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Renewable energy doctoral programmes in sub-Saharan Africa: A preliminary assessment of common capacity deficits and emerging capacity-building strategies

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ABSTRACT

Renewable energy technologies offer many advantages in sub-Saharan Africa, but widespread deployment will require strong endogenous innovation capabilities. Universities in general and doctoral research in particular play a key role in tailoring technologies to local contexts and equipping future educators, policymakers and entrepreneurs with relevant skill sets. This capacity assessment of four sub-Saharan African universities identifies common functional capacity deficits in their renewable energy PhD programmes: (1) highly centralised institutional arrangements, (2) lack of accountability for supervisors, (3) tendency to produce low-impact research, and (4) poor physical infrastructure, particularly internet access. However, this cross-institutional comparison also highlights low- or no-cost capacity-building strategies that are being piloted within the four universities, including joint supervision policies, weekly seminar programmes, the establishment of specialist centres to engage stakeholders and the introduction of internal monitoring processes. These results suggest that, despite limited resource envelopes and with mutual learning, there is substantial scope to enhance the quality of renewable energy doctoral programmes in sub-Saharan African universities.

1. Introduction

1.1. Energy supply in sub-Saharan Africa

At night, a view of the world from space reveals significant differences in the global distribution of energy supply, with much of sub-Saharan Africa in darkness [1]. Even those areas that do have energy supply infrastructure, such as major cities, suffer from frequent disruptions to supply, and electricity consumption per capita remains low at just 6% of the global average (excluding South Africa) [2]. Since the provision of reliable, affordable electricity has a multiplier effect on development [3], increasing generation capacity and electrification rates is one of the key goals of African energy policy [4].

Electricity demand across the continent is expected to double between 2012 and 2035 [5]. When determining how to meet growing demand, it is important that policymakers take into account the relative social value of different energy options [6]. Several African countries have significant fossil fuel resources in the form of coal and gas that could be used for power generation.[1] However,

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[1] "African net oil exporters include: Algeria, Angola, Cameroon, Chad, Democratic Republic of Congo, Congo Republic, Equatorial Guinea, Gabon, Libya, Nigeria, and Sudan. Other producers are Cote d'Ivoire, Egypt, Mauritania, South Africa, and Tunisia. Emerging and potential oil producers are Ghana, Kenya, Liberia, Mozambique, Niger, Sao Tome & Principe, Sierra Leone, Somalia, Tanzania, and Uganda. With respect to gas, Algeria, Egypt, Equatorial Guinea, Libya, Mozambique and Nigeria are net exporters while other producers include Angola, Cameroon, Congo, Cote d'Ivoire, Gabon, Morocco, Senegal, South Africa, and Tanzania." [50] (pp. 1)

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Africa's vulnerability to the impacts of climate change suggests that new electricity generation capacity should preferentially be from low carbon sources. The continent's major economic sectors – agriculture, forestry and fishing – are highly sensitive to climate variability. Food insecurity, water stresses and the spatial distribution of vector-borne diseases are likely to increase with warmer average temperatures. Endemic poverty, poor institutional capacity, ecosystem degradation and limited access to capital mean that most of the continent has weak adaptive capacity [7]. While Africa has contributed only 7.1% of total global emissions (overwhelmingly from Nigeria and South Africa) [8], and therefore bears little responsibility for climate change, the high social cost of carbon emissions justifies African efforts to pursue a low carbon development path.

Nuclear power is one low carbon option. South Africa already generates 7% of its electricity from nuclear power [9], and Namibia and Niger have 16% of the world's uranium deposits [10].

However, renewable energy technologies offer particular advantages in an African context. There is vast latent potential for renewable energy generation including 1800 TWh per year of technically accessible hydropower [11], geothermal generation potential of up to 20 GW in the eastern Rift Valley, daily solar radiation of 5–6 kWh/m^2 and wind speeds of 7.2–9.7 m/s around the southwest coastline [11] (for a detailed assessment of wind energy potential, see [12]). Renewable energy technologies could reduce dependence on costly fuel inputs, which are subject to volatile international prices. Above all, the modular design of many modern renewable energy technologies could allow deployment away from major centres and incrementally as energy demand grows [13]. Modular renewable energy systems make electricity generation feasible in rural and peri-urban areas, where energy poverty is concentrated. This suggests that many African countries could 'leapfrog' fossil fuel energy use and improve energy access more efficiently by prioritising decentralised renewable energy technologies over fossil fuel options [14].

1.2. Need for local capacity

These opportunities have not been exploited because of deficits in human, organisational and institutional capacity as much as scarce financial resources [15]. Ockwell et al. [16] argue that technology transfer and financial support are not sufficient to allow low-income countries to pursue low carbon development paths; developing countries must become low carbon producers and innovators. Expanding clean energy access and supply requires local energy innovations, a transformation of incumbent energy systems, and engagement with the costs and benefits of alternative low carbon pathways [17].

This suggests that African countries urgently need to build endogenous capabilities across a wide range of fields relating to the development and deployment of renewable energy technologies. Regulators need to improve understanding of more sophisticated market forms (for example, retail or wholesale electricity markets instead of vertically integrated utilities), judicial systems need to enhance capacity to handle complex contracts and public officials need to develop the ability to manage power purchase agreements [18]. Governments and social businesses also need to refine the development of marketing, selling or financing mechanisms appropriate to more remote areas in order to address energy poverty. However, Simalenga [19] identifies 'training the trainers' as the 'first priority' in promoting renewable energy technologies. While Simalenga name a range of educational strategies, from primary education to tertiary level research to public awareness campaigns, this paper focuses on a critical aspect of 'training the trainers': the calibre of renewable energy doctoral programmes in sub-Saharan Africa.

1.3. African doctoral programmes in low carbon energy technologies

Low-income countries need to build their research capacities in order to ensure a suitably large and skilled cadre of prospective researchers and educators working on renewable energy [20]. Research capacity-building can be defined as 'a process of individual and institutional development which leads to higher levels of skills and greater ability to perform useful research' [21] (pp. 1321). While there are many strategies available to build local capacity, this paper specifically focuses on improving doctoral programmes in Africa for two reasons.

Firstly, doctoral programmes provide a valuable tool for training new researchers. While many other research institutions contribute to technological innovation and policy design, universities have a fundamental role to play in initiating and guiding social, economic and technical change [22]. As Léautier [23] writes (pp. 2):

> "*Academic capacity can be judged as to its contribution to the capacities needed to define and implement policies, to uncover innovations that solve the unique challenges facing countries, and to generate the cadre of leaders needed to transform societies and economies. Indeed, universities are at the top of the transformation chain that generates the skills and competences needed in development*."

Few universities in developing countries in sub-Saharan Africa are currently able to 'home grow' the world-class researchers necessary to deliver the technical and socio-economic innovations necessary to pursue low carbon development paths [24]. Improving the calibre of renewable energy doctoral programmes offers one way to help redress a critical skills shortage across the continent. While PhD recipients frequently transition out of academia [25], there are still positive externalities to investing in renewable energy research skills. Whether graduates apply their expertise in the public, private or not-for-profit sector, they have the potential to stimulate broader economic productivity by increasing energy supply and avoid the negative externalities of additional carbon emissions. Renewable energy research also generates knowledge spillovers comparable in scale to those observed in the IT sector [26].

Secondly, universities in Africa can serve as 'development hubs' by, among other things, providing education services according to social needs [27]. African universities today urgently need to improve the quality and relevance of teaching to respond to skill shortages in the broader economy [27,28]. Certainly, the expansion of renewable energy generation envisioned in the introduction to this paper will need to be supported with appropriate education and training systems [29]. Doctoral programmes provide a means to train a cadre of future educators in renewable energy technologies, so that they can effectively communicate this knowledge when teaching undergraduate and postgraduate courses. Investing in renewable energy doctoral programmes therefore has the potential to have a multiplier effect on relevant technical capacity in Africa by 'training the trainers' [19] (pp. 117).

Despite their importance, there has been little published research to date on the quality of renewable energy doctoral programmes in sub-Saharan Africa. This paper seeks to redress this gap by applying a pioneering doctoral capacity assessment methodology developed for the health sector to the field of renewable energy research. The results offer some important insights into key capacity gaps in sub-Saharan African universities, and low or no cost pilot programmes that could enhance the calibre of doctoral research in this field. Four universities serve as case studies: Kwame Nkrumah University of Science and Technology (KNUST) in Ghana; University of Dar es Salaam (UDSM) in Tanzania; University of Makerere in Uganda; and Université Marien NGouabi (UMNG) in the Republic of the Congo. This research is part of a networking project on renewable energy funded by the Royal Society-DfID Africa Capacity-building Initiative.

The remainder of this paper is divided into four sections. Section 2 introduces the four universities included in this study and the methodology employed, developed by [30]. Section 3 summarises the results of the capacity assessment, looking at the major functional capacity gaps in the four university case studies and strategies currently in place to address these deficits. Section 4 identifies technical capacity-building priorities in the region, and discusses the scope for doctoral programmes to meet these needs. Section 5 offers some recommendations to research institutions, funders and partners seeking to build sub-Saharan Africa's capacity to conduct and lead renewable energy research.

2. Methods

2.1. Case studies

We assessed renewable energy doctoral programmes available at four universities: Kwame Nkrumah University of Science and Technology (KNUST) in Ghana, University of Dar es Salaam (UDSM) in Tanzania, University of Makerere in Uganda, and Université Marien NGouabi (UMNG) in the Republic of the Congo. These four, which gained fully independent university status between 1961 and 1971, were selected based on three criteria. Firstly, they are the largest public universities in their respective countries. Secondly, all of the universities included in this analysis are public universities that operate under decentralised collegiate systems. Thirdly, they are part of a capacity-building research consortium that focuses on renewable energy technologies, along with the University of Leeds in the United Kingdom. This assessment was completed as part of a broader capacity-building and research planning exercise. Below is a brief overview of the universities, including number of students and relevant energy programmes.

- The Kwame Nkrumah University of Science and Technology (KNUST) in Ghana has approximately 45,580 students, of whom 7141 are postgraduates. Most of the research on energy is under the umbrella of The Energy Centre, which focuses on solar photovoltaic panels, concentrated solar power (CSP) and bioenergy (biogas, biodiesel and bioethanol). The Centre has a strong focus on applied energy research, providing consultancy services to policymakers and training programmes to prospective renewable energy professionals.
- The University of Dar es Salaam (UDSM) in Tanzania has approximately 19,700 students, of whom roughly 2600 are postgraduates. The Department of Electrical Engineering specialises in, among other energy research, the development and optimisation of hybrid renewable energy systems. This involves the use of power electronics equipment such as converters for electric energy transactions.
- The University of Makerere in Uganda has approximately 40,000 students, of whom roughly 10,000 are postgraduates. Clean energy research is led by the Centre for Research in Energy and Energy Conservation (CREEC), within the College of Engineering, Design, Art and Technology. CREEC conducts largely applied research on energy management, solar photovoltaic (PV), pico-hydropower and biomass, with a large focus on clean energy technology transfer to the business community and general public.
- The Université Marien NGouabi (UMNG) in the Republic of the Congo has approximately 25,000 students, of whom 3000 are postgraduates. The Department of Physics specialises in solar photovoltaic (PV) technologies, particularly the optical and transport properties of dye sensitive solar cells, electronic structure and magnetism of low dimensional systems and catalysis chemisorption properties of thin films.

2.2. Identifying capacity deficits

A range of institutional capacity-building guidelines are available in the academic and grey literature (for example, see [31,32]). This paper uses a capacity assessment method customised to doctoral programmes in low-income countries, published in [30]. Among other applications, this approach underpins the Capacity-building Initiative launched by the UK Department for International Development and the Royal Society [33]. This is the first documented example of this methodology being applied to renewable energy research.

The methodology in [30] is designed to support universities in the development, implementation and monitoring of strategies to strengthen their doctoral programmes. This paper provides a survey template for academic staff and students, which has been refined through testing in five African universities. The foci of the interview questions are summarised in Fig. 1 from [30] and the full interview matrix used for this paper is included in the supplementary material. This has been slightly modified from the original in [30] to include only questions relevant to PhD supervisors and students.

The interview matrix was completed by the authors during a week-long workshop, with further data subsequently collected by the authors from PhD supervisors and students at their universities. In the workshops, we explicitly focused on doctoral programmes that focused on renewable energy technologies conducted within the Schools of Engineering and Physics. This paper is an outcome of the workshop: the capacity deficits explored in detail below are those which were shared by at least three of the participating universities, or those that participants collectively identified as priority challenges as part of their planning process for future collaborative capacity-building initiatives.

Interviewees included one PhD student from Kwame Nkrumah University of Science and Technology, one from Université Marien NGouabi, and two from University of Makerere. One of the Makerere PhD students participating in this study is also the Head of the Centre for Renewable Energy and Energy Conservation, and therefore has significant managerial and strategic responsibilities within the university. We also interviewed two PhD supervisors from Kwame Nkrumah University of Science and Technology, one from Université Marien NGouabi, two from University of Dar es Salaam and one from the University of Makerere. Participants' responses were triangulated by reviewing the doctoral regulations for each university, where available: *Graduate Training and Research Handbook* [34], *General Regulations and Guidelines for Postgraduate Programmes* [35] and *Entry Requirements and General Regulations for Graduate Programmes* [36]. Doctoral policies and regulations are currently under development at UMNG.

We recognise that this sample size is too small to draw definitive conclusions on its own, particularly since participants are not neutral agents: their individual experiences and subjective interests will shape their view of the university's capacity. This methodology would have been considerably strengthened if we had been able to obtain interviews with the provost, postgraduate dean and staff from the ethics committee, administration, library and IT units, as

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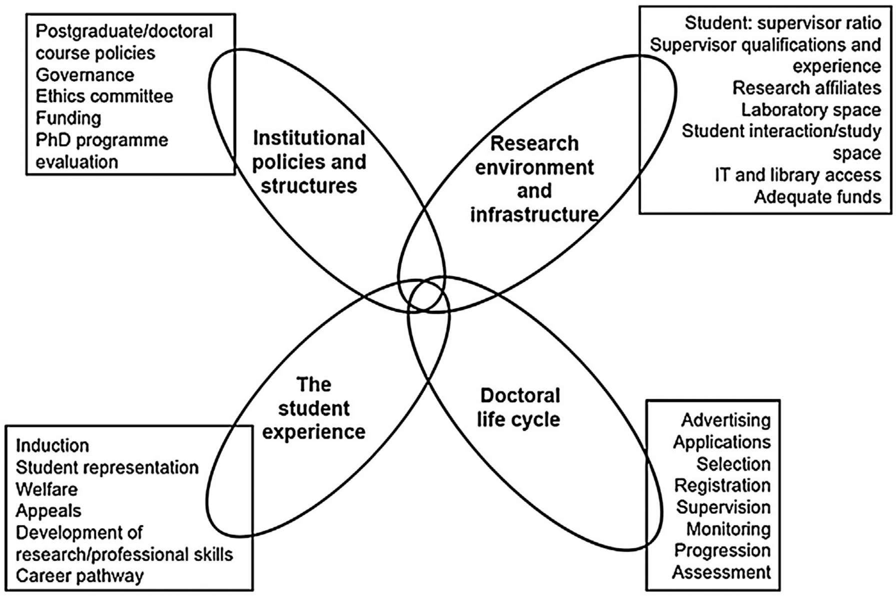

Fig. 1. The four components of doctoral programmes, with examples of the constituents of the components.

From [30].

outlined in the Bates et al.'s [30] methodology. However, this exploration of the particular experiences of PhD supervisors and doctoral candidates will, we hope, provide a useful if preliminary overview of institutional capacity gaps and opportunities with respect to renewable energy doctoral research in sub-Saharan Africa.

3. Institutional capacity gaps and capacity-building strategies

This capacity assessment of renewable energy doctoral programmes at KNUST, UDSM, UMNG and the University of Makerere suggested that there are many areas where PhD supervisors and students are satisfied by their universities' performance. For example, all four universities are considered to have access to wide range of electronic resources, often facilitated by international research partnerships (UMNG) or dedicated national government agencies (UDSM). PhD students and staff also felt that cross-cutting regulations and policies were thorough: for example, provision was made for students with disabilities and the formal assessment criteria outlined in the doctoral handbooks were considered clear and fair. Crucially, doctoral candidates at all four universities have access to skill development classes on research methods and writing for publication.

However, this capacity assessment revealed some functional capacity deficits or challenges shared by most or all of the African universities in this study. For the purposes of this analysis, these gaps have been identified as: (1) highly centralised institutional arrangements, (2) limited accountability for PhD supervisors, (3) low-impact research, and (4) poor infrastructure. However, bringing together representatives of each university also offered cross-institutional lessons about some of the innovative strategies being deployed to redress these capacity deficits.

3.1. Institutional arrangements are highly centralised

The participants in this study were confident of high-level capacity at their university to develop strategic visions and policies. Three of the universities have established university-wide regulations and policies to govern doctoral programmes, which are outlined in handbooks available in hard copies and (for UDSM and Makerere) online. Equivalent guidelines are currently under preparation at UMNG. However, none of the universities in this study issued faculty- or college-level regulations for postgraduate studies, but instead depend on the handbooks issued by the School of Graduate Studies, Directorate of Postgraduate Studies or equivalent. This means that departmental management, senior researchers and doctoral students lack tailored guidelines for the specific programmes within their faculties. Postgraduate programmes are planned by administrative staff in the School of Graduate Studies without involving junior academic and support staff within faculties and colleges. Poor communication by the School of Graduate Studies means that, while each faculty has enough support staff relative to the postgraduate student body, the library, laboratory and IT resources do not necessarily align with those required for doctoral research. This is less the case for UMNG because the university's small size facilitates coordination among departments, although the high degree of centralisation may inhibit future growth and development.

The hierarchical, centralised structures are manifest within faculties as well. The participants in this study stated that coordinating seminar programmes or academic discussions is typically regarded as the prerogative of individual, senior academics. This means that research-led teaching is limited, and doctoral students have limited exposure to other research conducted within their faculty. It also means that there are few spaces where senior academics, doctoral researchers and support staff can interact informally. The exception to this among the universities in this sample was KNUST, where the Energy Centre has established a weekly seminar programme to encourage learning, collaboration and feedback among researchers within the university. Industry representatives are also invited to speak on a regular basis. This ensures that doctoral students are engaged with and integrated into existing academic and industrial research. While the other universities offered occasional lectures or seminars for postgraduate students (particularly during the early stages of their programmes), there was substantial scope to regularise and formalise academic discussions between faculty, students and administrative staff inline with KNUST's initiatives.

3.2. Supervisors are not accountable for doctoral students' progress

The academic handbooks at each university outline systems to protect doctoral students. In practice, however, all participants in this study agreed that the supervisor is regarded as the ultimate authority, and that doctoral candidates can expect to be penalised if they seek recourse to independent channels. This perception leads to poor monitoring or enforcement of formal policies, which in turn means that students face long delays and low completion rates. In one case, these were enshrined in the handbooks: while KNUST has an expected turnaround of five weeks for supervisors to edit thesis drafts, the University of Makerere gives supervisors a six-month window.

Two participants elaborated that cultural norms would not permit students to oppose or criticise their supervisors. Consequently, although conflict resolution guidelines may be laid out in the handbooks ([35]: 32; [34]: 74; [36]: 22), approaching the Dean or Head of Department is regarded as a last resort that students will only pursue if they are likely to lose funding. Even in this case, the participants suggested that students are likely to experience discrimination or retribution by their former supervisors' colleagues. The students are consequently vulnerable to capricious decision-making and over-worked management, and the completion of their doctoral research is enforced by loss of stipends or financing at the end of a four-year period.

It should be clarified that this situation is not solely a consequence of poor professional practice by supervisors. Supervisors have heavy teaching loads, poor remuneration and little support from universities in mentoring junior researchers [37]. None of the universities in this study have established regular initiatives to develop supervisory skills: the PhD supervisors participating in this study learned from experience or international collaboration. All felt that the quality of supervision would benefit from the introduction of training and peer support schemes, a perception that is validated by the literature (for example, see [38,39]).

In the absence of supervisory support systems, all four universities have sought to improve the quality of supervision by establishing a formal policy that all doctoral candidates should be jointly supervised (KNUST actually requires three internal and one external supervisor). Both UMNG and KNUST require one of the supervisors to be based at a foreign university. This offers the student the co-benefits of a valuable network of international researchers, access to a larger collection of electronic resources and exposure to additional funding opportunities.

UDSM has also set individual targets and performance indicators for its PhD supervisors, and has begun monitoring progress against them. The UDSM doctoral programme is divided into phases i.e. a data collection phase, design phase, running of the pilot system and presentation of the achievements. In each of these phases, the student has to defend his/her work to the department and submit a progress report. This evaluation programme is coordinated by a dedicated office for quality assurance, which also conducts tracer studies to collect feedback on UDSM doctoral programmes from graduates and employers. Such mechanisms of endogenous accountability are essential for meaningfully improving performance [40]. Indeed, participants from UDSM stated that they observed improvements in doctoral completion rates within a few years of establishing this new monitoring scheme. It should be emphasised that none of the participants at the other universities knew of any regular systems to monitor supervisors or to collect/provide feedback on doctoral programmes.

3.3. Research is not impact-oriented

Participants from both KNUST and UMNG expressed concerns that faculties do not actively promote engagement with policymakers and other prospective research users. In the case of KNUST, this is because academics independently set their own research projects without consultation with government and industry. In the case of UMNG, participants stated that local policymakers tend not to be receptive to research findings, which further manifests in Francophone Africa in the form of relatively low levels of investment in research-intensive universities.

By comparison, participants from both Makerere and UDSM felt that academic research within their universities is closely aligned with national goals, and that their energy researchers collaborated closely with prospective research users. Makerere has established the Centre for Research in Energy and Energy Conservation (CREEC) for this purpose. CREEC coordinates workshops, guest lectures and training on, for example, manufacturing clean cookstoves, installing solar PV panels and gasifiers or maintaining pico-hydro systems. The model substantially increases researchers' engagement with end users including local communities, NGOs, small business and government. Notably, it offers doctoral students (among other researchers and consultants) experience tailoring energy research to key stakeholders' needs. In Tanzania, the Commission on Science and Technology (COSTECH) provides a vehicle to link research in the country to policymakers. COSTECH is responsible both for commissioning research in response to government needs, and helping researchers to communicate important research findings to policymakers. As well as improving the relevance and impact of academic work, these kinds of research centres can ensure that doctoral students acquire the knowledge and capabilities to respond to skills shortages in the public and private sector.

3.4. Infrastructure is low quality

This capacity assessment identified general concerns about doctoral students' access to physical equipment and working space. Participants from UMNG, KNUST and Makerere emphasised poor or unreliable internet as a major barrier to research and communication within the university. This was most pronounced at UMNG, where Wi-Fi is only available in the central library: senior staff must consequently budget for individual modems, which have low connection speed. Supervisors felt that strong information technology infrastructure could create multiple opportunities for open and distance learning: doctoral students could not only utilise their universities' electronic resources more effectively, but also complete Massive Online Open Courses (MOOCs) and other skill development programmes. This particular capacity deficit would require substantial investment to overcome, often at a regional scale: in 2013, the Republic of the Congo was ranked 137th and Uganda was 146th with respect to ICT development [41]. Therefore, while this capacity assessment identified limited internet access as a severe constraint on doctoral programmes, the participants were unable to identify any low-cost strategies to redress the problem.

4. Regional capacity gaps

Tied closely to the question of infrastructure (Section 3.4) is the question of financing capacity-building initiatives, both within African universities and across the continent. The researchers identified a strong bias in investment and research towards large energy infrastructure, such as power plants (including hydro), wind and solar farms or transmission lines. This is strongly related to donor and lending policies that favour major projects rather than dispersed local individual or community-based generation initiatives. These policies are in turn a response to the relatively high risk-adjusted returns from large energy infrastructure compared with decentralised technologies. This strongly influences the research conducted by sub-Saharan African universities, which generate much of their revenue from consultancy work that tends to be more readily available and better paid on these kinds of large projects.

While the academic focus on large energy systems is understandable, the consequences are problematic. Large energy infrastructure in sub-Saharan Africa mainly serves the resource extraction industry and cities. While it has an important role to play in economic growth and industrial development, it does not meaningfully address the most urgent human development challenges in sub-Saharan Africa. 44.3% of West Africans live in cities and only 21.4% of East Africans [42]: since only 3% of rural households have access to electricity [43], this means the majority of the population in both regions lacks access to modern energy. Rural electrification is necessary in order to meet basic needs, such as access to health care and education services, and decentralised renewable technologies offer an increasingly economic way of generating electricity in these settings.

The participants feel that sub-Saharan Africa has serious technical capacity gaps (as opposed to the functional capacity gaps outlined above) with respect to decentralised energy technologies such as concentrated solar power (CSP) for electricity and drying, solar PV, microhydropower, indigenous biofuel species and clean cookstoves. The lack of skilled personnel with respect to small-scale energy provision has long been flagged by academics and practitioners working in the region (for example, see [44–46]). Where there is local research on promising technologies, the team are often 'junior partners' in a multilateral project due to constraints on human and financial capital. UMNG's work on solar photovoltaic technologies, for example, is part of a broader consortium led by European universities. UMNG contributes expertise on modelling the optical and transport properties of dye sensitive solar cells and the optimisation of solar PV cells. There is currently no applied research on solar photovoltaic energy conducted at the university, although UMNG plans to redress this by installing a pilot project in partnership with the University of Yaounde I in Cameroon.

Yet it is precisely in these small-scale technologies where African academic leadership is paramount. Solar panels and wind turbines are rapidly becoming cheaper and established renewable energy options, such as biofuels, are becoming more environmentally friendly. *In situ* research is required to tailor these technologies to an African context, while large-scale deployment and ongoing maintenance will require local ownership and expertise. By contrast, large-scale energy infrastructure projects can take many years to move from planning to construction and operation; and much of the human and financial capital can be met by international consultants. It is also worth highlighting that small-scale technologies lend themselves much better to small and medium enterprises, which cover more than 95% of all firms in sub-Saharan Africa [47]. Building capacity in decentralised renewable technologies rather than large-scale energy infrastructure is therefore more likely to foster local entrepreneurship and ownership, and create a vibrant energy industry that can respond more quickly to new technology or market opportunities.

While doctoral programmes are just one of many options to build technical capacity in renewable energy, these considerations suggest that sub-Saharan African universities, donors and governments should particularly prioritise doctoral programmes that focus on decentralised renewable energy technologies rather than, for example, large-scale hydropower plants. These investments would respond to a critical capacity gap in the region, producing a generation of educators, innovators and entrepreneurs with the technical skills to support large-scale deployment of small-scale renewables. Where possible, African universities, their international research partners and funding bodies should therefore preferentially support doctoral research on decentralised renewable technologies to help build academic and technical capacity across the continent.

5. Conclusions and recommendations

If they are to pursue low carbon development paths, low-income countries need to develop the technical capabilities to innovate and adapt renewable energy technologies [16]. Doctoral programmes are a central part of this process, equipping educators, policymakers and entrepreneurs with the necessary knowledge and skills to deploy and adapt renewable energy systems to local contexts. This research highlights some common functional capacity gaps in sub-Saharan African energy doctoral programmes and, more valuably, identifies a range of low- or no-cost capacity-building strategies being piloted by universities across the continent. This reveals a significant opportunity for university leadership, policymakers and donors to enhance the quality of clean energy doctoral programmes in African universities despite their limited resource envelopes.

The workshops underpinning this paper further highlighted the valuable role that research networks can play in developing capacity-building strategies for universities in low-income countries. North–South relationships can provide examples of good practice by sharing sample handbooks, induction processes, supervisor training modules, co-supervisors and so on. These ties can also increase students' access to electronic resources and exposure to international research relatively cheaply. South–South relationships offer different advantages. Universities in low-income countries face the common challenge of resource-constrained environments. They can therefore share more relevant ideas and lessons on capacity-building strategies with limited financial, human and institutional capital, as illustrated by the mutual learning among the universities involved in this study. South–South relationships also provide more scope for universities in low-income countries to take a leadership role in capacity-building initiatives and collaborative research. Such ownership ensures that researchers not only acquire technical skills, but also the capability to use them [48]. This might be an opportunity for some of the emerging economies to provide leadership outside of the extractive sectors (see [49] for a discussion of Brazil's South–South cooperation as it relates to renewable energy in Africa).

More broadly, there is a case to be made that policymakers, international donors and university leadership must recognise regional capacity deficits in energy research and education. There is therefore an onus on national governments, development agencies and other funding bodies to support academic work on decentralised clean energy technologies, including but not limited to doctoral programmes. Where technology transfer or large-scale energy infrastructure do not adequately meet the needs of the rural poor, doctoral research provides a tool to tailor low carbon decentralised technologies to local environments and needs. Depending on their subsequent career paths, training doctoral students could also have potentially large co-benefits with respect to increasing energy provision in rural or peri-urban areas, expanding education options in renewable technologies and encouraging local entrepreneurship and ownership in the energy sector. Above all, encouraging doctoral students to focus on clean energy technologies will help to produce a cohort of future leaders in policy,

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business and academia with the innovation capabilities necessary to help sub-Saharan Africa pursue a low carbon development path.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.erss.2014.12.010.

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