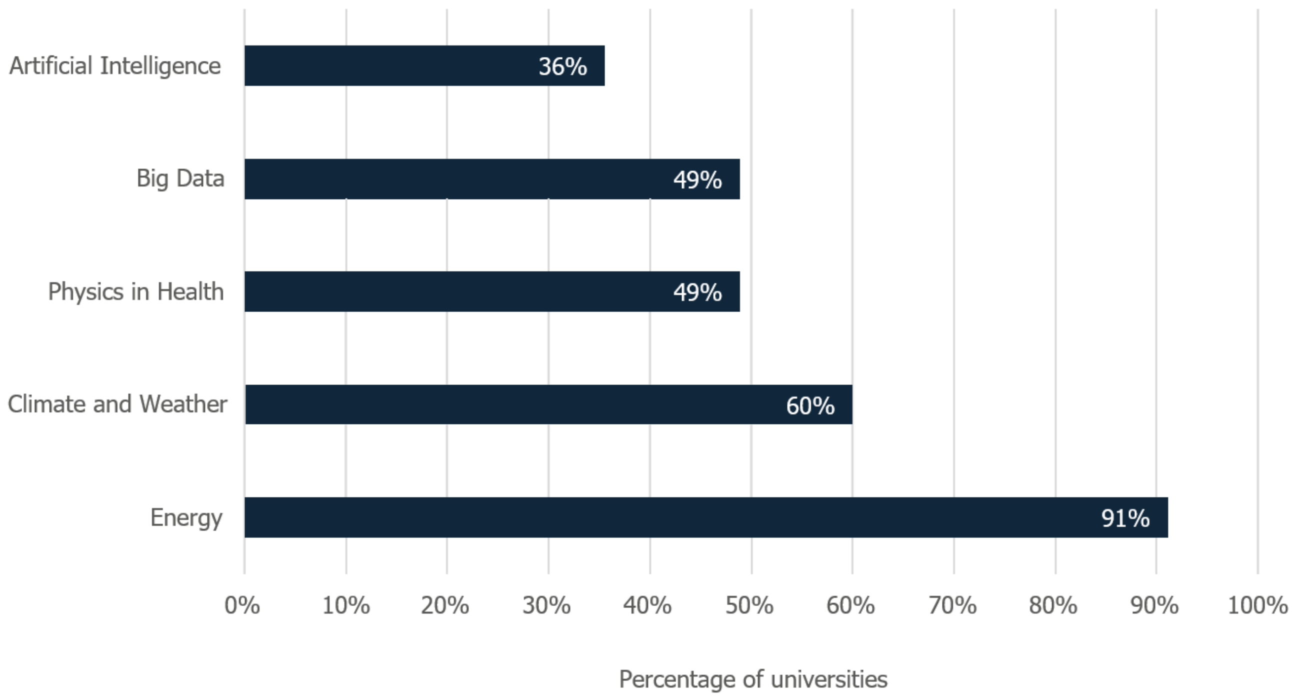


Figure 5: Percentage of surveyed universities with programmes available for research themes

Of the universities that took part in the study, 91% have research programmes associated with energy, mainly in energy materials (condensed matter physics and nanotechnology) for applications such as photovoltaic solar cells, solar thermal, radiative cooling, or selective absorbers. Energy research is multidisciplinary between physics, mechanical engineering, electrical engineering, chemistry, biotechnology, and chemical engineering.

Climate and weather programmes are the second most prevalent, with 60% of the universities indicating offering relevant programmes. While energy research, medical physics and atmospheric physics are mainly taught in the physics departments, climate and weather typically belong to a separate institute or department outside of physics.

Under health physics, medical physics departments are mainly attached to university academic hospitals and separate from the central physics departments. Physicists in biophysics and structural biology usually have strong links with biology and life sciences departments.

Big data and AI are the least developed research themes across all partner countries, with universities offering 49% and 36% of their programmes in these areas respectively. While energy, medical physics and atmospheric physics usually have course modules taught at the undergraduate level, big data and AI are generally used as tools for physics research at postgraduate level.

3.2. Academic and research human capital

3.2.1. Staff availability

The available academic and research human capital was determined through an assessment of staff numbers, qualifications, gender and experience.

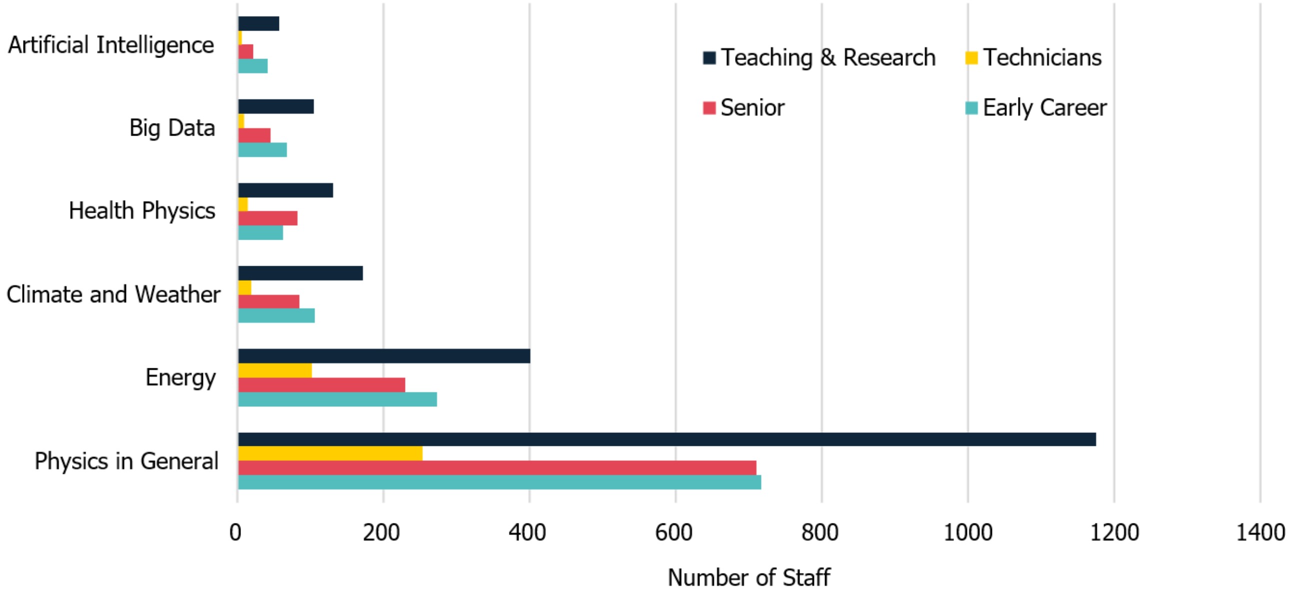


Figure 6: Total number staff available in surveyed universities per research theme

In terms of staff numbers per research theme, energy has the highest number of researchers and academics, followed by climate and weather, with the smallest number in big data and AI. It is significant to note that big data and AI have higher ratios of early-career staff, at 55% and 66%, respectively. The presence of a large percentage of early-career staff highlights potential for growth.

i. Gender distribution

The ratio of female to male staff members is low across all employment levels and research themes, with an average of 20% female and 80% male.

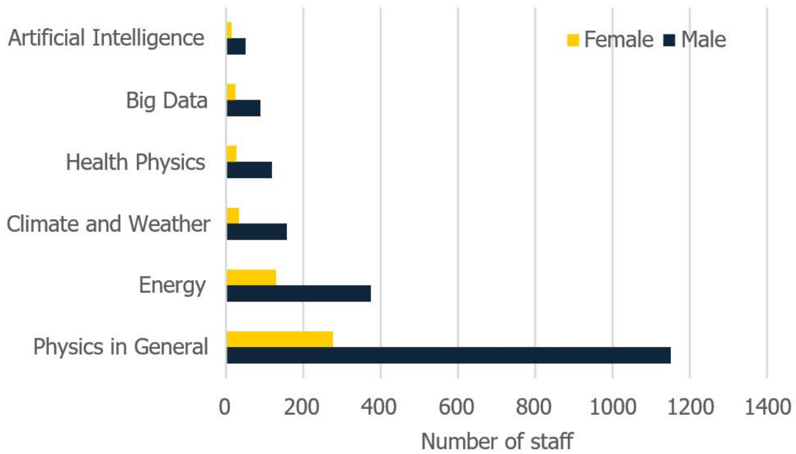


Figure 7A: Number of staff by gender

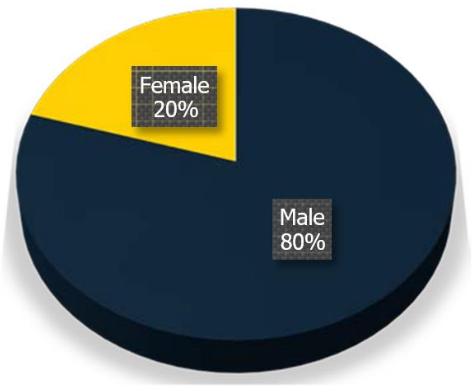


Figure 7B: Ratio of staff by gender

ii. Staff qualifications

Figure 8 below shows the distribution of academic and research staff available by highest qualification amongst survey respondents. Figure 9 breaks down the proportion of female and male staff who hold a PhD.

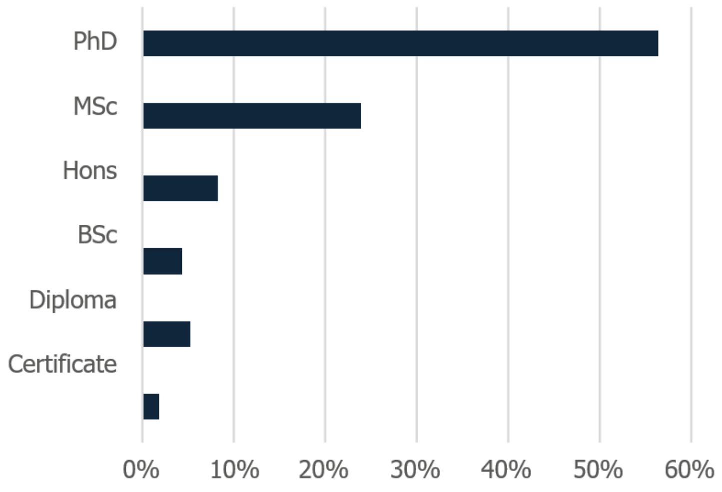


Figure 8: Academic and research staff by highest qualification

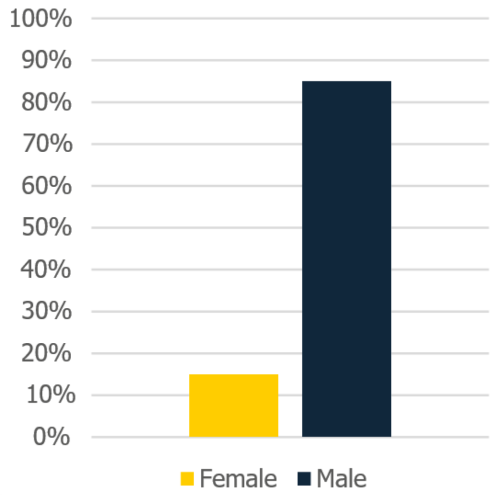


Figure 9: PhD holders by gender

In summary, it was found that:

- Technicians' qualifications start at certificate up to a PhD degree, teaching and research staff qualifications start at BSc up to PhD (BSc are teaching assistants doing postgraduate degrees or lecturing in non-degree programmes);
- 56% of lecturers and researchers hold a PhD;
- 85% of PhD holders are male, and 15% of PhD holders are female;
- 75% of universities have staff development programmes. Such programmes include benefits such as yearly continuous professional development courses, paid sabbatical leave, funding to attend conferences, school fees waiver, paid study leave and scholarships.

3.2.2. Reported challenges

i. High workloads

Study participants highlighted work overload as their main challenge. Lecturer to student ratios are remarkably high, leaving lecturers with little to no time for research. Similar observations were made in the SAIP Review of Physics Training in South Africa[14]. This is linked to the fact that most government- funded universities do not have separate research positions. Even though research is expected, a lecturer's primary role is still seen as teaching and any research work must be done in their spare time.

Work overload and insufficient time for research appears to be a common complaint from the community, and universities must employ more academic staff to relieve the burden and create more time for research.

[14] SAIP; CHE - Review of SA Physics Training [2017]

ii. Insufficient support for staff development

The second challenge the community highlighted relates to staff development. 44% of research and teaching staff do not hold a PhD, barring lecturers from teaching at a higher level where a PhD is required. Several comments made regarding skills development of staff are given below:

"Our challenge is related to [human capital], in our Department of Physics we are short in terms of PhD holders; hence we cannot offer postgraduate programmes in physics."

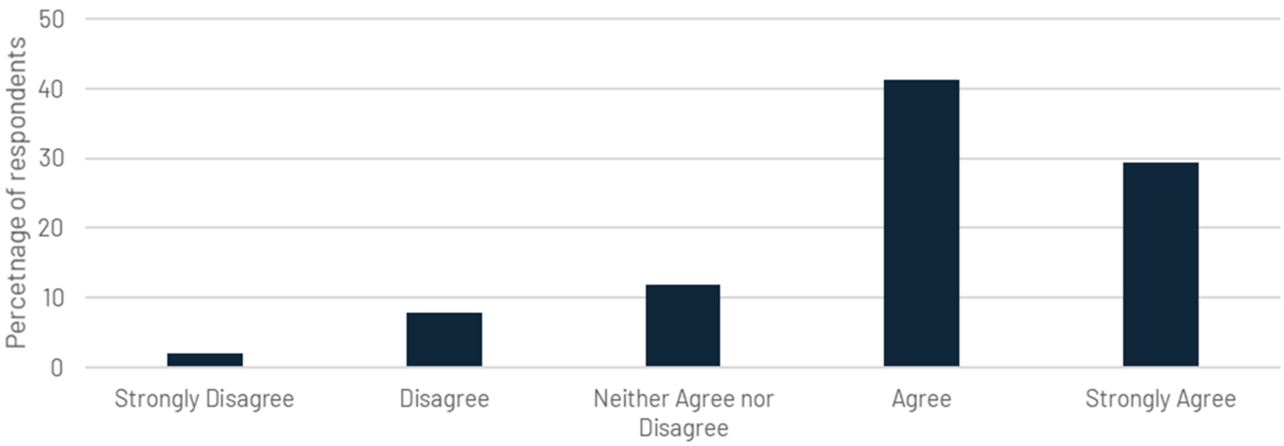
Dr Festo Kiragga (Gulu University, Uganda)

"Exchange programmes for early-career staff are inadequate. We need a healthier mentorship environment, especially for younger researchers. It should not be limited to just the university one is based in but other universities and in other countries and continents through collaboration and mentorship."

Dr Akyana Britwum (Kwame Nkrumah University of Science and Technology, Ghana)

iii. Shortage of skilled technicians

Another issue identified by some respondents was the shortage of skilled technicians to repair and service specialised research equipment. All respondents were asked to rate the extent to which they view this shortage as a major challenge, and results are shown in Figure 10 below.



Question: To what extent do you agree that technician shortages are a major challenge?

Figure 10: Extent to which respondents find technician shortages a major challenge

3.2.3. Opportunities to enhance academic and staff capacity and development

Based on the data and the common challenges identified by the community, the following opportunities to enhance academic and staff capacity and development have been identified:

- Engage governments on the need to have more academic staff, and to appoint research-only staff in universities;

- Implement a human capital development programme for partner countries which specifically targets physics (i.e. the National Research Foundation (NRF) Scarce Skills Postdoc15);
- Train more technicians to maintain research facilities;
- Implement programmes aimed at increasing the number of females working in physics;
- Implement staff-exchange and mentorship programme.

3.3. Physics training and education

Most participant universities indicated that physics students at the undergraduate level do not specialise in the research themes of energy, climate and weather, health, big data and AI, with specialisations starting at honours level up to PhD. However, some universities do offer medical physics BSc honours as a primary degree.

The BSc, honours and masters' programmes offered have various course modules in energy, atmospheric physics, medical physics, and data analysis. Meanwhile, big data and AI are mainly used as tools for research from honours level up to PhD.

3.3.1. Physics graduate outputs

The average collective annual physics graduate output across all partner countries over the last five years is shown in the graph below:

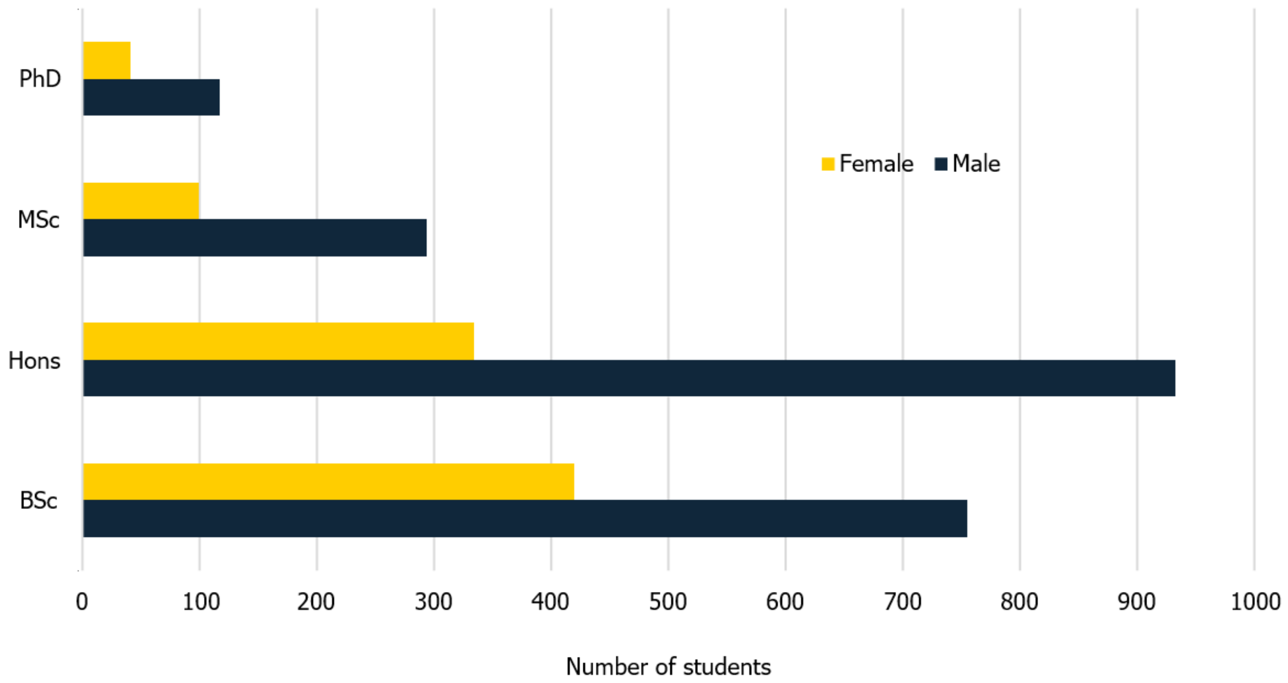


Figure 11: Average number of students graduating with physics and physics-related degrees in the last 5 years

It was observed that some universities do not offer BSc programmes and start at the honours degree level. Few females take up physics-related degrees starting at the BSc-level; for example, females make up only 36% of students studying BSc physics, a ratio which drops to 26% at the PhD level.

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[15] NRF (National Research Foundation) Freestanding Innovation and Scarce Skills Postdoctoral Fellowships 2021 Framework

Additionally, some institutions do not offer MSc and PhD programmes and are teaching universities only. For example, although Uganda has 11 public universities and 29 private universities[16], only Makerere University offers PhDs in physics. There are also other universities which only teach physics as a service course to engineering and technology programmes.

The SAIP Review of Physics Training in South Africa found similar challenges and identified a need to introduce degree programmes such as physics and nuclear engineering, physics and electronics, physics and computer science and related topics in order to attract more students to physics.

For poorly resourced universities and those without capabilities that wish to offer postgraduate courses, shared online teaching and learning platforms can offer possible support. The World Economic Forum (WEF) has indicated that remote learning would be prominent beyond 2020 due to COVID-19[17], this can provide opportunities to engage African students in courses that will be held at UK universities, especially at postgraduate level. This type of shared online teaching has already been observed elsewhere, such as the online data science postgraduate course in Jordan organised by UKRI-Science and Technology Facilities Council (STFC). South Africa has also proposed to develop a physics online teaching and learning platform during a review of physics training in the country.

3.3.2. Physics graduate outputs per research theme

The study found that the research theme of energy has the highest share of physics students per year at 55%, followed by climate and weather at 25%. Once again, these findings confirm that energy research is relatively well-developed across SSA universities. In contrast, big data and AI have the smallest share of students at 6% and 4%, respectively.

Figure 12 below breaks down the percentage share of graduate outputs by research theme:

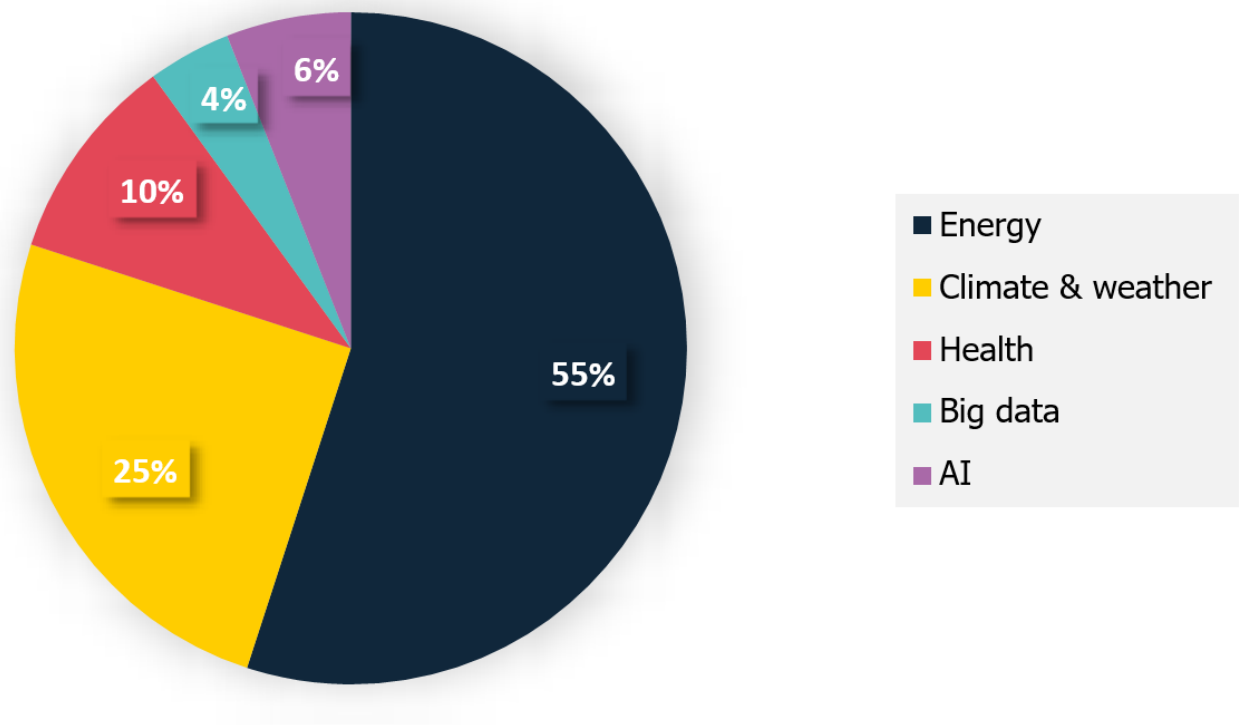

Figure 12: Graduate output percentage share per research theme

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16 Uganda. Ministry of Education and Sports – Higher Education

17 World Economic Forum, How COVID-19 is driving a long-overdue revolution in education (12 May 2020)

Similar trends were observed in the number of postdoctoral positions available, with some departments indicating that they do not have enough funding to support postdoctoral fellows. It is worth noting that the study found no recorded female postdocs for big data and AI.

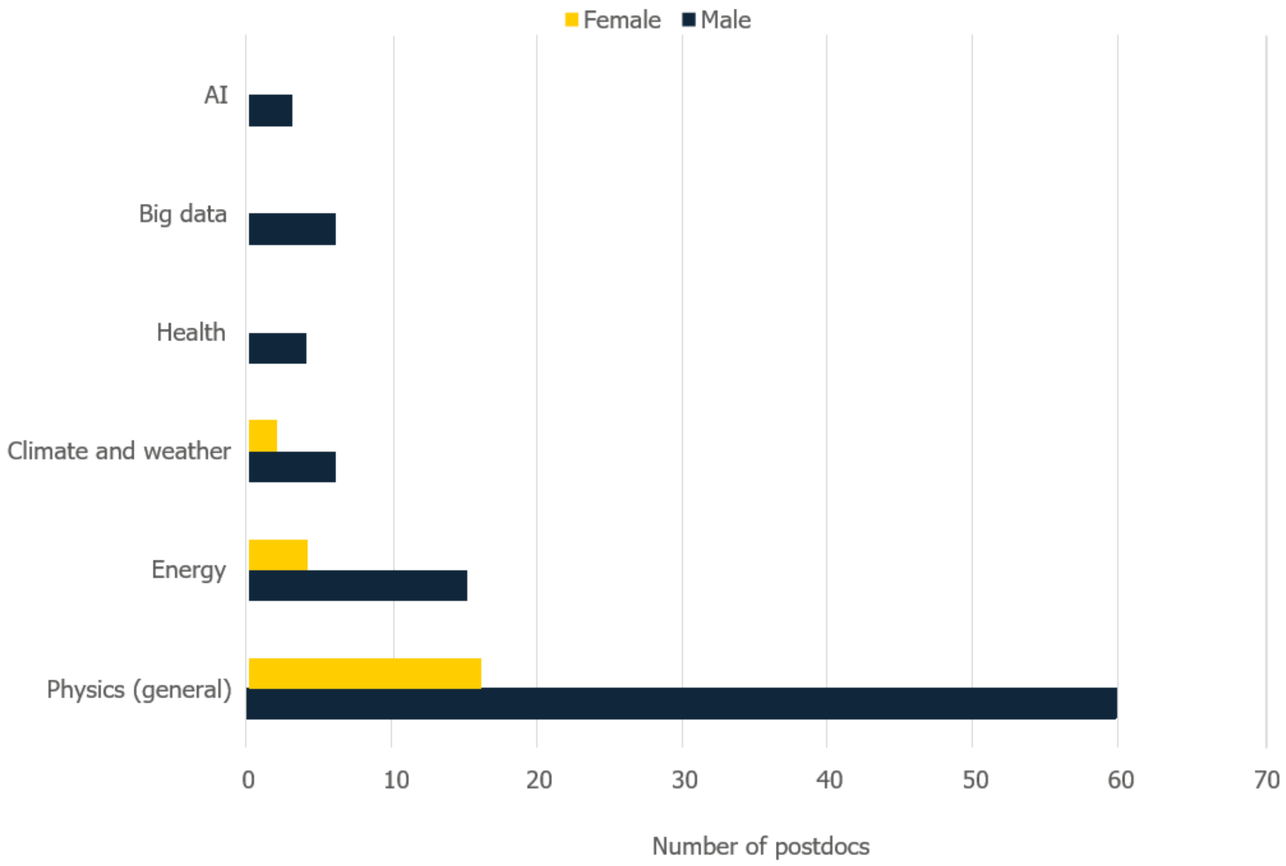

Figure 13: Postdoc positions by research theme and gender

3.3.3. Reported challenges

i. Attracting and retaining students in physics

Of the survey respondents, 86% indicated that they face challenges in attracting and retaining students in physics compared to other science programmes. The same proportion of respondents also agreed that the main problem relates to the perception of poor career prospects for physics graduates. There is a common assumption that students completing their first degree in physics primarily go on to become teachers, while those with postgraduate degrees can become lecturers or researchers.

Other issues negatively affecting the physics education pipeline include a lack of understanding of the value of staying in academia, and low levels of encouragement for students to pursue continued physics education. Figure 14 on the following page shows the percentage of respondents rating each individual challenge as significant and relevant.

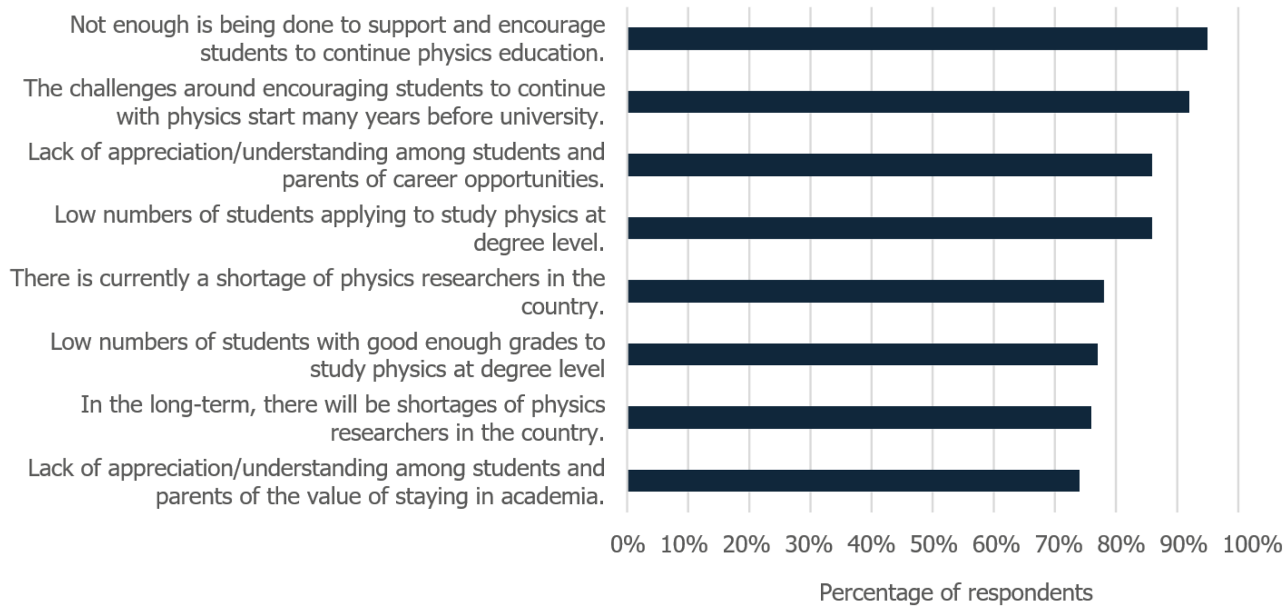

Figure 14: Proportion of respondents agreeing with each challenge

Commenting on his own experience with the education pipeline, Dr Tilahun Tesfaye (Addis Ababa University, Ethiopia) shared his perspective on challenges and possible solutions:

> *"Once we had around 800 first years coming into the faculty of science, but only an average of 5 students was coming to physics. We then researched and found that if 100 students are joining physics at high school, practically less than 1% go to physics. To try and address this problem, we changed the physics curriculum. We introduced minor topical subjects along with physics, then the number of students choosing physics increased eight-fold. We learned that if you are designing physics BSc programmes, you must address the needs of students, career prospects and the industry…however, the problem is back because the country decided to harmonise all degrees in the country."*

Difficulties attracting and retaining students continue at postgraduate level. Most undergraduates do not go on to pursue postgraduate degrees. The main reason cited is a lack of funding; while undergraduate students often receive government scholarships, at postgraduate level most students cover their own tuition fees or depend on bursaries and scholarships. Professor Mmanstae Diale (University of Pretoria, South Africa) suggests that postgraduate numbers can be increased with adequate funding, describing the problem as follows:

> *"In terms of postgraduate training - students can be easily retained if they are given a good stipend, the student must be kind of employed by the university or research centre. Understand that Africa faces the problem of "Black Tax", soon after the first degree you are expected to look after your family and siblings, in Africa parents do not budget for sending children for postgraduate studies, only first degree…."*

ii. Incoming undergraduates

A total of 96% of respondents agreed that the problem of attracting students into physics starts many years before university, and to improve the situation early interventions must be developed at the school level. This will be significant as problems at the school level affect not only the numbers of students going into physics, but also the quality of incoming undergraduates. 86% of respondents concur that incoming students have a greater interest in learning physics concepts for an exam rather than learning to understand, to solve problems, or to apply physics in real life. For example, Professor Omololu Akin- Ojo (University of Rwanda) mentioned that even though his students could memorise formulas and laws of physics, they cannot use that information to solve problems.

Figure 15 below shows the percentage of respondents rating each individual challenge as significant and relevant.

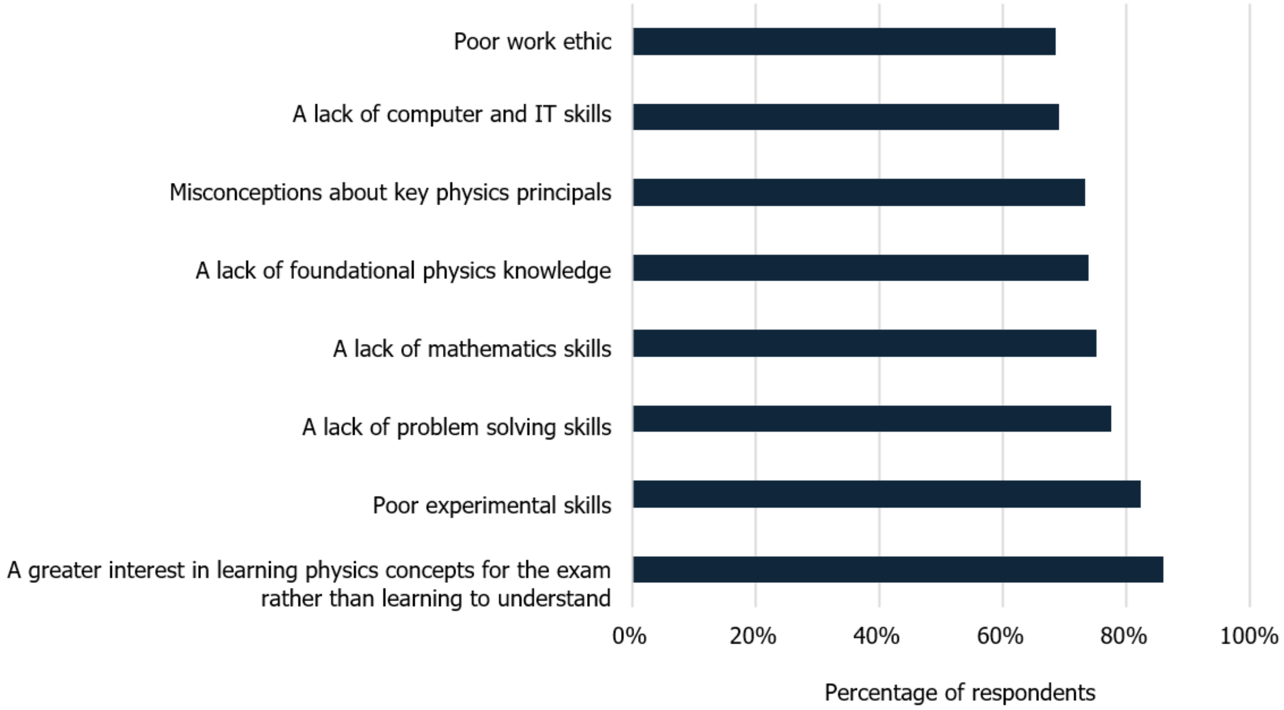

Figure 15: Proportion of respondents agreeing with each challenge

Additionally, a lack of experimental skills among incoming undergraduates was identified as a significant concern, with 82% agreeing this presents a major challenge. Dr Tilahun Tesfaye (Addis Ababa University, Ethiopia) puts this problem into perspective:

> *"Although the Ethiopian curriculum states that 30% should be on hands-on experiments, experimental physics is dead in some schools. We once did a teacher training workshop where we found that more than 50% of physics teachers had never done an experiment, not even a simple pendulum; hence they have no confidence at all to teach physics experiments…."*

Similar challenges around the lack of competency and confidence in doing physics experiments were also observed in the SAIP physics teacher development programme in South Africa. Due to the shortage of physics teachers, some of the teachers engaged in physics teaching are not suitably qualified to teach the subject.

3.3.4. Opportunities to enhance the physics education pipeline

The institutions that participated in the study are currently conducting several interventions at various levels to improve the physics education pipeline. Figure 16 below overviews the current types of interventions and the percentage of surveyed universities participating in them.

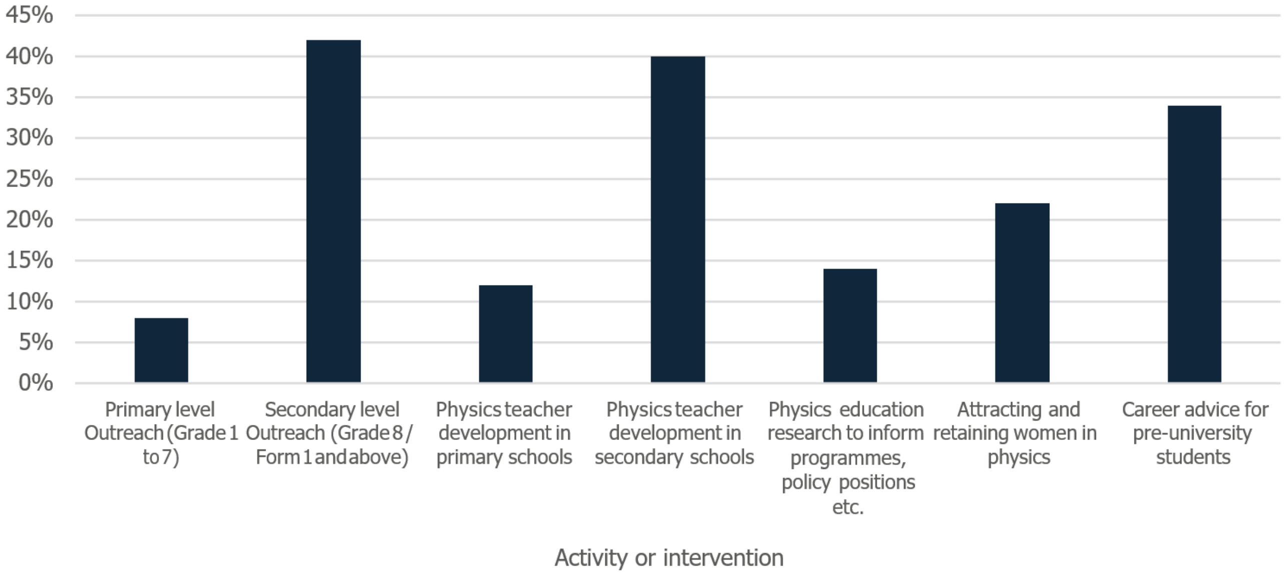

Figure 16: Percentage of surveyed universities involved in activities to support the physics education pipeline

Universities are largely using their own resources to fund these interventions. However, respondents also gave several examples of support for activities from NGOs and external bodies such as the World Bank, Government Science Departments and national physical societies such as the Nigerian Institute of Physics.

Primary school physics outreach and teacher development interventions are low at 8% and 12% respectively. More institutions are involved in outreach and teacher development projects at secondary school, which sit at 42% and 40% respectively. A significant concern is that only 14% of universities are involved in physics education research. This finding also corresponds to the SAIP Review of Physics Training in South Africa, which observed that physics departments do not support physics education research.

In addition to suggestions already made, several other recommendations have been put forward to address the education pipeline. These include but are not limited to:

- Develop structured outreach programmes in high schools to better their understanding of and interest in physics and demonstrate distinct career paths for physicists;
- Create platforms where career trajectories for physics graduates are showcased;
- Invite students to research facilities and physics departments to show exciting research and encourage students to continue studying physics;
- Implement physics teacher development programmes and begin interventions at the primary school level;
- Train students in application-oriented and problem-solving transferable skills at all levels, for example beginning in primary schools with activities such as "lego" building;

- Raise public awareness of the socio-economic impact of physics and encourage questions from the general population.

3.4. Research infrastructure

The study evaluated available research infrastructure in terms of access to large-scale research facilities, research labs and equipment, innovation support systems and Centres of Excellence (CoEs).

3.4.1. Large-scale research facilities

All surveyed institutions indicated having several reasons to access large-scale research facilities. Figure 17 below shows the proportion of respondents agreeing with each reason.

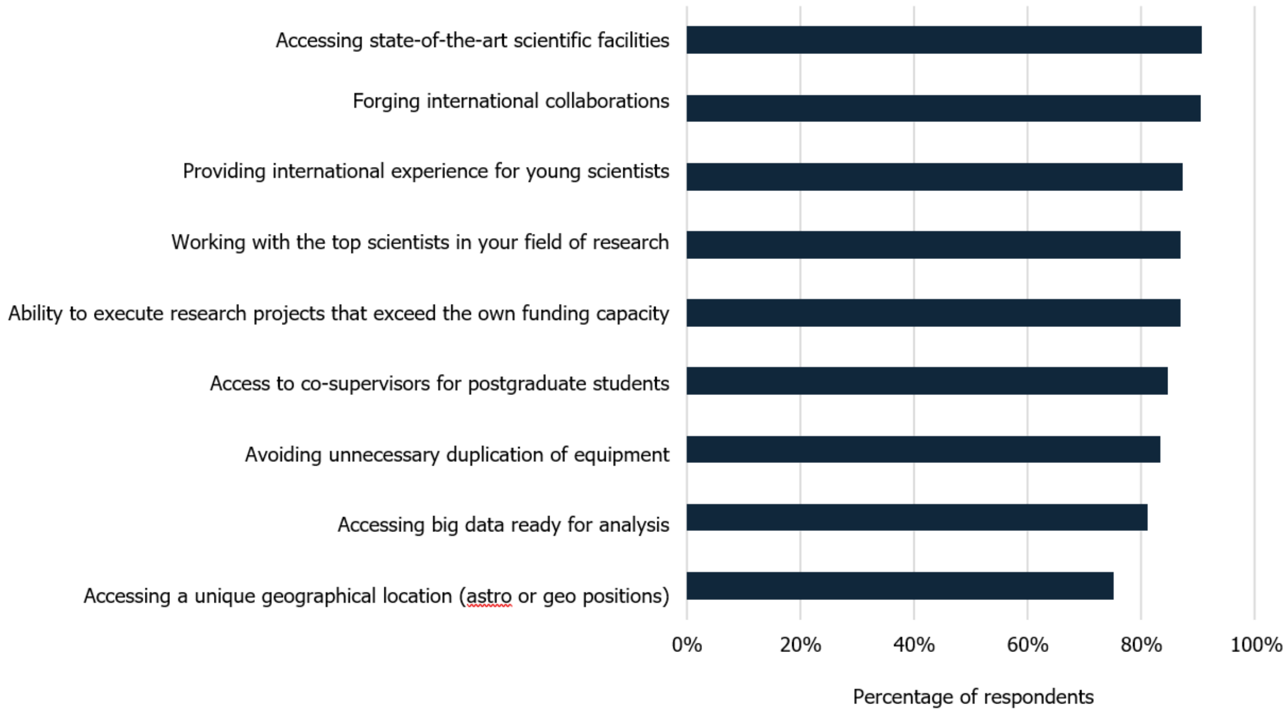

Figure 17: Proportion of respondents agreeing with each reason

Of the institutions surveyed, 91% indicated that their interest is in accessing the state-of-the-art equipment and forging international collaborations. 87% would like to collaborate with large-scale research facilities to provide young scientists with international experience, to work with leading scientists in their field of research, and to run experiments requiring expensive equipment that is not available at their own institution. Access to large-scale research facilities also creates opportunities to identify co-supervisors for postgraduate students.

In addition to training and human capital development, large-scale research facilities contribute to innovation and technology transfer. An example of local and national facility innovation can be found in NECSA's spin-off company, NTP[18], which is now among the world's leading medical isotope producers. This example illustrates how physics research from SSA can contribute to solving global health challenges such as cancer.

[18] NTP Radioisotopes (& South African Nuclear Energy Corporation (NECSA)

i. Available facilities

The most significant large-scale research facility available on the African continent is the Square Kilometre Array (SKA), and several counties in the Africa-UK physics programme are also SKA partner countries. Certain African scientists also have access to large-scale research facilities; for example, 177 physicists are part of the South Africa-CERN[19] collaboration, which participates in seven big-science experiments. The SA-CERN activities include PhD training, hosting of postdocs and a physics teacher development programme for teachers from South Africa.

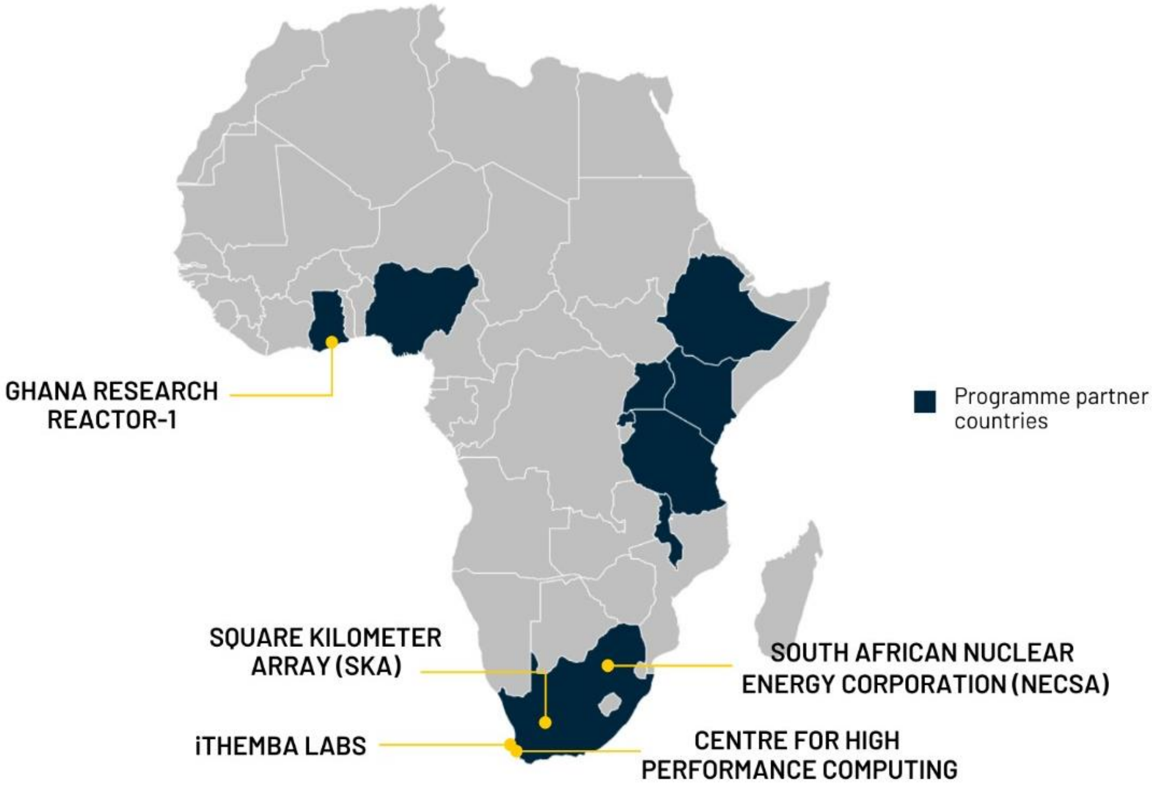

Figure 18: Large-scale research facilities cited by respondents

The major large-scale research facilities in SSA cited by study participants are shown in Figure 18 above.

Professor Simon Connell (University of Johannesburg, South Africa) provided an example of how technology transfer and innovation can emanate from African scientists accessing large-scale research facilities. He describes one of his scientific innovations from the South Africa-CERN collaboration:

> *"This technology transfer project builds on the technologies learned at CERN of novel sensors, high throughput electronics, big data, high-performance computing, quantitative imaging, artificial intelligence and digital twins to innovate new commercial applications in mining and medical environments. The technology can be deployed in several contexts, including Medicine, Security and Mining."*

[19] South African scientific collaboration with CERN

Participants in the study also indicated that they have ongoing projects in energy materials, astronomy, big data, high energy physics, medical physics and other areas which would greatly benefit from access to the following large-scale research facilities:

- CHPC - Centre for High-Performance Computing (cited by researchers in all research themes);
- Nuclear and High Energy Physics facilities in Ghana, Nigeria, South Africa and CERN;
- International climate and weather facilities;
- SKA for astronomy and big data research;
- iThemba Labs in South Africa for medical physics research;
- Synchrotron light sources such as Diamond in the UK and the ESRF in France.

ii. Future developments

The establishment of a National Solar Energy Research Facility is being planned in South Africa, and this facility would collaborate with existing renewable energy facilities such as South African Renewable Energy Technology Centre (SARETEC)[20], the Centre for Renewable and Sustainable Energy Studies (CRSES)[21], and the South African National Energy Development Institute (SANEDI)[22] among others. There is also a proposal to establish an Africa Meteorological, Climatological, Environmental Data Centre (AMCEDC) in Nigeria.

The development of the African Light Source Initiative[23], a large-scale continent-wide facility, is also currently under discussion. Africa is currently the only habitable continent without a light source, and the proposed initiative would link to all the five focus areas of the Africa-UK Physics Partnership Programme (energy, climate and weather, health and big data and AI, and large-scale research facilities). Health is a particularly strong area for light sources; there is existing research taking place on COVID-19 at light sources, as well as previous research focused on TB, HIV in biophysics and structural biology. Light sources have been regarded by many governments as an essential frontline service and have therefore been kept open during COVID-19 lockdowns as a key facility in the fight against the pandemic[24].

iii. Reported challenges and factors promoting access

The major challenge in accessing research facilities is the lack of funding and the lack of equipment to prepare samples for analysis. Figure 19 on the following page shows the proportion of respondents rating each challenge as significant and relevant.

[20] South African Renewable Energy Technology Centre

[21] Stellenbosch University -- Centre for Renewable and Sustainable Energy Studies (CRSES)

[22] South African National Energy Development Institute (SANEDI)

[23] African Light Source

[24] Connell, S. - The Coronavirus Synchrotrons and Cryo-EM to the rescue (African Lighthouse blog) (3/3/20))

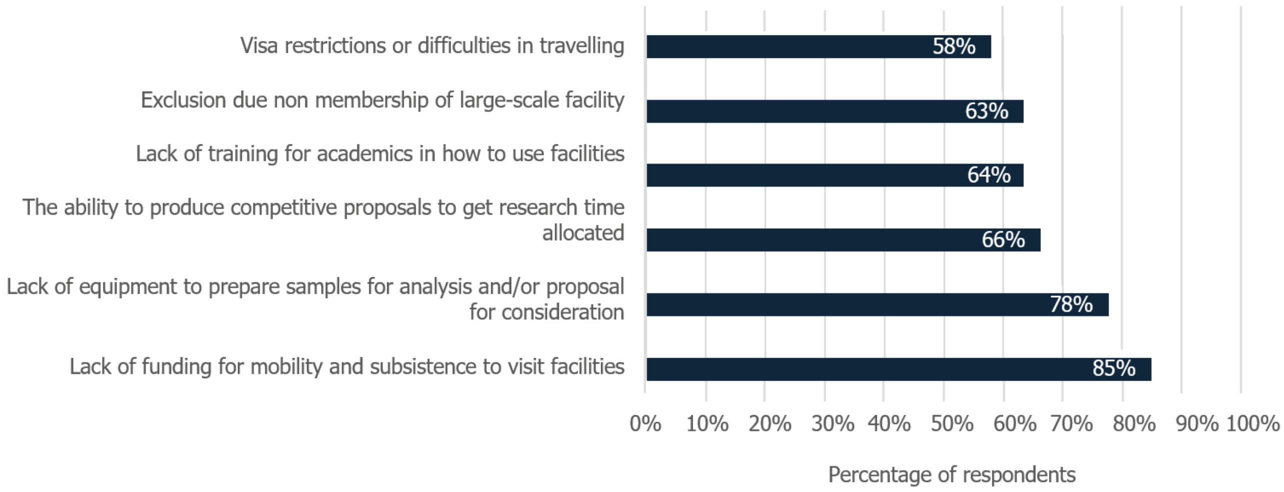

Figure 19: Proportion of respondents agreeing with each challenge

The top three factors promoting access to large-scale research facilities are exchange programmes for early career and postgraduate students, the availability of mobility grants, and competitive proposals. Figure 20 below shows the proportion of respondents agreeing that each factor would facilitate access to large-scale research facilities.

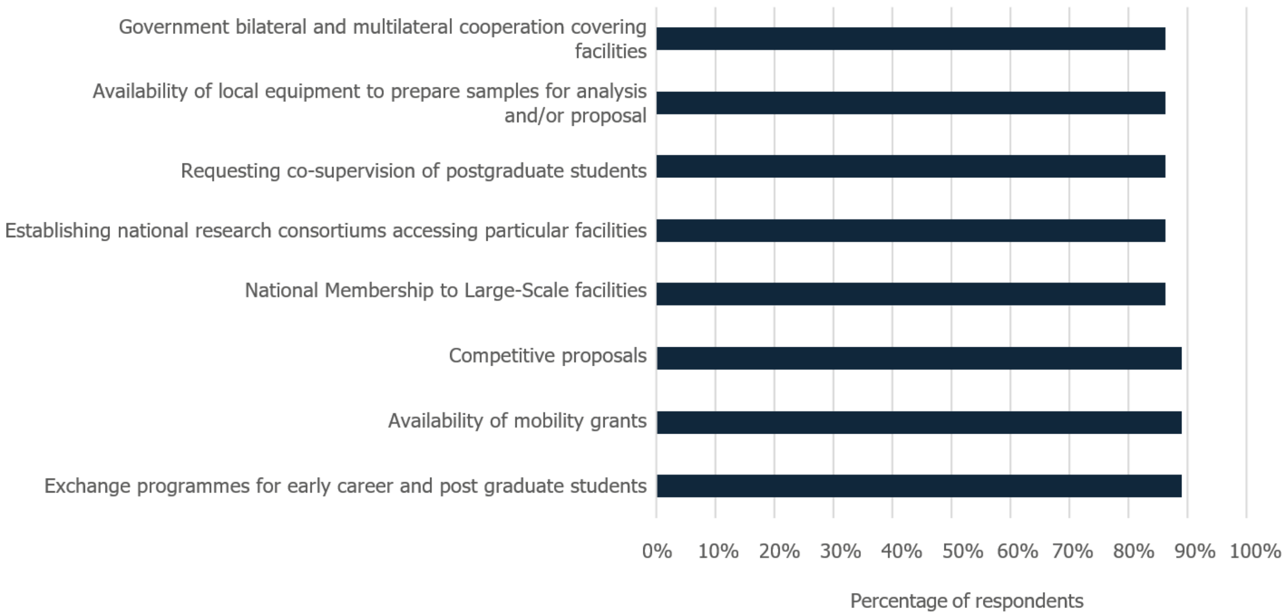

Figure 20: Proportion of respondents agreeing with each facilitating factor

3.4.2. Innovation support systems

Innovation and commercialisation support systems are not well developed across the partner countries. Only 54% of institutions surveyed offer training on innovation and the commercialisation of research, while 64% have offices that support R&D commercialisation.

Figure 21 shows the proportion of surveyed universities that currently have support systems or activities in place for R&D, innovation and commercialisation.

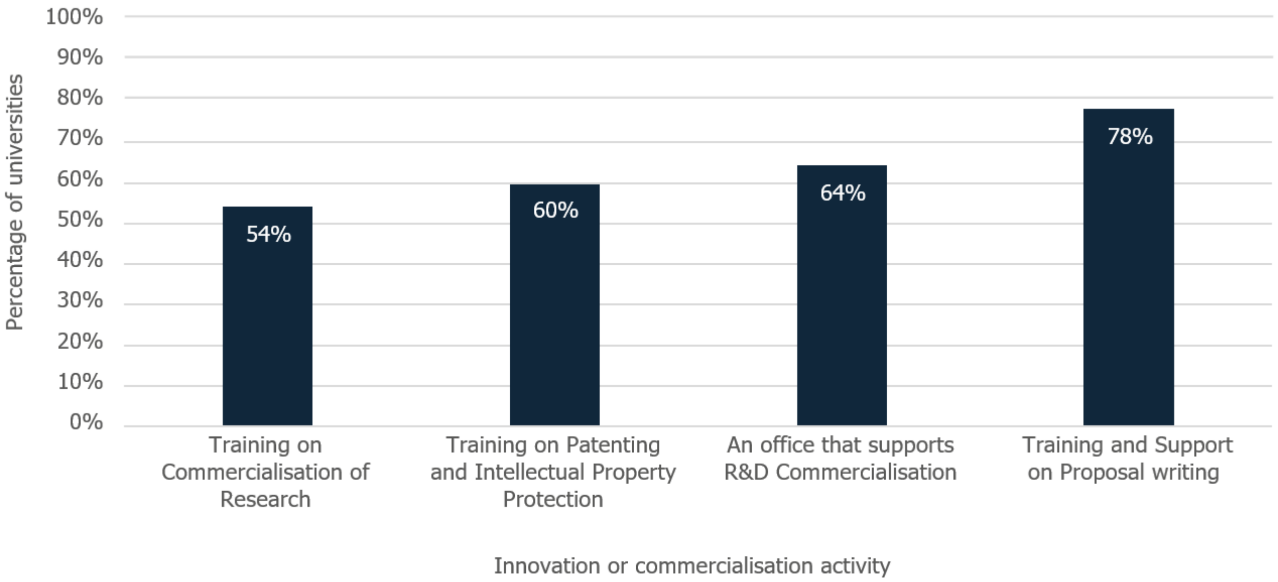

Figure 21: Proportion of surveyed universities with innovation and commercialisation activities or support systems

3.4.3. Physics research equipment

In most universities, local research infrastructure is mainly available for student training in labs reserved for undergraduate physics experiments. In some cases, universities have established CoEs and research chair laboratories in areas such as materials science, electron microscopy, energy, photonics and astronomy. An example of a high-end research facility is the Centre for High-Resolution Transmission Electron Microscopy (CHRTEM)[25] at Nelson Mandela University, South Africa. However, 80% of universities indicated that their lab equipment requires upgrading; only a small number of universities reported that their equipment is still in good condition.

i. Equipment availability by research theme

Within the research theme of energy, better infrastructure is available for solar energy, energy material synthesis and characterisation. There is also equipment for research in other forms of renewables such as biomass, wind and hydro. Equipment and national research facilities for nuclear energy, such as the Ghana Atomic Energy Agency and NECSA in South Africa, are also available. Hydrocarbon energy research equipment is available in Ghana, Nigeria and Tanzania.

The research theme of climate and weather is supported by a reasonable amount of equipment, and this mainly includes weather monitoring equipment, climate centres, and weather modelling computers and software. Some advanced equipment is also available, such as Light Detection and Ranging (LiDAR) lasers. Various national facilities are working in weather and space science, such as the South African National Space Agency, the Kenya Climate Innovation Centre, and the Centre for Atmospheric Research in Nigeria.

In the area of health, the main equipment available for medical physics includes nuclear accelerators, dosimetry measurement equipment, radiation diagnostic equipment, nuclear medicine equipment and imaging equipment. Available equipment is being used both for clinical treatment and research activities; medical physics departments are attached to medical universities where most of the training and work is focused on offering clinical services, especially for cancer treatment. Some large-scale research facilities such as iThemba Labs and NECSA in South Africa are also involved in medical physics.

[25] Nelson Mandela University - Centre for High-Resolution Transmission Electron Microscopy (CHRTEM)

Under biophysics, the leading facilities and equipment available are for microscopy and bio-photonics. The CSIR National Laser Centre and the UCT-Centre for Electron Microscopy work in biophysics and bio- photonics, respectively.

Big data and AI have the least amount of facilities reported, and these are mainly in the form of cluster, grip and high-performance computers in various institutions. The most advanced big data research centre in SSA is the Centre for High-Performance Computing[26] (CHPC) in Cape Town, South Africa. Other research facilities are also involved in big data, such as the SKA, the South African Radio Astronomy Observatory, the Africa Data Analytic Centre at iLabafrica[27] in Kenya, and the Centre for Quantum Technology[28] at the University of KwaZulu Natal in South Africa, among others.

ii. Reported challenges

The lack of funding is the main challenge reported in the management of research facilities. Other challenges cited include the lack of equipment, failure to access large-scale research facilities, shortage of technicians to service and repair equipment, and the shortage of research collaboration networks.

Figure 22 below indicates the proportion of respondents rating each challenge as significant and relevant.

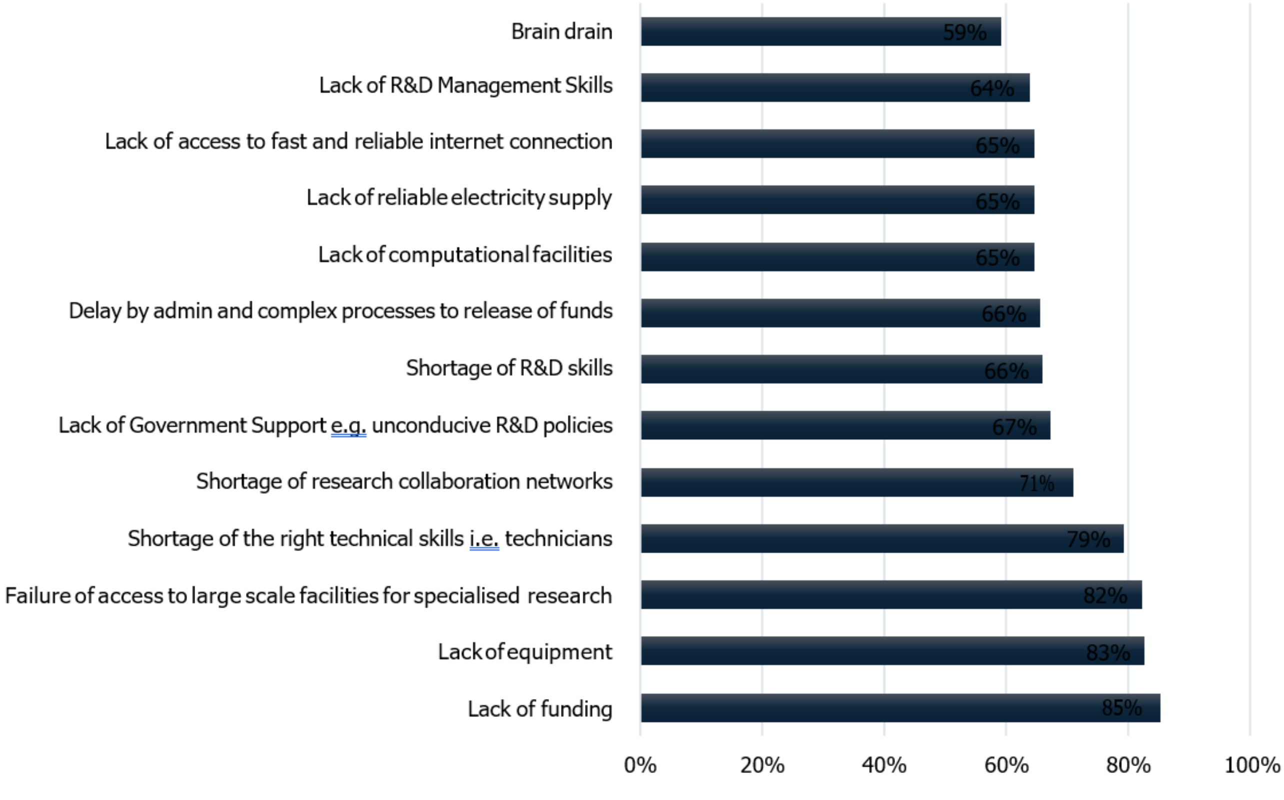

Figure 22: Proportion of respondents rating each challenge as significant and relevant

3.4.4. Centres of Excellence

Academic CoEs have emerged as one of the core components in research and development infrastructure. CoEs can be made up of a team, a shared facility or an entity that provides

[26] Centre for High-Performance Computing (CHPC)

[27] Africa Data Analytic Centre, iLabafrica

[28] University of KwaZulu Natal, Centre for Quantum Technology

leadership, best practices, research, support and training for a focus area[29]. The establishment of CoEs can bring many benefits, including: keeping international best practice in the field; contact and engagement with the international research community; identification of relevant research agendas; promotion of critical thinking in the focus area; enhanced capacity to train future generations of researchers; and stimulation of national innovation systems, among others[30].

The study found several CoEs in the field of energy in SSA. Some examples include the South African Renewable Energy Technology Centre (SARETEC)[31], the Centre for Renewable and Sustainable Energy Studies (CRSES)[32], University of Nigeria Nsukka Centre of Excellence for Sustainable Power and Energy Development[33], the Nelson Mandela Institute's Innovative Technology and Energy Centre[34] located in Tanzania. There are also CoEs dedicated to big data and AI, such as the Centres in Artificial Intelligence & Robotics and High-Performance Computing and Big Data Analytics[35] at the Addis Ababa Science and Technology University.

Some of these CoEs are collaborative in nature. For example, the African Research Universities Alliance (ARUA) Centre of Excellence in Materials, Energy and Nanotechnology (CoE-MEN)[36], hosted by the University of the Witwatersrand also includes the Universities of Pretoria, Ghana and Nairobi. The ARUA African Climate and Development Initiative (ACDI)[37] also has CoEs in three regional nodes in partner countries, located at the Universities of Cape Town, Ghana, and Nairobi.

In terms of opportunities, there is space to establish new CoEs for health or medical physics within the partner countries as only a few have been identified in the field of health, such as the ARUA CoE for Non- Communicable Diseases in the University of Nairobi and Kenya's African Population and Health Research Centre. Additionally, as most CoEs are country-focused, there is a need to establish CoEs that involve more than one country like those under ARUA.

3.4.5. Opportunities to improve research infrastructure

Following an assessment of the data and challenges found through the study, many opportunities have been identified to improve research infrastructure across all research themes:

Large-scale research facilities

- Increase access to large-scale research facilities for African partner countries through various forms of support, such as travel grants to existing research facilities;
- Improve the promotion of opportunities to access large-scale research facilities (i.e. the African Light Source initiative is well-established; light sources produce the greatest number of PhDs and cover all research themes);

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[29] World Bank. Higher Education

[30] Hellstrom, T. - Centres of Excellence and Capacity Building: from Strategy to Impact (Science and Public Policy 45: 4, August 2018) and Centres of Excellence as a Tool for Capacity Building: Synthesis Report [OECD; IHERD; 2013])

[31] South African Renewable Energy Technology Centre

[32] Stellenbosch University -- Centre for Renewable and Sustainable Energy Studies (CRSES)

[33] University of Nigeria, Nsukka – African Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED)

[34] Nelson Mandela African Institute of Science and Technology, Innovative Technology and Energy Centre (Tanzania-Korea) https://itec.snu.ac.kr/facility/itec_center.php

[35] Addis Ababa Science & Technology University (AASTU) - Artificial Intelligence & Robotics Centre; High-Performance Computing and Big Data Analytics Centre and UNECA (23/4/20)

[36] University of the Witwatersrand - ARUA Centre of Excellence in Materials, Energy and Nanotechnology (CoE-MEN)

[37] African Climate and Development Initiative (ACDI)

- Improve researchers' awareness of existing international facilities and the significant research, economic, societal, scientific, and international benefits large-scale research facilities can bring;

- Support for remote access to large scale research facilities (i.e. remote access to the Diamond light source has been made available via courier samples and remote control of the beamline for experiments). Remote access can also bring convenience for groups unable to travel regularly, including female researchers who are often constrained by family responsibilities.

Appendix 2 gives a summary of SSA partner country collaborations with large-scale research facilities using co-authored papers with at least one SSA partner country and a large-scale research facility (Web of Science core collection). The number of papers and collaborations started to grow exponentially from 2010. South Africa has the largest number of papers co-authored with large-scale international research facilities. CERN is the biggest facility used, and particle physics the largest field of research. The top collaborating countries are the USA and the UK. Very high-quality papers are produced from these collaborations with an average citation ratio of 52.93 compared to physics field citation rate of 8.74 per paper.

There are therefore additional opportunities to do the following:

- Increase the number of partner countries that access and use large-scale international facilities;

- Increase awareness about what large-scale research facilities exist and what opportunities they provide;

- Increase the quality of physics research in partner countries through collaborations with large-scale international facilities;

- Identify which facilities are most in-demand from the partner-countries and establish multilateral cooperation and access arrangements.

Research equipment

- Support training opportunities for technicians who can maintain advanced research equipment;

- Support equipment purchasing for cluster-sharing and avoiding expensive equipment duplication for institutions that are within travel distance. This will also promote collaboration and the development of networks, e.g. the MSSESA Energy Research network between Kenya, Tanzania, and Uganda;

- Support opportunities and infrastructure for researchers to work from home (i.e. suitable computing hardware, software, and internet connectivity). In particular, researchers in the fields of computational and theoretical physics may greatly benefit from opportunities to work at home if improved research equipment is made available.

Centres of Excellence

- Establish CoEs dedicated to the research themes, which can be multilateral (i.e. the ARUA model);

- Establish an SSA CoE in medical and biophysics as there are currently none in this critical field. Africa has unique disease and cancer burdens that can be addressed by focused research in this area.

3.5. Gender inclusivity

The shortage of women in physics was an issue acknowledged by all who participated in this study. The biggest challenges are related to gendered family responsibilities and cultural norms. Female physics graduates often experience peer and family pressure to get married and start a family life before proceeding with their postgraduate studies.

3.5.1. Reported challenges

Professor Igle Gledhill (University of the Witwatersrand, South Africa), previous chair of the International Union of Pure and Applied Physics (IUPAP) Working Group on Women in Physics, strongly indicated that domestic responsibilities and childcare tend to become priorities for female physics graduates once they get married. She described the impact of life events and family expectations on women in physics as follows:

"A major problem for women is the fact that the traditional career path assumes the absence of children. This has been well formulated as the path no longer being BSc-MSc-PhD -postdoc, but BSc- baby-MSc-baby-PhD-childcare- then a postdoc maybe. This is a fundamental problem in the traditional evaluation of candidates for promotion in the early career but is common to most sciences. Why is it worse in physics? This question is still under discussion, but it appears that the problems of perception and discouragement play a key role …."

Professor Mmanstae Diale (University of Pretoria, South Africa), the founding chair of Women in Physics in South Africa (WiPiSA), described the challenge as such:

"It is a world problem (shortage of women in physics), a few female students are coming at the undergraduate, and as they graduate, they have marriages and babies, and they cannot continue to postgraduate. Remember, in Africa, it's a prestige to be married, and when you are old and not married, it's a stigma for African women, both from a religious and cultural perspective."

The study found shortages of female students and academics at all levels. Figure 23 below shows the proportions of graduate outputs by qualification level and gender in survey respondents.

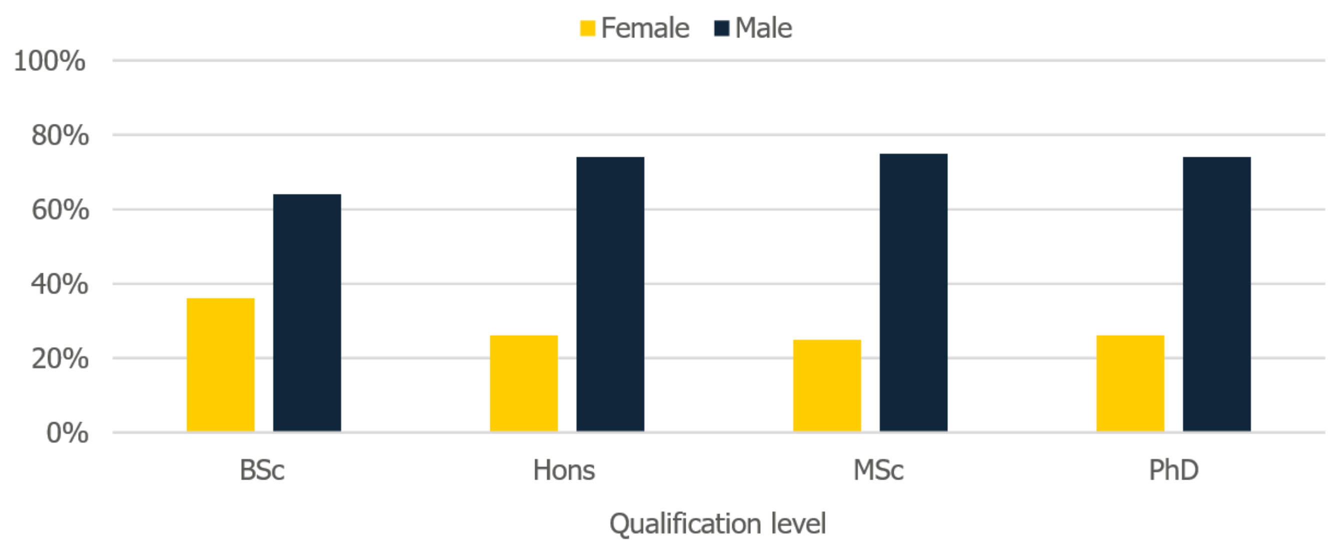

Figure 23: Proportion of graduate outputs by level and gender

In addition to the impact of stereotypes and cultural barriers, the shortage of women in physics is further exacerbated by overall challenges in the pipeline. Fewer females are joining university to pursue courses in physics, which can be attributed to factors such as: perceptions about physics being a hard subject not meant for girls; a lack of motivation for girls to study physics; and a lack of female physicists as role models. Furthermore, admission to physics at the tertiary level is determined by marks in mathematics and sciences at the school level. Generally, there is a small pool of female learners taking mathematics at school and passing with a good mark. Some women who do register tend to drop physics in the later years and divert to other programmes.

Women working in male-dominated environments are also exposed to sexual harassment, and some female respondents have also reported experiencing emotional harassment from senior female physicists. An example was given by Dr Michael Oloko (Jaramogi Oginga Odinga University of Science and Technology, Kenya), who indicated that these problems must be addressed:

> *"There is a big challenge to attracting and retaining women in physics not only in Kenya but in most African countries… we need to have discussions about unnecessary bullying and harassment by likening girls taking physics to men. This tact should be used to increase awareness and eliminate this kind of thinking within our society. In making friendships, boys feel inferior to partner with girls taking physics, making them lack reliable partners even in marriage. On some religious grounds, girls/women are not allowed to practice as professionals in practical areas like engineering which require physics. This presents limited opportunities for girls in such situations."*

An additional challenge causing low uptake of physics for both males and females is that career paths are not clearly defined. As mentioned in section 3.3.3, there is a commonly held notion that a physics graduate will end up being a teacher. It can indeed be challenging to get employment with a first degree in physics or even an MSc qualification, as there are very few related jobs in SSA.

The under-representation of women in physics not unique to SSA and represents a global problem. In 2010, a survey of 15,000 physicists worldwide revealed several barriers faced by female physicists[38].

3.5.2. Opportunities to address the shortage of women in physics

There have been several efforts to increase the representation of women in physics, including the creation of the International Conference on Women in Physics (ICWIP) and the International Science Council's 'Gender Gap in Science' work[39]. The programme partner countries are undertaking ongoing efforts to address the issue through departmental, institutional, and national programmes. Figure 24 below shows the proportion of surveyed universities participating in interventions supporting women in physics at national, institutional or departmental levels.

Organisations have also put in place policies on sexual harassment, gender equity and promoting more women to study physics. Some institutions have implemented affirmative action for degree enrolments where women can study physics with lower exam entry requirements. Other institutions have adopted employment quotas reserved for female scientists. Figure 24 shows the percentage of surveyed universities involved in WIP interventions at different levels.

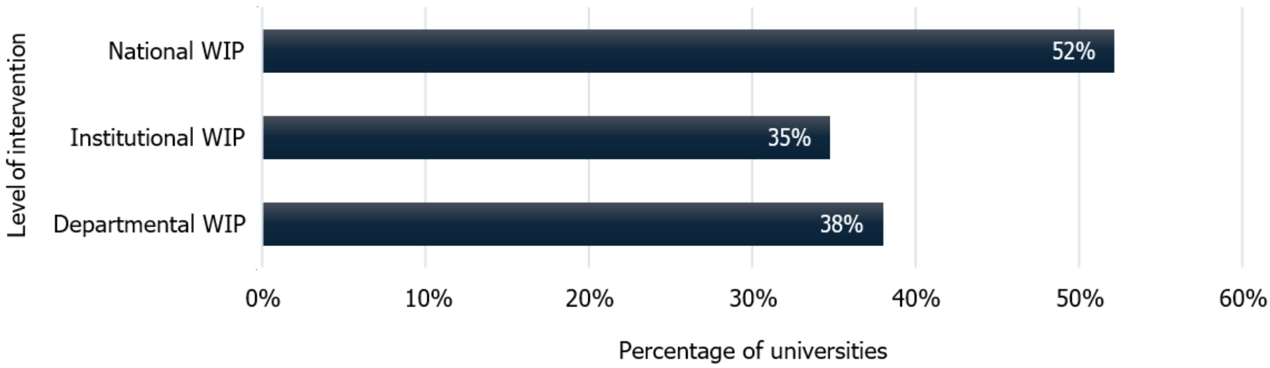

Figure 24: Percentage of surveyed universities involved in WIP interventions at each level

There are several additional opportunities to address the shortage of women in physics, including support for in-country postgraduate studies that do not require women to travel away from their families for postgraduate research. Elaborating on this point, Professor Gledhill suggested the following:

> *"For women in particular, for young physicists, and in the COVID era in general, computational, and theoretical physics can be addressed largely from home if there is enough hardware, connectivity, and guidance on connection and software. Therefore, this is an excellent route to take in Africa to increase the number of women in physics."*

Director of ICTP Rwanda Professor Omololu Akin-Ojo (University of Rwanda) also suggested that the physics community must pursue more interdisciplinary research with other scientific disciplines with greater female participation, such as biology, biochemistry, chemistry, pharmacy and nursing.

[38] AIP - Global Survey of Physicists and Ivie, R.; Tesfaye, C. - Women in Physics: a Tale of Limits (Physics Today 2/12)

[39] International Science Council - Gender Gap in Science [ISC; 2017]

In summary, the following opportunities have been suggested to reduce the shortage of women in physics:

- Support for in-country postgraduate programmes to reduce the need for travel;
- Affirmative action for degree enrolments;
- Implementation of institutional policies on sexual harassment and gender equity;
- Implementation of employment quotas reserved for female scientists;
- Support for interdisciplinary research between physics and other disciplines with higher rates of female participation.

3.6. R&D and innovation outputs

R&D and innovation outputs demonstrate the impact of physics research on addressing global challenges. This study evaluated R&D outputs based on conference participation, academic publications, prototypes produced, patents, technology transfers and start-up companies older than five years.

3.6.1. Conferences

There are several physics-related conferences regularly held in SSA. The leading periodic meetings highlighted by respondents are the Nigerian Institute of Physics Annual Conference, the South African Institute of Physics Annual Conference and those sponsored or organised by the IUPAP. Respondents also participate in many international conferences worldwide. Over 80% of the meetings attended are focussed on physics in general, as well as in the specific areas of astronomy, nuclear physics, material science and renewable energy. These findings once again confirm that the research theme of energy is relatively well-developed in the SSA physics community.

Conferences on the research theme of climate and weather have the second highest prevalence. These conferences include meetings such as Mechanisms and Hierarchical Modelling of Climate Dynamics, Hydroclimate Modelling and Analysis Tools GCRF African School, and the School on Climate and Environmental Modelling in the West African Region among others.

Health physics conferences are mainly in the specific fields of nuclear and radiation physics, such as the Joint ICTP-IAEA School on Medical Physics, Advanced Nuclear Science Technique and Technology iThembaLABS. The leading periodic medical physics conference reported is the annual South African Association of Physicists in Medicine and Biology (SAAPMB) Conference[40]. However, respondents did not acknowledge any conferences specifically focused on biophysics. It is worth noting that SAIP has established a working group on biophysics, which holds sessions at the SAIP annual conference and participates in the IUPAP Commission on Biological Physics and IUPAP Biophysics conferences.

The few conferences and meetings identified under big data, AI and data science include the Hands-on Workshop on Design, Installation and Management of HPC Data Centres for Academic Institutions hosted by ICTP in April 2019 and the Ashesi Data Science Africa workshop and

[40] South African Association of Physicists in Medicine and Biology (SAAPMB)

summer school[41]. The relatively low number of meetings on big data and AI once again confirms the underdevelopment of this research theme.

Respondents identified the lack of funding, high attendance costs and the lack of a critical mass of physicists as the biggest barriers to participating in or organising conferences.

3.6.2. Academic publications

Academic publications are the most significant outputs for all research themes. General physics has the highest number of publications followed by energy and climate and weather. Health, big data and AI all have a lower number of publications. Figure 25 below shows the reported number of publications by research theme over the last 5 years.

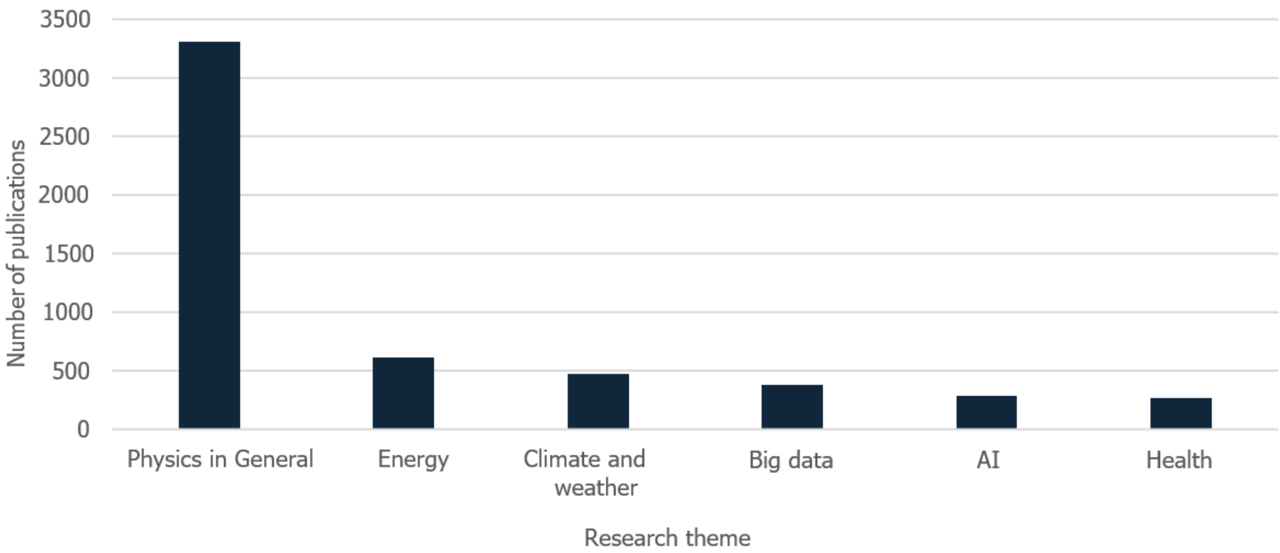

Figure 25: Reported number of publications by research theme over the past 5 years

According to director of Medical Physics, Mr Sonwabile Ngcezu (University of the Witwatersrand, South Africa), the relatively low level of medical physics research outputs compared to counterparts in high income countries can be attributed to the fact that academic medical physics departments in South Africa (including both medical diagnostic and radiotherapy departments) are primarily focused on clinical service delivery. This is due to low staffing levels for both academic and non-academic hospitals, a situation observed across the rest of the continent. There is therefore a need to address this problem in order to establish optimal departments involved in both clinical work and research and development.

Low numbers of research outputs in big data and AI again corroborate the finding that this research theme is relatively underdeveloped.

3.6.3. Patents, prototypes, tech-transfers and start-ups

Among the research themes, energy has the highest number of innovation and commercialisation outputs. Climate and weather follow as the second most productive area. There were no reported innovation outputs related to AI. Figure 26 below compares the reported quantities and types of R&D outputs over the last five years by research theme.

[41] Ashesi Data Science Africa workshop and summer school 2019 (21-5/10/19)

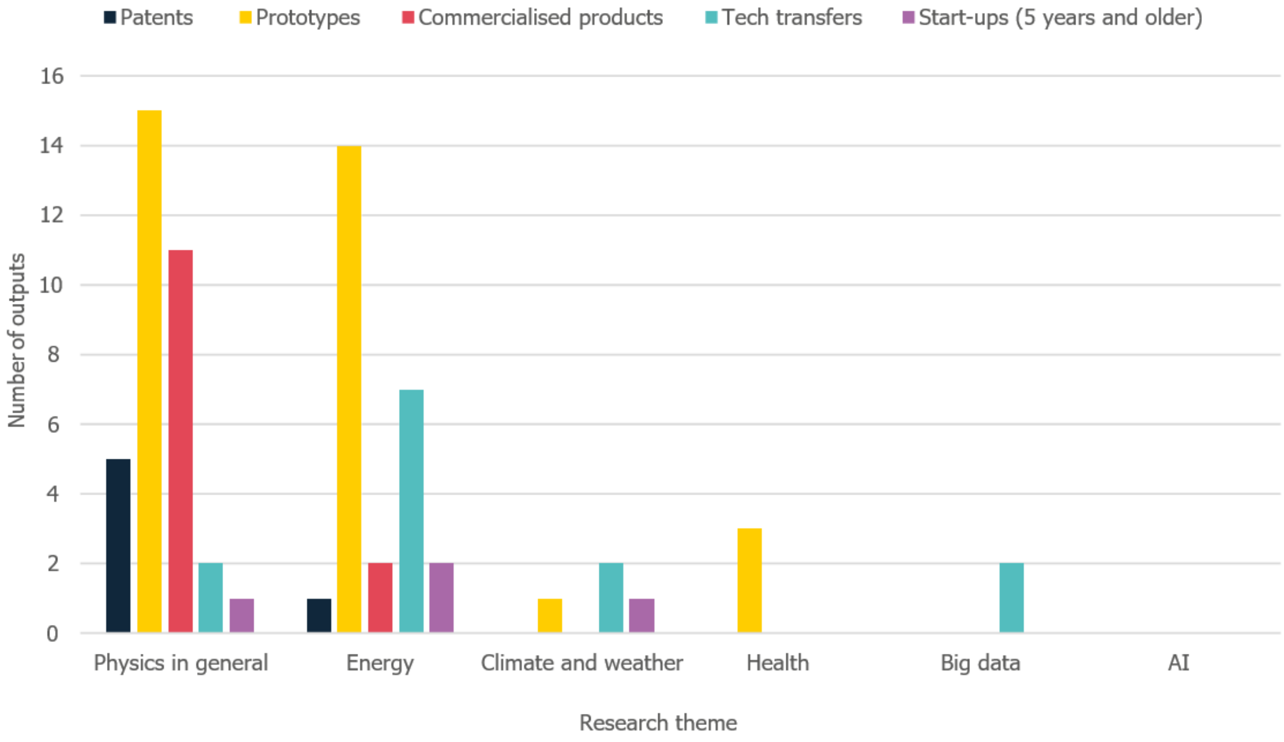

Figure 26: Reported innovation and commercialisation outputs in the last 5 years

3.6.4. Reported challenges

In summary, the above trends indicate major challenges regarding innovation and the commercialisation of research in SSA physics. The focus is primarily on academic outputs, such as conferences and papers, as opposed to innovation and commercialisation outputs. During discussions with the community, respondents cited the following as reasons for this discrepancy:

- Academic promotion is conducted using publications and not measured by innovation and commercialisation outputs;
- There is a lack of innovation and commercialisation training and support for physicists;
- The current approach to teaching physics in SSA is traditional, with most universities focusing on theoretical physics as opposed to experimental and applied physics. Most universities are not using problem-based learning in physics;
- Lack of funding and poor research infrastructure;
- Due to weak industry-academic collaborations, researchers are not aware of industry needs and existing market gaps while industry is not aware of what universities are doing. This situation leads to low uptake of innovation ideas;
- Most university appointments are teaching positions. Lecturers often face large teaching loads, which leave them with insufficient time to conduct research; most lecturers are required to research in their spare time.

Additionally, 88% of survey respondents identified a lack of funding and 84% identified a lack of research equipment as the most significant challenges to producing R&D outputs. Figure 27 below shows the percentage of respondents rating each of the challenges as significant.

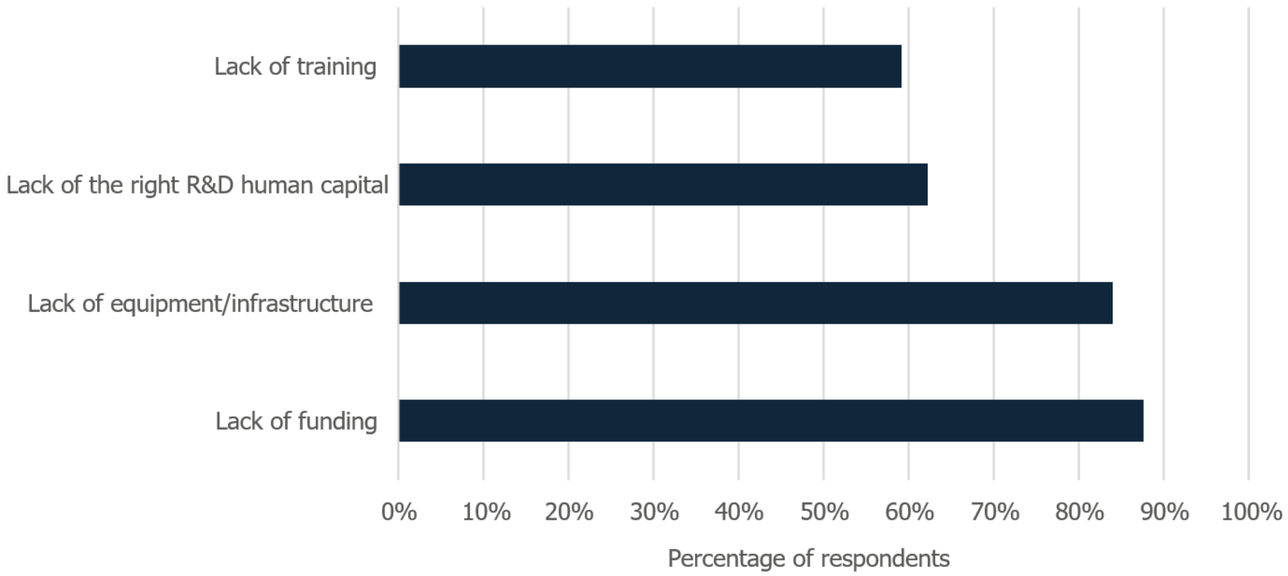

Figure 27: Proportion of respondents rating each challenge as significant

3.6.5. Opportunities to improve R&D and innovation outputs

All respondents indicated that they require innovation and commercialisation support through various types of interventions, including industry-academia partnerships, training on how to do research linked to global challenges, more opportunities to build start-up and business growth skills, and the establishment of innovation clusters or hubs. Elaborating on the importance of linking industry with academia, Dr Consalva Msigwa (Dar es Salaam Institute of Technology, Tanzania) explains that:

> *"Academic industry networks are very critical for innovative research…. before we worked on research to support COVID19 pandemic, we first had to engage the hospitals and government to understand what their needs are. We understood hospitals do not have ventilators. Hence, we started research on building a low-cost Automatic Emergency Ventilator."*

In summary, the key opportunities identified to improve R&D and innovation outputs are as follows:

- Encourage physics lecturers to move away from traditional methods of teaching physics towards problem-based teaching and learning, and to contextualise the physics being taught, so that it specifically addresses socio-economic challenges in SSA;
- Promote and support interdisciplinary research between physics and the applied sciences, such as projects between physics and the disciplines of engineering, medicine, pharmacy, computer science and economic and management sciences;
- Encourage physics degree programmes to incorporate workshop practice and development course modules. This will support physicists to develop prototypes for their research, as well as develop their research equipment;
- Encourage physics degree programmes to integrate courses in entrepreneurship, patenting and intellectual property protection, and the commercialisation of research;

- Create networks or forums between the physics community, industry and government, so that physicists can understand market needs and gaps and can carry out research focused on addressing them. Such networks will encourage financial support as well as research uptake.

3.7. Collaborations and networks

National, regional, and international collaborations and networks at various levels are essential for science. One of the major aims of this study was to investigate the different level of partnerships and networks that currently exist among SSA partner countries. The findings indicate that the presence and strength of collaborations is highly varied: particularly strong partnerships were found in some disciplines and universities, while other physicists interviewed indicated no involvement in collaborations.

3.7.1. University-industry collaborations

Collaboration between universities, industry and the private sector can be a powerful vehicle to enhance innovation and knowledge transfer. As such, universities participating in the study were asked if they took part in any academic-industry collaborations at various levels. Figure 28 below shows the proportion of surveyed universities taking part in different collaborative activities.

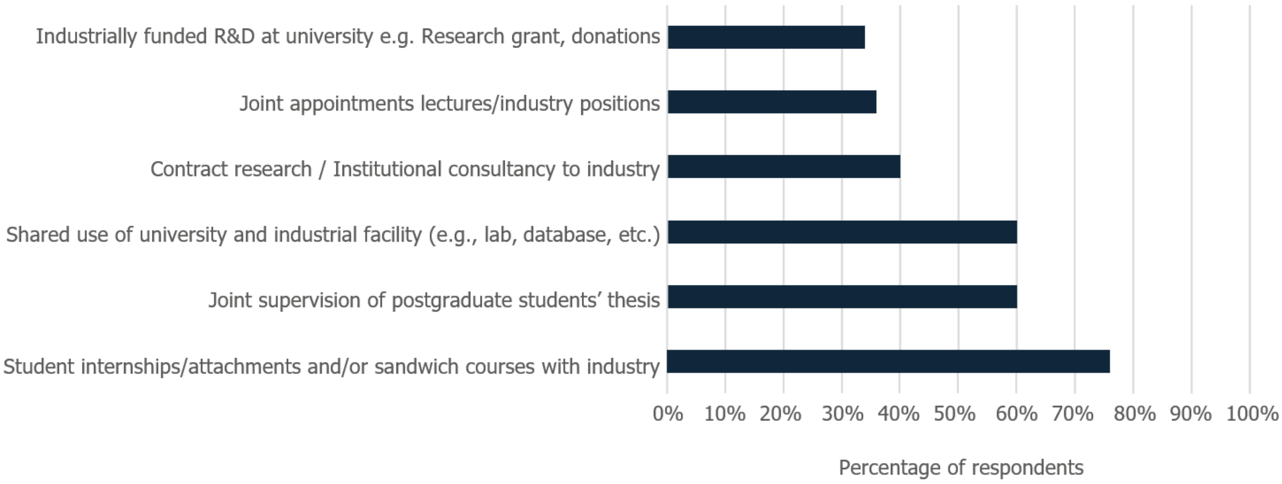

Figure 28: Proportion of surveyed universities taking part in different collaborative activities

As shown above, 76% of universities surveyed currently have some form of a student internship programme, while 40% are carrying out consultancy work for industry, and 34% have industry-funded research programmes. In general, these proportions demonstrate that the link between the private sector and academic research remains relatively weak, and this represents one of the main causes for low levels of innovation and commercialisation outputs from the SSA physics community.

3.7.2. Regional and international collaborations

The study found that the main types of existing partnerships are joint-research, co-supervision of students, and staff and student exchanges. Within the research themes of interest, energy research collaborations are particularly prominent followed by collaborations for climate and weather. Big data was mentioned under partnerships with CHPC and SKA, while in the area of medical physics Kenya was found to have a collaboration with iThemba labs in South Africa. There were no collaborations mentioned for AI.

The main sources of funding mentioned were the NRF, World Bank, African Union, and various sources from the UK such as the Royal Society, the Engineering and Physical Sciences Research Council (EPSRC), and UKRI-STFC. The main funding programmes mentioned under UKRI are the Newton Fund, Synchrotron Techniques for African Research and Technology (START)[42], Development in Africa with Radio Astronomy (DARA) project, and the Global Challenges Research Fund (GCRF).

South Africa and the UK are the two most frequently mentioned collaborating partner countries. Figure 29 below shows the types of collaborations and the sources of funding reported.

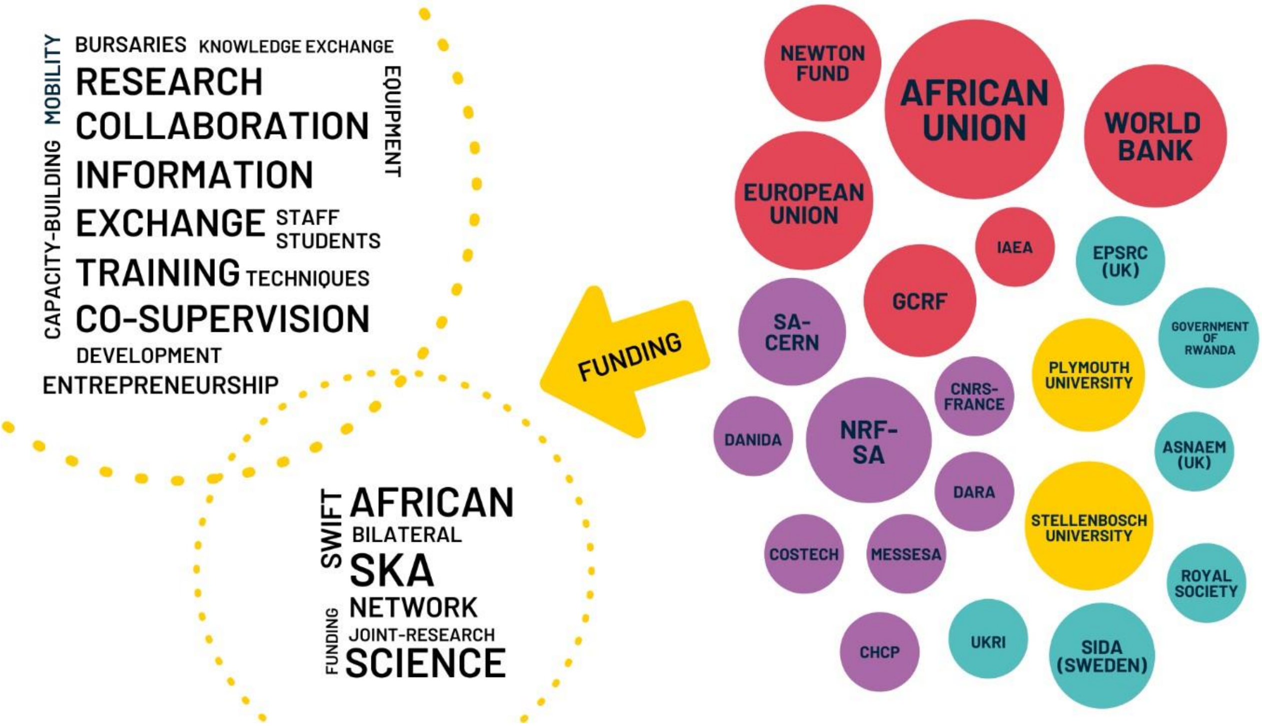

Figure 29: Types of collaborations and funders reported by respondents

Most of the collaborations identified in this study are bilateral, with two institutions participating in a cooperative partnership. Few respondents mentioned multilateral collaborations. Examples of multilateral partnerships identified include:

- Materials Science and Solar Energy for Eastern and Southern Africa (MSSESA[43]);
- African Network for Solar Energy (ANSOLE[44]);
- African Laser Centre[45], a virtual organisation, bringing together researchers from across Africa in the field of lasers and spectroscopy;
- Nano-Science Africa Network (NANOAFNET[46]);
- African Open Science Platform[47] ;

[42] Synchrotron Techniques for African Research and Technology and UKRI GCRF - START (Diamond Light Source)
[43] Materials Science and Solar Energy for Eastern and Southern Africa (MSSEESA)
[44] African Network for Solar Energy (ANSOLE)
[45] African Laser Centre (ALC)
[46] Nano-Science Africa Network (NANOAFNET)
[47] African Open Science Platform (AOSP) and NRF - Launch of the African Open Science Platform (14/12/18)

- African Light Source[48], a network of African countries working on establishing a light source for Africa;
- The COVID-19 Africa Rapid Grant Fund, which aims to contribute to the African regional and continental response to the COVID-19 pandemic.

3.7.3. Reported challenges

Respondents reported the following factors as the main challenges hindering the establishment of collaborations and networks:

- Lack of information on available collaborating opportunities;
- Lack of knowledge of other scientists' activities and facilities available in Africa;
- Poor internet connectivity in Africa (The International Telecommunication Union highlighted that while Europe had the highest internet usage (82.5%) Africa had the lowest at 28.2%[49])
- Difficulty obtaining visas;
- Challenges traveling between African countries (some respondents indicated it is often easier to go to Europe first then back to Africa).

On the other hand, there are also a host of factors that can create enabling environments for successful collaborations. Figure 30 below lists the proportion of respondents rating each of the main factors as significant and relevant.

Figure 30: Proportion of respondents rating each promotional factor as significant

It was found that the key factor supporting successful collaborations is the existence of long-term relationships with a partner. Other top factors include trust and open communication within the project team. The presence of governmental multilateral and bilateral agreements covering an area of collaboration was also found to be particularly important.

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[48] African Light Source

[49] ITU (International Telecommunication Union) - Measuring digital development: Facts and figures 2019 [ITU; 2019]

3.7.4. Opportunities to build stronger collaborations

Funders and partners

- UKRI-STFC noted that its primary partner in SSA is South Africa, through the NRF. UKRI-STFC did not report strong links with other SSA countries, and therefore welcomes the Africa-UK Physics programme as a platform to facilitate the establishment of such relationships. Additionally, the Programme can work with the STFC to facilitate access for African physicists to large-scale international research facilities.

- The NRF has been exploring the possibility of establishing multilateral cooperation with many African countries. The NRF Director of Africa Cooperation Mr Mike Nxumalo expressed enthusiasm at the prospect of developing multilateral collaborations between South Africa and the Africa-UK physics partner countries. Moreover, a recent analysis of cooperation between South Africa and other SSA countries recommended the establishment of multilateral intra-Africa corporations instead of bilateral corporations[50].

- The African Union and the New Partnership for Africa's Development (NEPAD) were mentioned as funders in some of the projects. They can serve as a platform to develop political-level cooperation in physics.

Targeted interventions

- Build capacity and support existing networks and collaborations;

- Support the activities of local physical societies and encourage conferences and networking. It is recommended to start at the national level as some countries do not have physical societies;

- Support co-supervision or split-site PhD agreements and student mobility grants;

- Promote existing collaboration opportunities and funds to increase awareness;

- Establish an online international networking platform for Africa-UK physics with the partner countries (using the contact information collected by this study).

[50] Scientometric Assessment and Study Report 2018 - R&D priority - R&D priority areas of South Africa and its S&T collaborative partners on the African continent [NRF; DST2; 2019]

4. Summary of findings and discussion

The findings from this feasibility study provides a narrative of physics in SSA with the voices of diverse Programme partner countries. All institutions participating in this study expressed enthusiasm about the potential impact of the proposed Africa-UK Physics Partnership Programme and indicated a strong willingness to be a part of it. Participants have also offered to coordinate various research themes aligned with their skills and expertise.

Figure 31 below provides an overview of the number of surveyed institutions currently undertaking research, training and R&D activities or offering relevant programmes for each of the research themes.

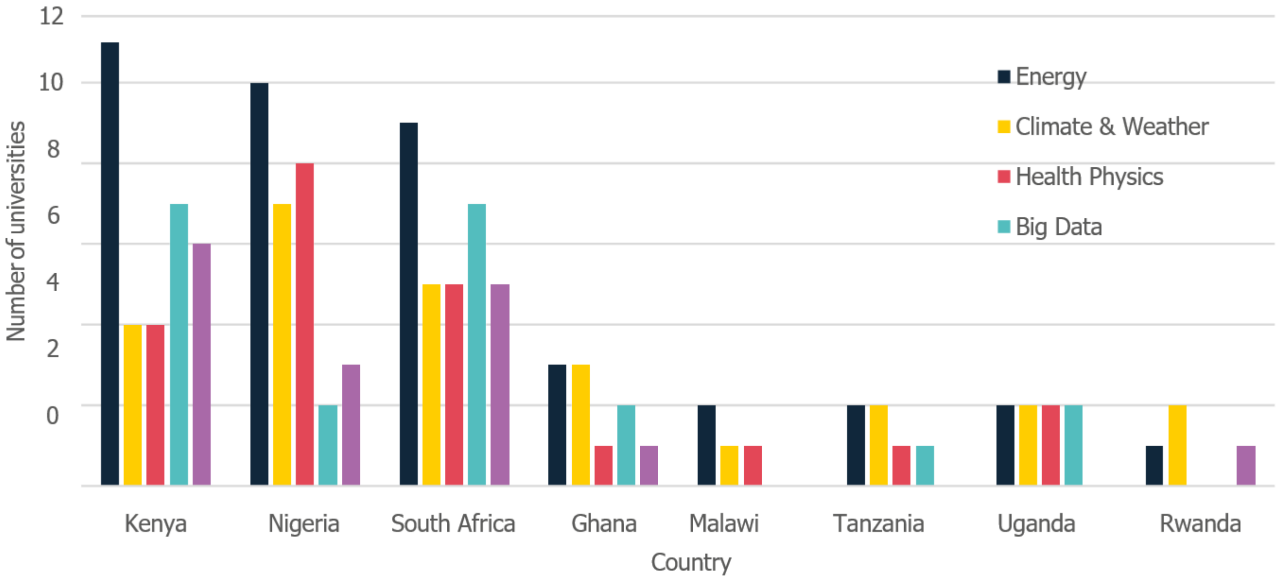

Figure 31: Number of institutions with activities in research themes by country

The study findings presented in this report provide a solid evidence base to support a future Africa-UK Physics Partnership Programme. It is essential that the immediate outputs of this proposed Programme align with the landscape of need, and that any capacity-building interventions envisioned would directly address reported challenges while leveraging identified opportunities.

Section 4.1 below provides a brief summary of the key study findings, followed by a discussion of learnings derived from the study that will be integrated into the Programme planning phase.

4.1. Summary

4.1.1. Areas requiring capacity-building support

All participants strongly indicated the need for capacity-building support and have provided their input on specific targeted interventions that would have particularly strong positive on their work.

Across the diversity of voices included in this study, there is a consensus that support for the following seven areas would help the SSA physics community advance scientific solutions and address wider socio-economic challenges:

1. Provide funding and support to enhance the physics education pipeline beginning at the school-level through to university in order attract and retain more students in physics;
2. Provide encouragement for students, particularly young women and girls, to pursue physics education by clarifying career opportunities, raising awareness about the importance of physics, and promoting the value of academia;
3. Grant financial support for post-graduate students;
4. Develop R&D infrastructure and strengthen commercialisation support systems through strengthening academia-industry ties and increasing placement and opportunities for consultation work;
5. Engage governments on the need to have more academic staff, and to appoint research-only staff in universities;
6. Address gender-based cultural stereotypes and workplace harassment to reduce barriers for women in physics;
7. Improve access to large-scale research facilities and build multilateral Centres of Excellence, particularly in the field of health and medical physics;
8. Enhance opportunities to establish new bilateral and multilateral research collaborations and strengthen existing networks.

4.1.2. Research themes

In terms of human capital, publications outputs, student training, collaboration networks and research infrastructure, it was found that the most developed research theme is energy, followed by climate and weather, and health. While the least-developed research theme is currently big data and AI, there are significant opportunities available in all themes to build capacity.

4.1.3. Requests for intervention: research capacity-building

In terms of research capacity-building, the top three interventions participants requested were to improve access to research equipment and infrastructure, increase funding, and improve access to training for technicians to service and maintain research infrastructure. Figure 32 below lists the main requests for interventions, and the proportion of respondents rating each intervention as significant.

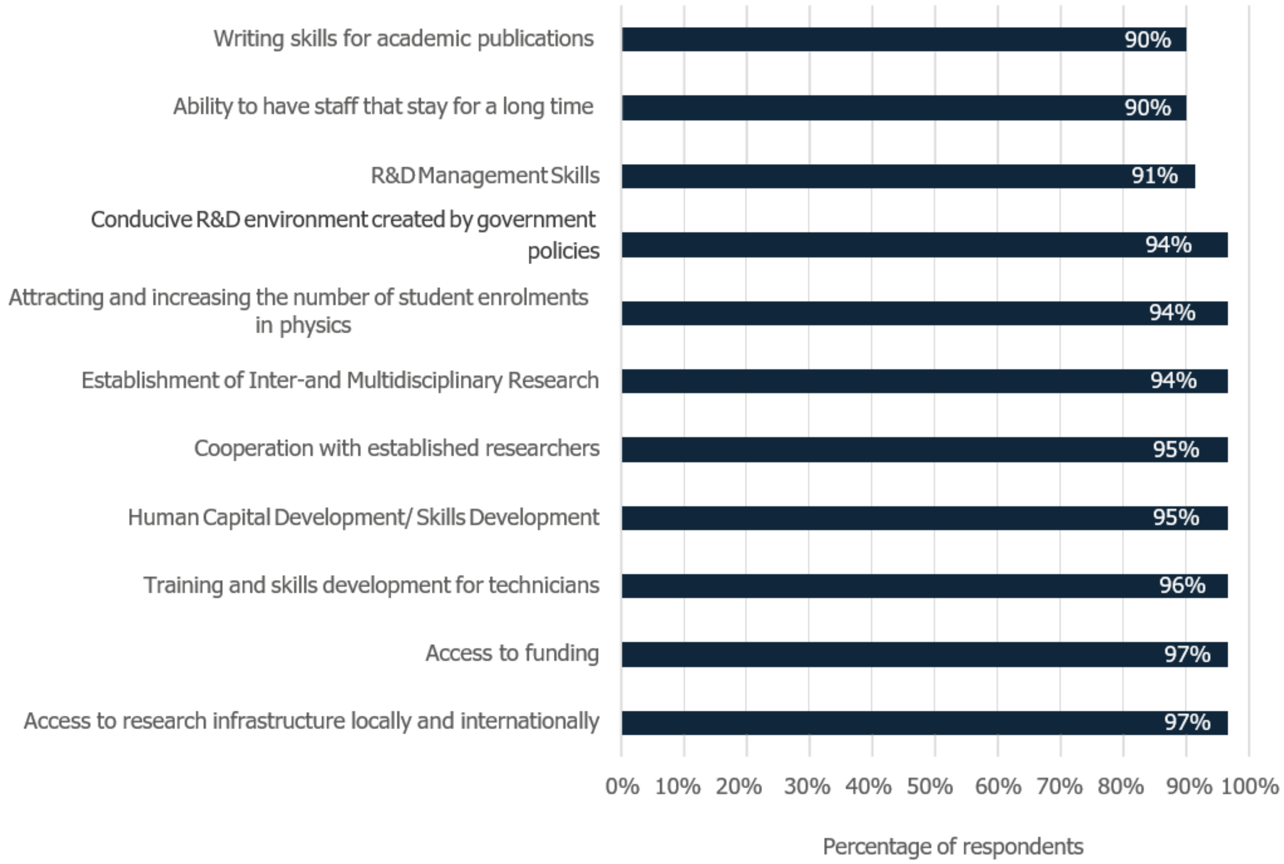

Figure 32: Proportion of respondents requesting each intervention

4.1.4. Requests for intervention: innovation and commercialisation support

With regards to improving innovation and commercialisation support, the top three interventions participants requested were to increase access to funding, link research to existing socio-economic challenges, and strengthen industry-academia partnerships. Figure 33 below lists the main requests for interventions and the proportion of respondents rating each intervention as significant.

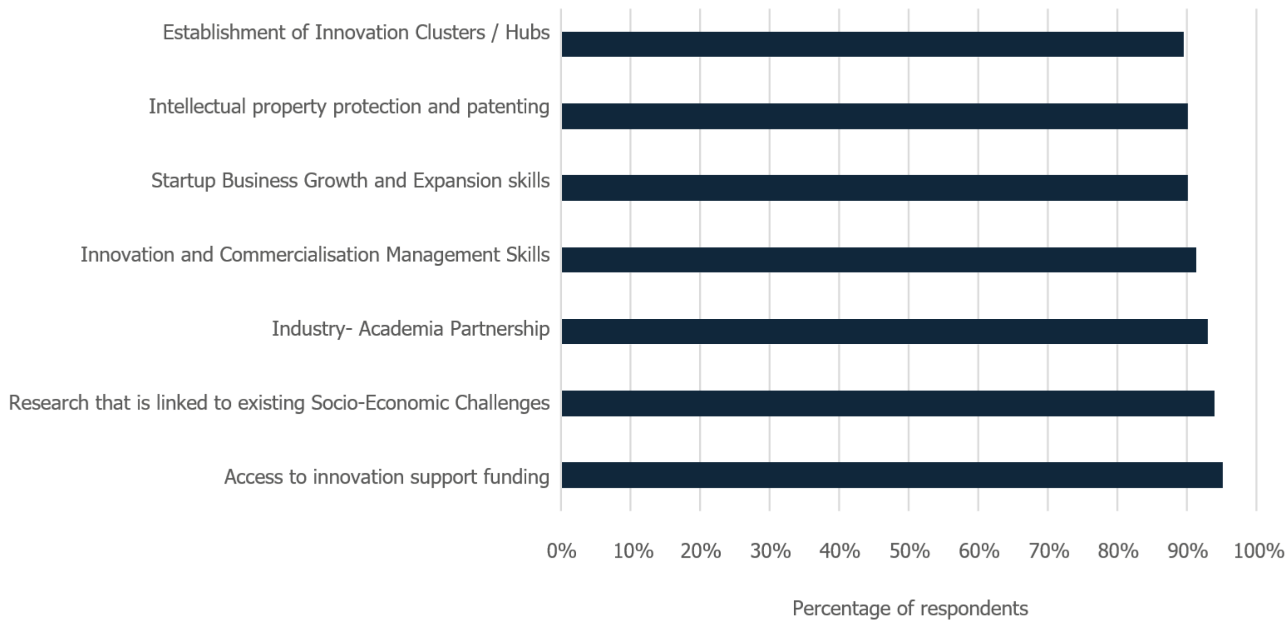

Figure 33: Proportion of respondents requesting each intervention

4.1.5. Summary of key opportunities

Section	Opportunities identified
Academic and staff capital	1. Engage governments on the need to have more academic staff, and to appoint research-only staff in universities; 2. Implement a human capital development programme for partner countries which specifically targets physics; 3. Train more technicians to maintain research facilities; 4. Implement staff-exchange and mentorship programmes.
Training and education pipeline	1. Develop structured outreach programmes in high schools to better their understanding of and interest in physics and demonstrate distinct career paths for physicists; 2. Create platforms where career trajectories for physics graduates are showcased; 3. Invite students to research facilities and physics departments to show exciting research and encourage students to continue studying physics; 4. Implement physics teacher development programmes and begin interventions at the primary school level; 5. Train students in application-oriented and problem-solving transferable skills at all levels; 6. Raise public awareness of the socio-economic impact of physics.
Large-scale research facilities	1. Increase access to large-scale research facilities for SSA partner countries through various forms of support, such as travel grants; 2. Improve the promotion of opportunities to access large-scale research facilities; 3. Improve awareness of existing large-scale research facilities and the significant economic, societal, scientific, and international benefits they bring; 4. Improve support for remote access to facilities; 5. Increase collaborations with large-scale research facilities; 6. Identify which facilities are most in-demand from the partner-countries and establish multilateral cooperation and access arrangements.

Research infrastructure	**Equipment** 1. Support training opportunities for technicians who can maintain advanced research equipment; 2. Support equipment purchasing for cluster-sharing and avoid expensive equipment duplication for institutions that are within travel distance; 3. Support opportunities and infrastructure for researchers to work from home; 4. Establish research clusters with distributed equipment between institutions that are within easy travel distance to each other. **Centres of Excellence** 1. Establish CoEs dedicated to the research themes, which can be multilateral (i.e. the ARUA model); 2. Establish SSA CoEs in medical and biophysics.
Gender inclusivity	1. Support for in-country postgraduate programmes to reduce the need for travel; 2. Affirmative action for degree enrolments and employment quotas reserved for female scientists; 3. Implement programmes aimed at increasing the number of females working in physics; 4. Implementation of institutional policies on sexual harassment and gender equity; 5. Support for interdisciplinary research between physics and other disciplines with higher rates of female participation.
R&D and innovation outputs	1. Encourage a move away from traditional methods of teaching physics towards problem-based teaching and learning; 2. Contextualise the physics being taught so that it specifically addresses socio- economic challenges in SSA; 3. Promote and support interdisciplinary research between physics and the applied sciences; 4. Encourage physics degree programmes to incorporate workshop practice and development course modules; 5. Encourage physics degree programmes to integrate courses in entrepreneurship, patenting and intellectual property protection, and the commercialisation of research; 6. Create networks or forums between the physics community, industry and government.

Collaborations and networks	1. Build capacity and support existing networks and collaborations; 2. Support the activities of local physical societies and encourage conferences and networking; 3. Support co-supervision or split-site PhD agreements and mobility grants; 4. Establish an online international networking platform for Africa-UK physics with the partner countries; 5. Promote existing collaboration opportunities and funds to increase awareness.
Funders and partners	1. The Programme can work with UKRI-STFC to facilitate access for African physicists to large-scale international research facilities; 2. The NRF have expressed enthusiasm at the prospect of developing multilateral collaborations between South Africa and partner countries; 3. The African Union and the New Partnership for Africa's Development (NEPAD) could serve as a platform to develop political-level cooperation in physics.

4.2. Discussion

4.2.1. Application of learning from previous capacity-building initiatives

Study participants who have previously taken part in similar capacity-building and collaborative initiatives drew from their experiences to suggest points for consideration when designing the Africa- UK Physics Partnership Programme. Respondents provided several key suggestions, as quoted below:

- *"It essential that Africans highlight what they want to be invested in Africa. Africa must have a stronger leadership in the Africa-UK initiative, we must not wait for handouts but take leadership if we want this to be successful. In addition, the African governments must also be involved in funding these activities not just beneficiaries of grants."* (Professor Simon Connell, University of Johannesburg, South Africa)
- *"Bilateral and multilateral cooperation from the government level is essential, e.g. it will help with visas and duty, customs costs can be waived."* (Dr Nuru Mlyuka, University of Dar es Salaam, Tanzania)
- *"Most people do research with the sole aim of obtaining a qualification and publication only. In addition, Government & Industries are not in close ties with universities regarding scientific research."* (Dr Michael Okullo, Kyambogo University, Uganda)
- *"Any project needs to go beyond the university to have an impact in the lives of those outside the university; the area of entrepreneurship should be emphasised."* (Professor Elijah Oyeyemi, University of Lagos, Nigeria)
- *"The transfer of project funds to other African countries can be done. The existence of the Science Granting Councils Initiative (SGCI), in which a number of African countries*

are participants, including the NRF, makes it easier to negotiate modalities for such transfers. Other avenues such as the bilateral platforms can be utilised for countries falling outside the SGCs." (Mr Michael Nxumalo, NRF, South Africa)

- *"In connection with women in physics, we observe that after an initiative reaches the end of its resourced life, the situation for women snaps back to where it was before. It is suggested that this is because the underlying culture has not changed. How do we deal with this? My response: (1) we have to keep going, (2) behaviour does change thoughts, and we do observe that cultures have changed with enough work."* (Professor Igle Gledhill, University of the Witwatersrand, South Africa)

4.2.2. Addressing global challenges

Within this study, the ability of the SSA physics community to address global challenges was largely evaluated using the level of R&D and innovation outputs. It was observed that only a small number of innovation and commercialisation outputs were produced by the system over the last five years. To begin addressing this issue, participants have agreed upon four essential principles that must be considered when planning capacity-building exercises linking physics with developmental priorities:

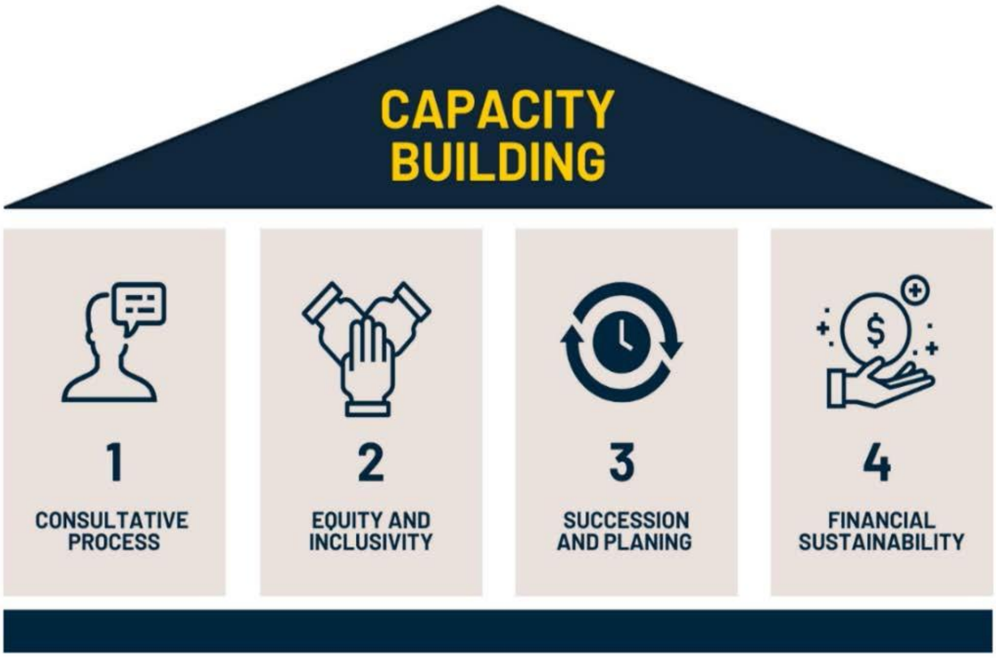

Figure 34: Key principles for capacity-building interventions

1. Consultative processes: Consultations with key stakeholders, from scientists to management to government officials, is vital. Any capacity-strengthening process, whether human, infrastructural or both, ought to be participatory from the very beginning to ensure ownership and sustainability.

2. Equity and inclusivity: It is essential to build an inclusive physics community that meets essential cross-cutting requirements in terms of gender, race, ethnicity, individuals with disabilities, economically disadvantaged groups and people from fragile and conflict-affected states.

3. Succession planning: Efforts must be made to ensure project continuity. Those who start a project may retire or leave an institution, resulting in disruptions to workflows and collaborations. A system should be in place to pass on the importance of programmes to successors, continue evolving the programme alongside current needs, and keep interventions and activities running successfully. Furthermore, programmes involving students need to be sustained and must include aspects such as long-term mentorship through to graduation and into professional careers.

4. Financial sustainability: Most science capacity-strengthening projects in SSA become inactive when funding comes to an end. The primary reason is the lack of funding from other local sources and poor support of science funding from African governments. Therefore, long-term systematic change will only occur if funding is sustained over a longer period and aligned to the strategic priorities of governments.

4.3. Concluding remarks

The conclusion of this study is that, in spite of pockets of excellence and a community of outstanding academics, the current ecosystem for physics research in SSA needs significant strengthening to enable it to address pressing global challenges. A future Africa-UK Physics Partnership Programme can provide the necessary support for partner countries in SSA and enable the development of a stronger culture of innovation and problem-based physics training. It can also build upon the existing pockets of excellence in all research themes to strengthen the overall capacity of the SSA physics community. This could have significant multiplier effects and result in developmental benefits across the continent.

As noted in this report, there is already an enthusiastic and able community of physicists ready to participate and contribute to the goals of a future Africa-UK Physics Partnership Programme. This study encountered leading academics with the expertise and drive to help create the conditions for the Africa- UK Physics Partnership Programme to thrive, and to produce cutting-edge solutions to the global challenges that Africa and the world need to address with urgency.

Appendix 1: Survey questions

Africa-UK Physics Partnership Feasibility and Baseline Study

Background

The physical sciences are fundamental to our ability to tackle the global challenges that humanity currently faces and physics in particular, sits of the heart of innovation. From the science and technology for new climate models and weather forecasts, to drone delivery networks, ferrying medicines, vaccines and blood to remote regions, to cancer treatment, to drug development for Malaria, HIV and Tuberculosis at synchrotron light sources, physics equips us with the tools, technology and skills to unlock the potential of every nation in order to meet the challenges we face.

The Institute of Physics (IOP), the Association of Commonwealth Universities (ACU) and a network of partners are proposing an ambitious Africa-UK physics partnership programme to address the Global Challenges using the capabilities that physics can provide.

The UK's Department for Business, Energy and Industrial Strategy (BEIS) has provided funding for the ACU and IOP to carry out a feasibility study to support the development of this multi-year, long-term programme between the UK and African nations.

The study will assess participants' capacity to engage in physics research, development and innovation in target partner countries and seek to identify opportunities to develop long-term partnerships.

Scope

The ambition is for this study to help to inform and support bids for a multi-year long-term project, which the UK government will be approached to fund. Co-funding will be sought from African Governments from the participant countries, and philanthropic organisations with whom the IOP are engaging.

The intent of the multi-year long-term project is for African nations to drive scientific solutions to Global Challenges from physics and for the UK to be partners with them in this endeavour. The programme will focus on physics projects and capacity building in the thematic areas of Energy; Climate and Weather; Health; Big Data; Artificial Intelligence (AI); and, Large research Facilities. It will include the following countries: Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Tanzania and Uganda.

Invitation to Participate in the Survey

In order to build a proposal for this ambitious programme, physics research, development, and innovation capacity must be assessed and understood in the contexts of each partner country.

Your institution is invited to participate in this survey, which will build on existing research and provide the foundation for the proposal. Your valuable inputs will contribute to shaping a coherent, long-term, substantially funded programme that addresses capacity issues in physics at multiple levels and builds on existing research partnerships. The survey is comprised of the following sections;

Section 1: Institutional Demographic Information
Section 2: Human Capital and Skills Available
Section 3: Human Capital Development and Physics Education Pipeline
Section 4: Research and Innovation Infrastructure
Section 5: Research Development and Innovation Outputs
Section 6: Research Collaborations, Partnerships and Networks
Section 7: Africa-UK Physics Collaboration Participation Potential

We will be following up with individuals for interviews and hope to run workshops to provide further insight into the data we are gathering.

The survey will close at 12pm, Sunday 31st May 2020.

Instructions to Complete:

1. We have provided you with a PDF version of the questionnaire that will enable you to collect the information needed to complete the survey beforehand (for example, staff information, graduates information, research facilities etc.). Once that information is collected then completing the online survey should take no more than 45 minutes.

2. When completing the questionnaire please consider the situation as at the point before the COVID19 pandemic.

3. Only complete what is applicable to your department/institution, if any part does not apply to your department or institution please leave it blank.

There are 74 questions in this survey and it will take approximately 45 minutes to complete.

Thank you.

Section 1: Institutional Demographic Information

1.1 Please provide details of the person leading the completion of this questionnaire below

	Contact Details
Full Name:	
Job Title:	
Institution/Organisation/Company:	
Department:	
Country:	
Email:	
Phone:	

1.2 Does your department/institution have physics research programmes on any of the following?

	Yes	Uncertain	No
Energy			
Climate and Weather			
Health (biophysics & medical physics)			
Big Data			
Artificial Intelligence			

If you would like to elaborate on any of your responses above, please do so in the space below.

1.3 We are looking to interview physics experts working-in or whose research includes energy, climate and weather, health, big data, or artificial intelligence.

- Please provide the contact details of the Key Contact Person in your institution whose research includes these thematic areas.
- Please only complete what is applicable to your institution, if a thematic area does not apply you can leave it blank
- By providing contact details you are consenting to the individual to be contacted by the project team

	Full Name	Email	Phone/Mobile
Energy			
Climate and Weather			
Health (biophysics & medical physics)			
Big Data			
Artificial Intelligence			

If you would like to elaborate on any of your responses above, please do so in the space below:

Section 2A: Human Capital and Skills Available

Please indicate the number of Early Career staff (2.1) and Senior (2.3) research, teaching and technical staff employed by your department as follows;

- Start with the total numbers of physics in general in questions (2.1) and (2.3)
- Followed by a breakdown per thematic area where applicable in questions (2.2) and (2.4)
- A person fits a thematic area if they are working in, or their research includes Energy, Climate and Weather, Health, the use of Big Data, or Artificial Intelligence.
- If one is active in more than one field, please indicate the field in which they are most active.
- Please provide the headcount rather than the full-time equivalent for the most recently closed financial year.
- If you are not able to disaggregate your Teaching and Research staff, please provide the figures under 'Both Teaching & Research'.
- Only complete what is applicable to your department/institution, **if a thematic area does not apply please leave it blank.**

2.1 Please indicate the number of Early Career staff per category for physics in general

- Early Career Technicians are those with less than 5 years of experience
- Early Career Teaching and Research staff are those with less than 10 years experience

	Tech (Male)	Tech (Female)	Teaching (Male)	Teaching (Female)	Research (Male)	Research (Female)	Both Teaching & Research (Male)	Both Teaching & Research (Female)
Physics in General								

2.2 Please provide Early Career staff breakdown per thematic area **where applicable, if not applicable leave blank**

- Early Career Technicians are those with less than 5 years of experience
- Early Career Teaching and Research staff are those with less than 10 years experience

	Tech (Male)	Tech (Female)	Teaching (Male)	Teaching (Female)	Research (Male)	Research (Female)	Both Teaching & Research (Male)	Both Teaching & Research (Female)
Energy								
Climate and Weather								
Health (biophysics & medical physics)								
Big Data								
Artificial Intelligence								

Please provide any additional information on early career staff in the space below.

2.3 Please indicate the number of Senior staff per category for physics in general

- Senior Technicians are those with 5 years and above experience
- Senior Teaching and Research staff are those with 10 years and above experience

	Tech (Male)	Tech (Female)	Teaching (Male)	Teaching (Female)	Research (Male)	Research (Female)	Both Teaching & Research (Male)	Both Teaching & Research (Female)
Physics in General								

2.4 Please provide Senior staff breakdown per thematic area **where applicable, if not applicable leave blank.**

- Senior Technicians are those with 5 years and above experience
- Senior Teaching and Research staff are those with 10 years and above experience

	Tech (Male)	Tech (Female)	Teaching (Male)	Teaching (Female)	Research (Male)	Research (Female)	Both Teaching & Research (Male)	Both Teaching & Research (Female)
Energy								
Climate and Weather								
Health (biophysics & medical physics)								
Big Data								
Artificial Intelligence								

Please provide any additional information on senior staff in the space below.

2.5 Please provide the number of staff with a particular highest level of education under each category in the table below. Only indicate their highest qualification, counting each member of staff once only;

	Tech (Male)	Tech (Female)	Teaching (Male)	Teaching (Female)	Research (Male)	Research (Female)	Both Teaching & Research (Male)	Both Teaching & Research (Female)
Certificate								
Diploma								
BSc								
BSc Hons								
MSc/ MPhil								
PhD/DPhil								

2.6 Do you have a staff development programme in place? If yes, please provide a brief summary of the programme below.

Section 2.B: Human Capital and Skills Available - Women in Physics

Underrepresentation of women in physics is a global problem. In 2010 a **worldwide survey of 15,000** people revealed a number of barriers faced by women physicists. There have been several efforts to increase the representation of women in physics including the creation of the International Conference on Women in Physics (ICWIP) and the International Science Council's **'Gender Gap in Science'** work.

2.7 Does your department face any challenges in attracting and retaining women in physics? If yes, please list the 5 biggest challenges in the space below:

1.	
2.	
3.	
4.	
5.	

2.8 Does your department/institution have a policy or code of conduct in gender equity, supporting women in physics or sexual harassment? If yes, please provide a brief description under the relevant section below.

Gender Equity
Supporting Women in Physics
Sexual Harassment
Any other comments regarding gender related policies

2.9 Does your department participate in any programmes that promote Women in Physics (WIP) at the departmental, institutional, or national level?

Departmental WIP programme	
Institutional WIP	
National WIP	

Please provide any other comments regarding Women in Physics Programmes below

Section 3: Human Capital Development and Physics Education Pipeline

3.1 On average, how many physics-related qualifications does your university grant per year at each level? Please provide your answers in the tables below as follows;

- Start with 3.1 physics in general.
- Next complete 3.2 where we request that you break it down per thematic area, **where applicable.**
- A graduate fits a thematic area if their course modules or their research includes: Energy, Climate and Weather, Health, the use of Big Data, or Artificial Intelligence.
- Only complete what is applicable to your department/institution;

If a thematic area, qualification class or degree class does not apply please leave it blank.

Please indicate the number of physics-related qualifications for physics in general below

	Certificate		Diploma		BSc		BSc (Hons)		MSc/MPhil		PhD/DPhil	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Physics in General												

3.2 Please indicate the number of graduates by thematic area **where applicable** below

	Certificate	Diploma	BSc	BSc Hons	MSc/MPhil	PhD/DPhil
Energy						
Climate and Weather						
Health (biophysics & medical physics)						
Big Data						
Artificial Intelligence						

Please provide any other comments on graduate output/training below

3.3 Please indicate the number of PhD supervisions, including joint supervisions in physics that have taken place at your institutions in the past five years

3.4 Please indicate the number of post-doctoral research fellows you currently have

- Start with 3.4 physics in general,
- Next complete 3.5 where we request that you break it down per thematic area **where applicable**,
- A person fits a thematic area if they are working-in or their research includes Energy, Climate and Weather, Health, the use of Big Data, or Artificial Intelligence,
- If one is active in more than one field, please indicate the field in which they are most active,
- **only complete what is applicable to your department/institution, if a thematic area does not apply please leave it blank.**

Please indicate the number of post-doctoral fellows available for physics in general below

	Male Post-Doc Fellows	Female Post-Doc Fellows
Physics in General		

3.5 Please indicate the number of post-doctoral research fellows per thematic area **where applicable**

	Male Post-Doc Fellows	Female Post-Doc Fellows
Energy		
Climate and Weather		
Health (biophysics & medical physics)		
Big Data		
Artificial Intelligence		

Please provide any other comments on Post-Doc Fellows below

3.6 What is the average number of student enrolments per year coming into your university to study physics vs other STEM subjects

	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
Physics					
Other STEM Subjects - Excluding Physics					

3.7 Based on your experience in your institution, what percentage of students complete the transitions listed below

	% Transitioning
BSc to Honours	
Honours to MSc/MPhil	
MSc/MPhil to PhD/DPhil	

Please add any comments to explain why you think a particular transition stage sees the highest drop off and share any recommendations on how this could be reduced

3.8 Is your physics department/ institution/ organisation involved in supporting the physics education pipeline to ensure the next generation of physicists?

	Yes/ No	Name of funder	Is the programme evaluated (Yes/No)	Short description of programme/ website
Primary level (Grade 1 to 7)				
Secondary level (Grade 8 / Form 1 and above)				
Physics teacher development in primary schools				
Physics teacher development in secondary schools				
Physics education research to inform programmes, policy positions etc.				
Programmes aimed at attracting and retaining women and girls in physics				
Career advice/opportunities for pre-university students				

3.9 What challenges does your institution face regarding the pipeline of students coming into physics education/ research? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Low numbers of students applying to study physics at degree level.					
Low numbers of students with good enough grades to study physics at degree level.					
Lack of appreciation/ understanding among students and parents of the further career opportunities that would come from studying physics.					
Lack of appreciation/ understanding among students and parents of the value of staying in academia.					
There is currently a shortage of physics researchers in the country.					
In the long-term there will be a shortage of physics researchers in the country.					
More could be done to encourage and support students to continue with their physics education.					
The challenges around encouraging students to continue with physics start many years before university.					
The country needs researchers for the future and preparing for that in pre-university education is needed.					

If you have experienced other challenges, please state them here.

If you have answered agree or strongly agree for any of the above, can you provide reasons as to why you think this is the case?

3.10 Please indicate if you agree with the following statements regarding the quality of incoming undergraduate students. Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Poor work ethic					
A lack of problem-solving skills					
A lack of mathematics skills					
A lack of computer and IT skills					
A lack of foundational physics knowledge					

Misconceptions about key physics principals					
A greater interest in learning physics concepts for the exam rather than learning to understand					
Poor experimental skills					

If you have any further comments regarding this question, please write them here.

3.11 Please indicate if you agree with the following statements regarding the quality of produced undergraduate students. Please tick the appropriate box below

	1 Strongly Disagree	**2 Disagree**	**3 Neither agree nor disagree**	**4 Agree**	**5 Strongly Agree**
There is a need for additional bridging courses for most BSc graduates before they can start their postgraduate studies					
Students can apply physics theories and concepts to solve problems					
Student have basic skills in synthesizing and organizing ideas and information in a logical way					
Students have good experimental skills, that is, they can setup, conduct and interpret results and relationships in experiments					
Students have the basic skills required to enter the job market in research, industry and commerce					

If you have any further comments regarding this question, please write them here.

Section 4: Research and Innovation Infrastructure

4.1 What type of physics research facilities are available at your institution? In particular, please indicate if you have specialised equipment, labs or Centres of Excellence, etc. related to each thematic area

	Facility/Equipment/ Centre of Excellence	**Capabilities**	**Condition (Good / Needs Upgrade etc.)**
Physics			
Energy			
Climate and Weather			
Health (biophysics & medical physics)			
Big Data			
Artificial Intelligence			

Please provide any additional comments on available infrastructure

4.2 Does your institution have any of the following innovation and commercialisation support facilities?

	Yes	Uncertain	No
Training on Commercialisation of Research			
Training on Patenting and Intellectual Property Protection			
An office that supports R&D Commercialisation			
Training and Support on Proposal writing			

Please provide any additional comments regarding innovation support facilities below.

4.3 What are the most important challenges that your institution faces in managing these facilities and related research activities? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Lack of funding					
Delay by admin and complex processes to release of funds/grants once it is in the universities					
Lack of equipment					
Shortage of R&D skills					
Shortage of the right technical skills i.e. technicians to service and repair specialised equipment					
Failure of access to large scale facilities for specialised research (e.g. synchrotrons, accelerators, telescopes etc)					
Lack of Government Support e.g. unconducive R&D policies					
Lack of R&D Management Skills					
Brain drain (staff who are sent for training do not return and experienced staff leave)					
Shortage of research collaboration networks					
Lack of access to fast and reliable internet connection					
Lack of computational facilities					
Lack of reliable electricity supply					

Please comment on any additional challenges that are not referenced above.

4.4 Does your institution have plans/ proposals to purchase/build/establish any new specialised /equipment research facilities related to the thematic areas within the next 10 years? If yes, please provide the details in the table below.

	Proposed Facility/Equipment/ Centre of Excellence/ Commercialisation Office etc	Capabilities	Proposed Timeline	Requirements / Needs
Physics				
Energy				
Climate and Weather				
Health (biophysics & medical physics)				
Big Data				
Artificial Intelligence				

Please add any additional comments below.

Research and Innovation Infrastructure

Large scale research facilities support a diverse range of scientific programmes focused on international priority areas that are particularly critical for African nations, such as materials for affordable and clean energy, food source security, technological innovation, and health. They are flagships of international collaboration and they provide an ideal environment in which new researchers can be developed and trained. They also provide many unique opportunities to establish a broad range of contacts and provide an opportunity for poorly resourced countries to access state of the art facilities for both cutting edge research as well as post-graduate training opportunities. Examples of these facilities include the Square Kilometre Array telescope, the CERN Large Hadron Collider, the Advanced Light Source at Berkley and the Centre for High-Performance Computing (CHPC) in Cape Town among others.

4.5 Do you have current or future research projects that use large-scale research facilities, especially in collaboration with any of the partner countries (UK, Kenya, South Africa, Ghana, Nigeria, Malawi, Tanzania, Rwanda, Uganda, or Ethiopia)? If yes, please complete the table below. Facilities outside the partner countries can also be included.

	Research Topic / Area	Name Large-Scale Facility	Country
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

4.6 What benefits does your department/institution derive from accessing large scale research facilities? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Ability to execute research projects that exceed the funding capacity of the department/institution/country					
Accessing state-of-the-art scientific facilities					
Avoiding unnecessary duplication of equipment					
Accessing a unique geographical location					
Working with the top physicists, scientists, engineers, technicians working in your field of research					
Accessing big data ready for analysis					
Providing international experience for young scientists					
Forging international collaborations					
Access to co-supervisors for postgraduate students					

Please reference any additional benefits below.

4.7 What barriers/challenges if any do you currently face in trying to access large- scale research facilities? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
The ability to produce competitive proposals to get research time allocated					
Lack of equipment to prepare samples for analysis and/or proposal for consideration					
Lack of funding for mobility and subsistence to visit facilities					
Exclusion because your country is not part of a particular large-scale facility collaboration/membership					
Lack of training for academics in how to use facilities					
Visa restrictions or difficulties in travelling					

Please list any other barriers/challenges below.

4.8 What factors/strategies do you find useful in accessing large scale infrastructure? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Competitive proposals					
Availability of local equipment to prepare samples for analysis and/or proposal					
National Membership to Large-Scale facilities					
Government bilateral and multilateral cooperation covering facilities					
Establishing national research consortiums accessing particular facilities					
Availability of mobility grants					
Requesting co-supervision of postgraduate students					
Exchange programmes for early career and post graduate students					

Please provide any additional factors/strategies below.

Section 5: Research Development and Innovation Outputs

5.1 Conferences, schools and workshops provide scientists with a platform to establish collaborations and forge new partnerships, disseminate their research, as well as get their work reviewed by peers. Please list any physics conferences, workshops, and schools attended by your students/researchers in the last year.

	Conference/School/ Workshop	Website	Location	Country	Focus Area	Dates
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

5.2 Does your institution face any of the following challenges with respect to organising or participating in conferences, workshops?

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Lack of funding and high cost of conferences					
Difficulty in obtaining VISAs to host countries					
Lack of critical mass to host physics conferences in own country					

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Lack of expertise in writing papers to present at conferences					

Please specify any other challenges you face with respect to organising or participating in conferences or workshops.

5.3 Please indicate the number (quantity) of R&D outputs produced by your department/institution in the last five years in the table below. If any output is not applicable, please leave it blank.

	Academic Publications	Patents	Product Prototypes	Commercialised Products	Technological Start-ups	Tech-Transfers	Start-up Business 5 years and older
Physics in General							
Energy							
Climate and Weather							
Health (biophysics, medical physics)							
Big Data							
Artificial Intelligence							

5.4 Do you face any of the following barriers and challenges in producing any of these R&D outputs such as publications, patents, prototypes, commercial products, start-ups, etc.? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Lack of Skills/Training					
Lack of Human Capital /People to do the work					
Lack of Funding					
Lack of Equipment / Infrastructure					

Please list additional barriers and challenges in producing any of these R&D outputs below.

Section 6: Research Collaborations, Partnerships and Networks

6.1 The collaboration between universities and industry/private sector is a vehicle to enhance innovation, knowledge transfer, and solving socio-economic problems. Is your department involved in any of the following forms of university-industry collaborations?

	Yes	Uncertain	No
Student internships/attachments and/or sandwich courses with industry			
Joint supervision of postgraduate students' thesis			
Joint appointments lectures/industry positions			
Shared use of university and industrial facility (e.g., lab, database, etc.)			
Contract research / Institutional consultancy to industry			
Industrially sponsored R&D programmes in university e.g. Research grant, gifts, endowments, trusts donations			

Please share any further forms of university-industry collaborations below.

6.2 Does your department or institution currently participate in research or capacity building collaborations/partnerships related to physics with other organisations within the proposed partner countries (UK, Kenya, South Africa, Ghana, Nigeria, Malawi, Tanzania, Rwanda, Uganda, or Ethiopia)? Also think in terms of large-research facilities that you access internationally for your research, joint post-grad supervisions, government bilateral co-operations in which you participate etc.

	Name of Partner(s)	Country	Nature of Partnership/Collaboration	Role in project	Funder
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

6.3 Is your institution currently receiving funds/grants to undertake applied physics research and innovation in the 5 thematic areas from proposed partner countries (UK, Kenya, South Africa, Ghana, Nigeria, Malawi, Tanzania, Rwanda, Uganda, or Ethiopia)? If yes, please provide details below.

	Funder Name	Country	Type of Funder (Govt, Private, NGO/Charity/NPO)	Grant Focus Area (e.g. Energy Research, Equipment, Bursary etc)	Duration
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

6.4 In your partnerships, collaborations, or funding agreements, what would you describe as challenges faced and what has made these partnerships or collaborations successful?

Factors Supporting Successful Collaborations, Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Well defined objectives and deliverables from the start					
Good project Management					
The ability to conduct financial Reporting					
Senior Management Support					
Government support (multi-and bilateral agreements covering collaboration)					
A multi-disciplinary project team (e.g. finance, project management, research skills etc in one team)					
Trust and open communication within the project team (e.g. when challenges are faced, or deadlines need adjustment)					
Knowledge and understanding of partner country national culture					
Existence of Long-Term Relationships with Partner (Previous projects with same partner / personnel)					

Please specify any other factors supporting successful collaborations.

6.5 **Challenges faced in executing collaborations**, Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Contradictory objectives between parties for example academic publications vs profit					
Different Strategic timelines for research vs Private sector (e.g. universities focussing on long-term R&D while industry focus on short-term financial returns)					
Geographic distance					
Time pressure and tight deadlines					
Multiple stakeholders with different objectives					
Institutional bureaucracy					
Lack of incentives					
Lack of cross-cultural understanding and different cultural values					

Please specify any other challenges faced in executing collaborations below.

Section 7: Africa-UK Physics Collaboration Participation Potential

7.1 What benefits do you foresee the Africa-UK Physics Partnership Programme bring to your institution? These can be related to your needs in terms of building capacity in the 5 thematic areas

Comment only when you choose an answer.

Research Infrastructure	
Attracting more students	
Human Capital Development	
Funding	
Other (Please specify)	

7.2 The following are generally claimed to be factors that will help in improving Physics Research Capacity. Do you also require similar interventions to help improve your institution's physics research capacity? Please tick the appropriate box below

	1 Strongly Disagree	**2 Disagree**	**3 Neither agree nor disagree**	**4 Agree**	**5 Strongly Agree**
Access to research infrastructure locally and internationally					
Conducive R&D environment created by government policies					
R&D Human Capital Development/ Skills Development					
Training and skills development for technicians and support staff					
Attracting and increasing the number of student enrolments in physics					
Human Capital Retention (ability to have staff that stay for a long time)					
Access to Funding					
R&D Management Skills					
Writing skills for academic publications					
Cooperation with established researchers					
Establishment of Inter-and Multidisciplinary Research Teams					

Please specify any other factors that can help improve physics research capacity below.

7.3 The following are suggested as factors that will help improve innovation & commercialisation Capacity. Do you require similar interventions to help improve your institution's innovation and commercialisation capabilities? Please tick the appropriate box below

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
Industry, Government or NGO partnerships					
Research that is linked to existing socio-economic challenges					
Access to funding					
Innovation and commercialisation management skills					
Start-up/ business growth and expansion skills					
Intellectual property protection and patenting skills					
Establishment of innovation clusters / hubs					

Please specify any other factors that can help improve physics innovation and commercialisation below.

7.4 Are there any Physics Capacity Building Reviews or Initiatives your department has been involved in, either at the institutional, national, or regional level? These can be for physics training or research infrastructure development. If Yes, please specify (email reports if available, or add a weblink)

7.5 Please feel free to add any additional information about the state of applied physics with a focus on the 5 thematic areas in your country and emphasising/prioritising where support is most needed.

7.6 We will be conducting follow up interviews and running online workshops with selected survey respondents, please indicate if you would be happy to participate in these.

Yes	
No	

Thank you for helping shape the Africa-UK Physics Partnership Programme.

Appendix 2: Survey data tables

Table 1: Staff working in physics in general by career and gender

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	91	35	120	30	89	23	274	74	736	50.1%
Senior Staff	118	17.00	86	24	64	17	346	60	732	49.9%
Sub Total	209	52	206	54	153	40	620	134	1468	
% Per Category	80.1%	19.9%	79.2%	20.8%	79.3%	20.7%	82.2%	17.8%		

Table 2: Staff working in energy

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	59.00	24	29.00	14	22.00	16	95.00	36.00	295	54.1%
Senior Staff	22.00	6.00	28	8.00	14	3.00	139	30.00	250	45.9%
Sub Total	81	30	57	22	36	19	234	66	545	
% Per Category	73.0%	27.0%	72.2%	27.8%	65.5%	34.5%	78.0%	22.0%		

Table 3: Staff working in climate and weather

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	9.00	5.00	18	2.00	22	4.00	36	11.00	107	52.5%
Senior Staff	5.00	0.00	15	1.00	9	2.00	56	9.00	97	47.5%
Sub Total	14	5	33	3	31	6	92	20	204	
% Per Category	73.7%	26.3%	91.7%	8.3%	83.8%	16.2%	82.1%	17.9%		

Table 4: Staff working in physics in health (medical, health and biophysics)

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	6.00	1.00	11.00	2.00	9.00	2.00	28.00	7.00	66	43.7%
Senior Staff	5.00	2.00	13	3	9	3	42	8	85	56.3%
Sub Total	11	3	24	5	18	5	70	15	151	
% Per Category	78.6%	21.4%	82.8%	17.2%	78.3%	21.7%	82.4%	17.6%		

Table 5: staff working in big data

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	4.00	1.00	7.00	2.00	8.00	3.00	31.00	13.00	69	55.2%
Senior Staff	3.00	1.00	6.00	2.00	5.00	0.00	35.00	4.00	56	44.8%
Sub Total	7	2	13	4	13	3	66	17	125	
% Per Category	77.8%	22.2%	76.5%	23.5%	81.3%	18.8%	79.5%	20.5%		

Table 6: Staff working in Artificial Intelligence

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Early Career	3	0	6	2	6	3	17	5	42	65.6%
Senior Staff	2	1	3	0	3	1	10	2	22	34.4%
Sub Total	5	1	9	2	9	4	27	7	64	
% Per Category	83.3%	16.7%	81.8%	18.2%	69.2%	30.8%	79.4%	20.6%		

Table 7: Staff by highest qualification

	Technician (M)	Technician (F)	Teaching (M)	Teaching (F)	Research (M)	Research (F)	Teach& Research (M)	Teach& Research (F)	Total	%
Certificate	20	2	0	0	0	0	0	0	22	2.0%
Diploma	46	11	0	0	0	0	0	0	57	5.1%
BSc	24	3	1	0	1	0	12	2	43	3.8%
Hons	46	20	8	3	4	2	11	3	97	8.6%
MSc	14	2	37	15	19	8	129	41	265	23.6%
PhD	4	0	87	18	79	15	369	67	639	56.9%

Table 8: Students training for physics in general

	BSc (M)	BSc (F)	Hons (M)	Hons (F)	MSc (M)	MSc (F)	PhD (M)	PhD (F)
Number	705	370	903	304	287	92	115	40
Percentage	66%	34%	75%	25%	76%	24%	74%	26%

Table 9: R&D outputs

	Publications	Patents	Prototypes	Commercialised Products	Tech-transfers	Start-up 5yrs and older
Physics in General	3307	5	15	11	2	1
Energy	614	1	14	2	7	2
Climate and Weather	475		1		2	1
Health, Medical and Biophysics	266		3			
Big Data	379				2	
AI	281					

Appendix 3: Bibliometrics for international large-scale research facilities collaboration

This appendix gives a summary of Africa-UK partner countries collaboration with international large- scale research facilities using co-authored papers mentioning at least one of the SSA partner countries and a large-scale research facility (WoS core Collection).

The number of papers/collaborations started to grow exponentially from 2010. South Africa has the largest number of papers co-authored with international large-scale research facilities. CERN is the biggest facility used, and particle physics the largest field of research. The top collaborating countries are the USA and the UK. Very high-quality papers are produced from these collaborations with an average citation ratio of 52.93 compared to physics field citation rate of 8.74 per paper.

Total number of records found is 2 307 (Web of Science Core Collection)

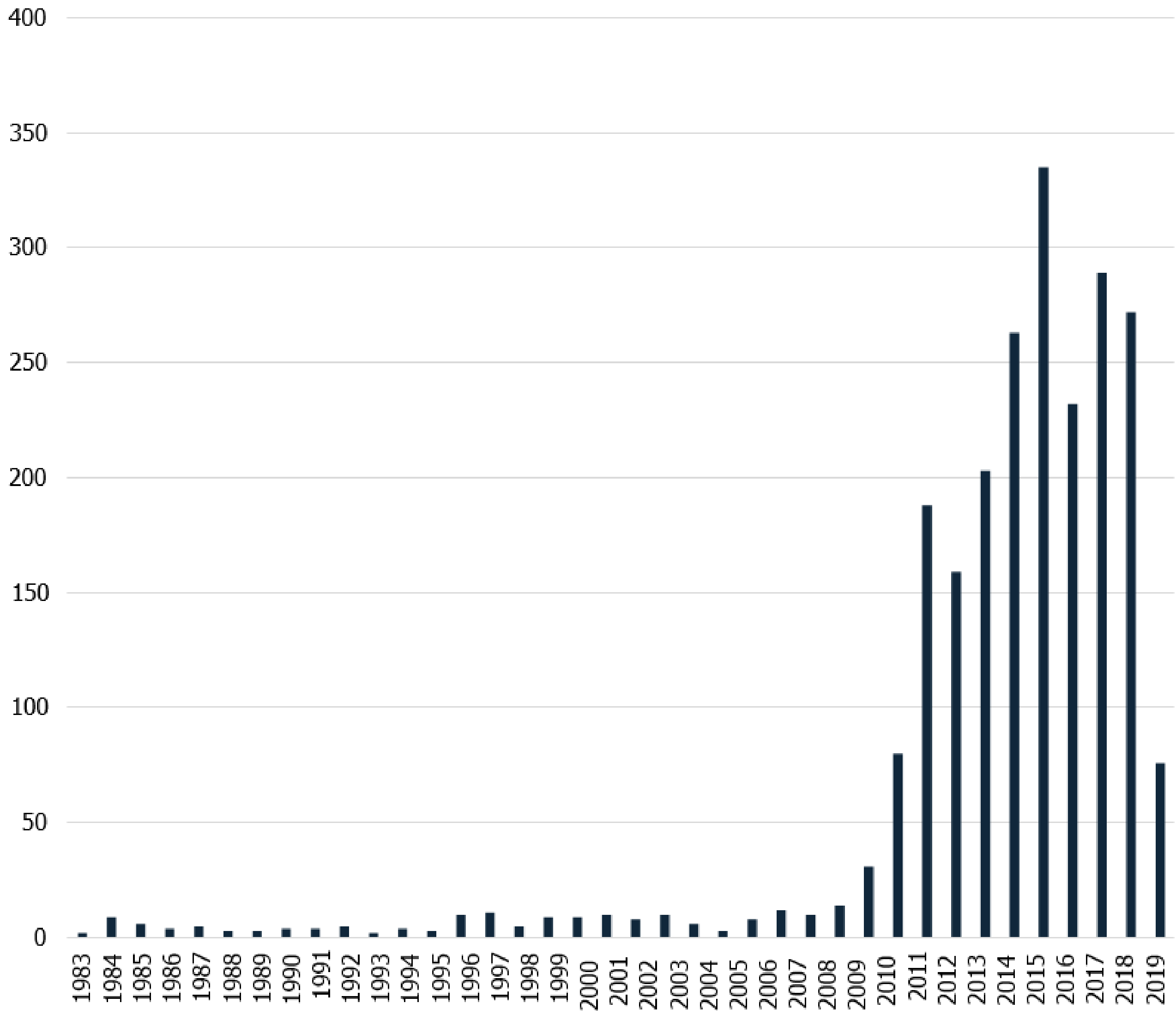

Figure 35: publications co-authored by large international facilities with partner countries per year

A) Top 30 Research Areas

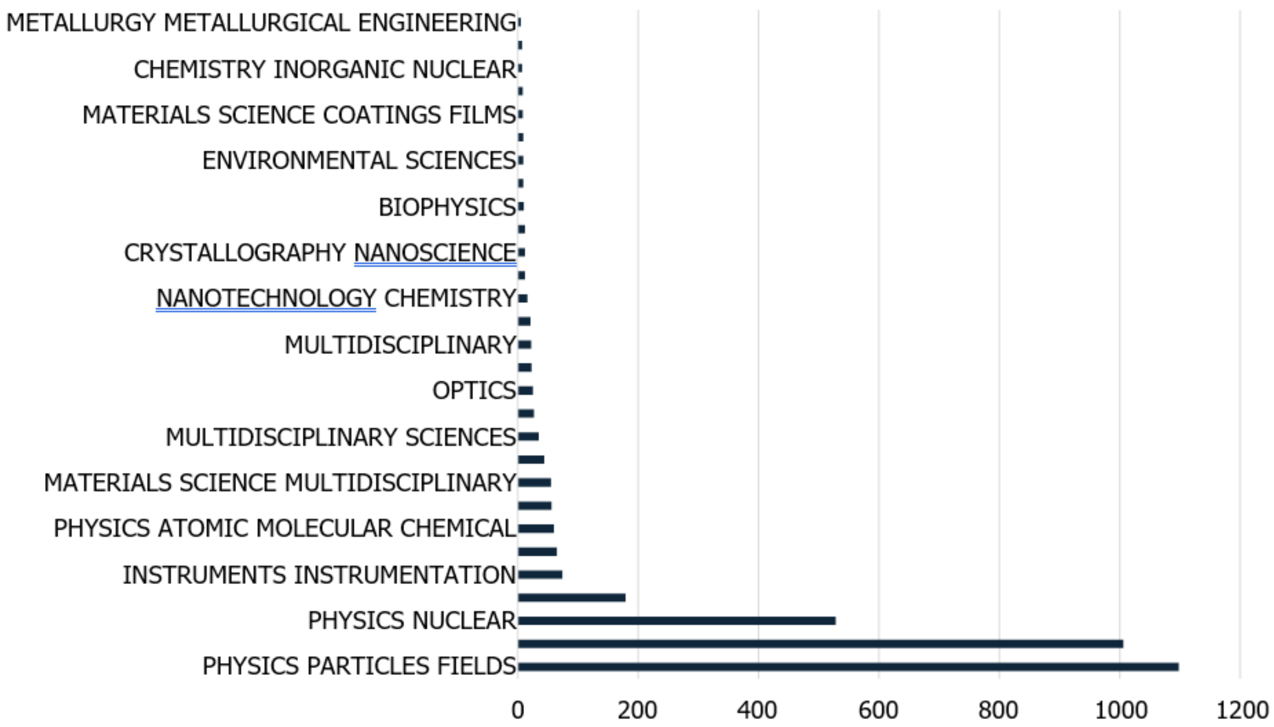

Figure 36: number of publications per research areas for large-scale co-authored papers

B) Quality of Papers

H-Index of 149 and average citations per paper of 52.93 per paper. This is very high quality as compared to the physics average field citation rate of 8.74 per paper[51] indicating that papers from large facility collaboration are very high-quality papers.

C) Publications per country

Table 10 shows the number of publications with international large-scale research facilities. South Africa has by far the largest share of papers co-authored with international large-scale research facilities.

Table 10: number of publications co-authored with international large-scale facilities per country

Country	# Records
South Africa	2253
Nigeria	17
Namibia	15
Kenya	7
Uganda	6
Ethiopia	5
Tanzania	5
Ghana	4
Malawi	1
Rwanda	1

[51] http://csr.spbu.ru/wp-content/uploads/2010/09/aver_cit_fields.pdf

D) Publications per research facility

Table 11 shows that CERN has the highest number of papers co-authored with the project partner countries.

Table 11: number of publications co-authored with large-scale international facilities per facility

Facility Name	# Records
CERN	1477
ARGONNE	1176
SLAC	1088
BROOKHAVEN	1032
DESY	990
SKA	315
DIAMOND	92
ELETTRA	27
ESRF	13
LIGO	10
AUS SYNCH	8
ESS	6
ALBA	4
SOLEIL	2
Canadian Light Source	1
ISIS	1
XFEL	1

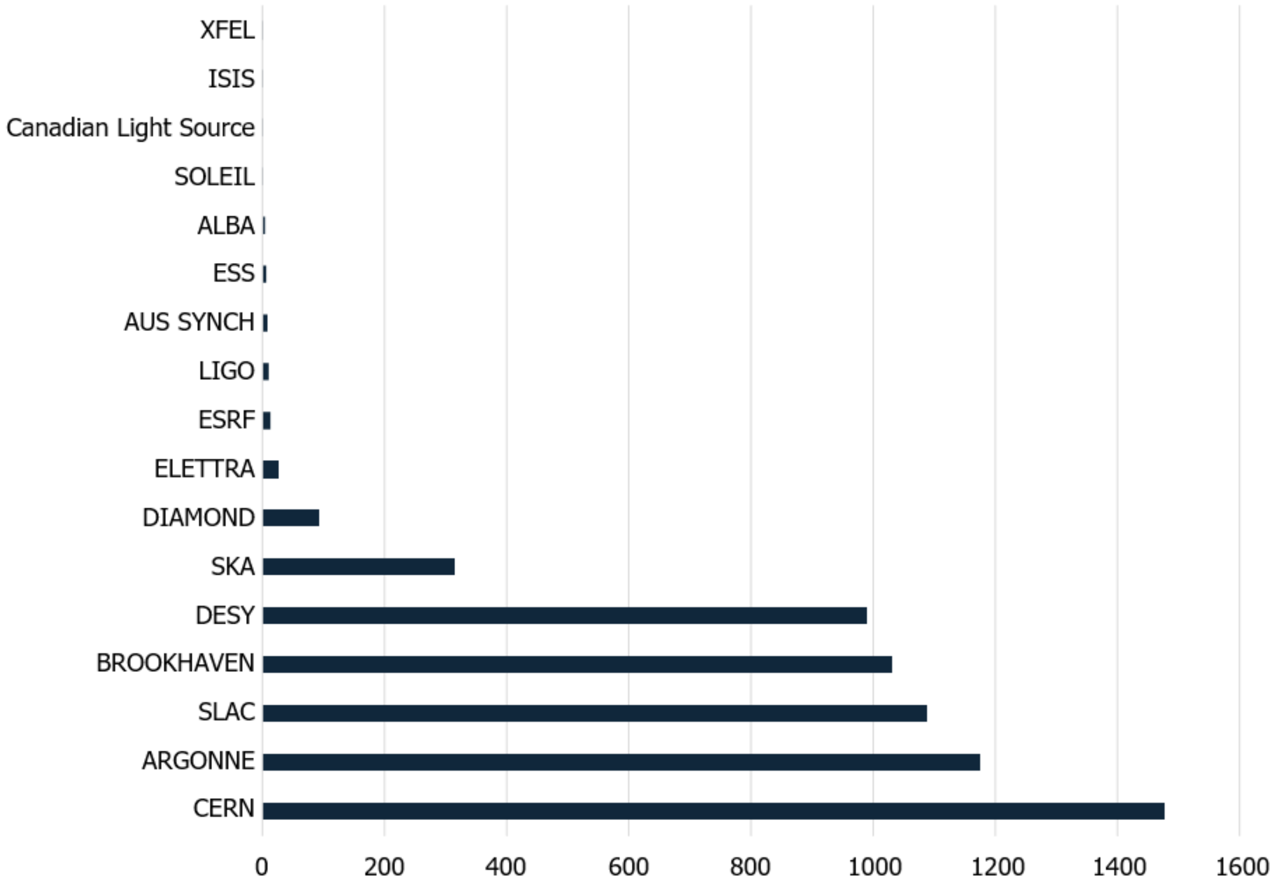

Figure 37: publications co-authored per international large-scale research facility

E) Co-authored papers between partner countries and large-scale research facility

Table 12: number of publications co-authored between country and facility

Large-scale research facility	# Records		CERN	ARGONNE	SLAC	BROOKHAVEN	DESY	SKA	DIAMOND	ELETTRA	ESRF	LIGO	AUS SYNCH	ESS	ALBA	SOLEIL	Canadian Light Source	ISIS	XFEL
1	2253	South Africa	1467	1156	1087	1027	990	315	79	24	13	10	7	6	4	2	1	1	1
2	17	Nigeria	1	10	1	1		4		2	1								
3	15	Namibia	1	10	7	2	9	2				1							
4	7	Kenya	1	2		3		2											
5	6	Uganda		4				2	1										
6	5	Ethiopia	1	1	2	1				1	1								
7	5	Tanzania	1	3		1													
8	4	Ghana	1	2				1											
9	1	Malawi		1				1											
10	1	Rwanda			1	1					1								

F) Collaborating countries on large-scale research facility

Table 13: number of publications co-authored between partner countries and top collaborating countries

Countries	# Records		South Africa	USA	UK	Germany	France	Switzerland	Italy	Netherlands	Spain	Brazil	Russia	Denmark	Poland	Sweden	Japan	China	Norway	Romania	Armenia	Australia
1	2253	South Africa	2253	1874	1774	1703	1635	1606	1583	1485	1444	1434	1411	1404	1380	1374	1371	1340	1328	1295	1275	1266
2	17	Nigeria	6	15	6	3	3	2	5	3	3	3	2	2	1	3	4	2	2	2		3
3	15	Namibia	15	15	15	13	14	12	12	6	13	11	1	6	9	8	12	2	1	1	8	13
4	7	Kenya	2	7	3	3	1	2	2	1	1	1	1	1	1	1	2	1	1	1		2
5	6	Uganda	3	5	3	2	2	1	2	2	2	1	1	1	2	2	1	1	1	1		2
6	5	Ethiopia	1	3			1	1	2							1	1	2				
7	5	Tanzania		5	2			1						1		1						
8	4	Ghana	2	3	3		1	1			1											
9	1	Malawi	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
10	1	Rwanda	1	1			1									1	1					

Appendix 4: Programme stakeholders and study participants

A) Africa-UK Physics Partnership Programme stakeholders

The Programme involves Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Tanzania, and Uganda as partner countries. Stakeholders for the programme will include; Government departments responsible for science, education, health, industry and energy; science councils, universities, university networks (e.g. African Research Universities Alliance), academics and researchers, pre- tertiary schools, CoEs, research chairs, national science funding agencies and national research facilities, international large-scale research facilities, charities supporting science and education, scientific bodies such as the International Union of Pure and Applied Physics(IUPAP), International Centre for Theoretical Physics (ICTP) and African Institute of Mathematical Sciences (AIMS); science arms of regional bodies South African Development Community (SADC), African Union and The New Partnership for Africa's Development (NEPAD); existing physics networks, national physical societies and Academies of Science.

B) Study participants

i. Survey consultation participants

Name	Title/ Affiliation	Organisation	Country
Prof Janet Ayobami Ademola	Head of Department, Physics	University of Ibadan	Nigeria
Prof Paul Baki	Head of Department, Physics	Technical University of Kenya	Kenya
Dr Julius Butime	Head of Engineering Programmes	Strathmore University	Kenya
Dr Cosmas Dumba	Lecturer	Mbarara University of Science and Technology	Uganda
Prof Ernest van Dyk	Head of the Photovoltaics Research Group	Nelson Mandela University	South Africa
Prof Igle Gledhill	Principal Scientist	CSIR/ University of the Witwatersrand	South Africa
Mr Offoro Kimambo	Lecturer	Sokoine University of Agriculture	Tanzania
Dr Korir Kiprono Kiptiemoi	Lecturer, Biological and Physical Sciences	Moi University	Kenya
Dr Christine Kyarimpa	Medical Scientist & Researcher	Kyambogo University	Uganda
Prof Bruce Mellado	Director of the Institute for Collider Particle Physics	University of the Witwatersrand	South Africa
Dr Consalva Msigwa	Lecturer & Principal Investigator (Education for Renewables)	Dar es Salaam Institute of Technology	Tanzania
Mr Nestor Mugabe	Research Administrator, Directorate of Research and Graduate Training	Makerere University	Uganda
Dr George Mulamula	CEO	Technivate Advisory Services	Tanzania

Prof Azwinndini Muronga	Dean of Science	Nelson Mandela University	South Africa
Ms Judith Irene Nagasha	Lecturer, Development Studies	Kyambogo University	Uganda
Prof Deena Naidoo	Head of Department, Physics & Chair of SAIP	University of the Witwatersrand	South Africa
Mr Sonwabile Ngcezu	Head of Department, Medical Physics	University of the Witwatersrand	South Africa
Prof Folorunso Ogundare	Dean of the Faculty of Science	University of Ibadan	Nigeria
Dr Vitalis Ozianyi	Lecturer, Faculty of Information Technology	Strathmore University	Kenya
Prof Winston Tumps Ireeta	Head of Department, Physics	Makerere University	Uganda

ii. Interview participants

Name	Title/Affiliation	Organisation	Country
Dr Yinka Ajiboye	Department of Physics	Afe Babalola University	Nigeria
Prof Omololu Akin-Ojo	Director	East African Institute for Fundamental Research	Rwanda
Mr Emirant Ambayo	Assistant Lecturer	Busitema University	Uganda
Dr Akyana Britwum	Lecturer, Physics	Khwame Nkrumah University of Science & Technology (KNUST)	Ghana
Prof Simon Connell	Department of Physics	African Light Source & University of Johannesburg	South Africa
Prof Mmanstae Diale	Department of Physics	University of Pretoria	South Africa
Dr Cosmas Dumba	Lecturer	Mbarara University of Science and Technology	Uganda
Prof A J Ekpunobi	Department of Industrial Physics	Nnamdi Azikiwe University	Nigeria
Prof Igle Gledhill	Principal Scientist	CSIR/ University of the Witwatersrand	South Africa
Dr Festo Kiragga	Department of Physics	Gulu University	Uganda
Prof Mawuadem Koku Ameedeker	Associate Professor, Physics	University of Education, Winneba	Ghana
Mr Stephen Loader	Head of Innovation & International Development	UKRI-STFC	UK
Dr John Makokha	Senior Lecturer	Kibabii University	Kenya
Dr Nuru Mlyuka	Senior Lecturer	University of Dar Es Salaam	Tanzania
Dr Najat K. Mohammed	Head of Department, Physics	University of Dar Es Salaam	Tanzania
Dr Consalva Msigwa	Lecturer & Principal Investigator (Education for Renewables)	Dar es Salaam Institute of Technology	Tanzania
Mr Michael Nxumalo	Director, Africa Collaborative Grants & Initiatives	National Research Foundation	South Africa
Dr Michael Okullo	Head of Department, Physics	Kyambogo University	Uganda
Prof John Okumu	Deputy Vice-Chancellor, Academic	Kenyatta University	Kenya

Dr Michael Oloko	Dean of Engineering & Technology	Jaramogi Oginga Odinga University of Science & Technology (JOOUST)	Kenya
Prof Elijah Oyeyemi	Department of Physics	University of Lagos	Nigeria
Dr Ronald K Rop	Chairman, Department of Physics	Egerton University	Kenya
Dr Tilahun Tesfaye	Assistant Professor, Physics	Addis Ababa University	Ethiopia
Prof Winston Tumps Ireeta	Head of Department, Physics	Makerere University	Uganda

iii. Validity consultation participants

Name	Title/Affiliation	Organisation	Country
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Prof Paul Baki	Head of Department, Physics	Technical University of Kenya	Kenya
Dr Julius Butime	Head of Engineering Programmes	Strathmore University	Kenya
Prof Ernest van Dyk	Head of the Photovoltaics Research Group	Nelson Mandela University	South Africa
Prof Igle Gledhill	Principal Scientist	CSIR/ University of the Witwatersrand	South Africa
Mr Offoro Kimambo	Lecturer	Sokoine University of Agriculture	Tanzania
Dr Korir Kiprono Kiptiemoi	Lecturer, Biological and Physical Sciences	Moi University	Kenya
Dr Justus Kwetegyeka	Dean Faculty of Science	Kyambogo University	Uganda
Ms Ndanganeni Mahani	Project Officer	South African Institute of Physics	South Africa
Dr Terry Mawby	Head of International (Rest of World)	STFC-UK	UK
Prof Bruce Mellado	Director of the Institute for Collider Particle Physics	University of the Witwatersrand	South Africa
Dr Consalva Msigwa	Lecturer & Principal Investigator (Education for Renewables)	Dar es Salaam Institute of Technology	Tanzania
Prof Azwinndini Muronga	Dean of Science	Nelson Mandela University	South Africa
Ms Judith Irene Nagasha	Lecturer, Development Studies	Kyambogo University	Uganda
Prof Deena Naidoo	Head of Department, Physics & Chair (SAIP)	University of the Witwatersrand	South Africa
Mr Sonwabile Ngcezu	Head of Department, Medical Physics	University of the Witwatersrand	South Africa
Dr Daniel Nyanganyura	Regional Director, Africa	International Science Council	Pan-African
Mr Angel Nyirenda	Lecturer, Physics and Electronics	Mzuzu University	Malawi
Prof Winston Tumps Ireeta	Head of Department, Physics	Makerere University	Uganda
Prof Patrick Woudt	Head of Department, Astronomy	University of Cape Town	South Africa