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The need to localize energy technologies for Africa's post COVID-19 recovery and growth

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ABSTRACT

Africa has limited capacity to develop its own energy technologies and has been largely dependent on importation for its economic development. It is anticipated that there will be huge challenge for the very limited manufacturing industries in the continent to respond to the increasing energy demand. This will largely require the up scaling of the local manufacturing industries in-terms of skills, design capability, engineering management, manufacturing process and other related issues. Experiences from the developed world showed that academics and industries play critical role in innovation and technology development with proper policy and focus from the policymakers. African academics and industries could play similar role but requires revitalizing with enabling policies and sufficient funding. For this reason, African governments should prioritize their policies and investments towards achieving local energy technology development and innovation in order to build resilient economy. In light of this, we provided necessary recommendations for African led development pathways and policies to promote local manufacturing of energy technologies. This will have huge implications in supporting post COVID recovery and sustainable growth of the African countries.

Introduction

Technology plays pivotal role in social, economic and political developments of nations around the world. Elevating science, technology and innovations by the world has been a pressing issue considering its potential to develop resilient economy [1]. This is the main reason that several countries are investing in technology and innovation because of its capability of greater productivity, efficiency and safety ensuring sustainable developments. Not only this, technology has played and is currently playing critical role in reducing worldwide crisis such as the recent impact of the COVID-19 pandemic. For example, digital technology has been implemented in Europe and Central Asia to reduce impact of the pandemic in the

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education systems [2], and several other countries utilized digital services to fight against the impact of COVID-19 on their activities [3]. It is clear that technologies, regardless of their type, have the potential to support growth and develop resilient infrastructures that can absorb impact from any crisis now and in the future. Having resilient infrastructure means building modern society that can respond and overcome any natural and manmade shocks.

For these reasons, Africa needs the development of its own technology in order to develop resilient infrastructures that can respond to any crisis similar to the COVID-19 pandemic [4]. However, Africa's dependence on imported technology is affecting the development of resilient and sustainable infrastructures. One example is Africa's huge dependence on imported energy technologies to develop its energy infrastructure. Despite having huge renewable energy potential, the share of Africa's exploitation of renewable energy is around 1.9% of the world share [5]. One of the key problems is the lack of local capacity and commitment by the policymakers to develop energy technologies. Any funding allocated to the energy sector is usually used to procure and import energy technologies making it vulnerable for worldwide crisis such as disruption of supply chain and lockdowns.

A combination of its high dependence on importation and ineffective governance is making Africa the least electrified continent with nearly 600 million of its population without access to electricity [6]. COVID-19 has exacerbated this problem as the share of the Sub-Saharan population without access to electricity increased from 71% in 2018 to 77% in 2020 compared to the global population [7]. Ensuring energy security for these millions of people requires the necessary knowledge and skills to innovate and develop its own technologies to support the COVID recovery and sustained growth of the continent.

This paper therefore focuses on the impact of COVID-19, Africa's performance in using technology and innovation to combat the pandemic, Experiences of African industries and technologies in innovation and technology development. It emphases the need for the African continent to localize energy technologies in order to facilitate reliable, affordable, modern and sustainable energy systems to support its recovery and growth. We strongly believe that this work widens the existing limited studies by exclusively looking on the need for African led pathways for the localization of energy technologies using local industries and academics as gateway. The results will be vital for the research community, policy makers, investors and other stakeholders to rethink on their approach in Africa's future energy development. It has become clearer than ever that localization of energy technologies is critical for developing resilient energy infrastructures in the continent to support its economic recovery from the pandemic and future growth.

This paper first provides the historical context of Africa's energy development followed by the impact of COVID-19 on Africa's energy development and the continent's performance in combating the pandemic. In addition, the experiences and contribution of academics and industries in the development of energy technologies both within Africa and other continents is presented. These sections are used as base to emphasis the need to use African led pathways to localize energy technologies with the final section containing concluding remarks.

Methodology

We have overwhelmingly used secondary data to explore and understand the impacts of COVID-19 and the lessons learned in order to highlight the need for African led energy technology developments. Systematic review of consequence of the COVID-19 pandemic in the development of the energy sector in Africa was conducted using latest publications, government reports and different strategies developed to overcome the crisis. The qualitative and quantitative data reported in few African countries was used to analyze Africa's performance in combating the COVID-19 pandemic. Historical dependence of the continent on imported technologies to develop its energy infrastructure is illustrated using data from few countries that have procured energy technologies from the developed world. In addition, the historical contribution of the African academics and industries in innovation and local development and manufacturing of energy technologies were illustrated using data from University policy reports, publications, and government reports. Some initiatives of the establishment of local industries that are attempting to locally manufacture components of renewable energy technologies are included from some African government reports, strategies, policies and publications. These quantitative and qualitative data were collated and analyzed to map out details of the challenges during the pandemic and to develop and recommend African led pathways and approaches. The recommendations also included internationally proven policies that can help the African academics and industries to localize energy technologies to support the post GOVID-19 recovery and growth of the African continent.

Historical context of Africa's energy development

The stereotype of Africa being taken as a giant market hub

Electrification in Africa is considered as the lowest compared to the rest of the world with several countries of the continent facing huge deficit leading it to become a global agenda [8]. This is making the continent as a giant market hub for developers and investors. The first UK-Africa investments submit in London revealed that Africa has more than $24 Billion market potential in the development of off-grid solar panels. The UK is argued to tap into this huge and growing market in the continent [9].

Africa's huge wind energy potential is another area where investors are looking for. A study in 8 countries that include Somalia, Sudan, Libya, Mauritania, Egypt, Madagascar, Kenya and Chad showed huge on-shore wind potential. Other five countries namely Mozambique, Tanzania, Angola, South Africa and Namibia having off-shore wind potential [10]. Similar studies by the African Development Bank showed high wind potential in several African countries that include Algeria, Egypt, Morocco Tunisia and Mauritania, Djibouti, Eritrea, Seychelles, Somalia, Cape Verde, South Africa, and Lesotho [11]. Several studies indicated that the continent has 180,000 terawatt-hour wind energy potential [12]; 96,600 GWh hydro potential; 1750 TWh geothermal potential; and 660 PWh solar potential [13,14]. Bioenergy, which is the form of fuels derived from Biomass, has huge potential in the continent. A 2013 report by IREA shows that the continent has a huge biomass potential, which amounted between 2360 PJ/year and 337,000 PJ/year [15]. Though the technology in most cases is traditional, bioenergy represents nearly 50% of the continent's total primary energy supply [16].

However, despite these huge renewable energy resource potentials the continent has only 1.9% share compared to the world renewable energy exploitation [5]. Such huge market potential is making Africa a lucrative place for investment in the energy sector. The question is: are the interested investors going to develop the African energy infrastructure using imported technologies? Based on the previous experiences, the answer is clear and this is the reason that Africa needs to get away from its dependence on imported technologies and change its approach in developing the energy sector.

Evidences of Africa's dependence on imported energy technologies

It has been known for centuries that the continent has been lagging behind in developing its own energy technologies leading to huge dependence on importation. Arrival of the COVID-19 pandemic has further exposed Africa's dependence on imported energy technologies. Researchers have looked at the impact of the pandemic in regards to the local development of energy technologies and the different investigations indicated that the continent has largely been dependent for centuries. This has been proved through the importation of solar and wind energy related technologies. Examples include nearly USD 342 million costs of wind turbines collectively imported by South Africa, Ethiopia and Egypt in the year from 2009 to 2013 [17]. In the same period, these countries imported PV cells from China worth of USD 869 million [17,18]. The cost of electricity in many sub-Saharan Africa is nearly 50 cents per kilowatt-hour, which is much higher than the global average of 10 cents [19]. This is a reflection of the higher energy investment costs for the energy infrastructure development because of its dependence on imported technologies.

Impacts of COVID-19 on Africa's energy development

Disruption of energy technology supply chain and mobility

The African continent has been dependent on imports of energy technologies and related equipment [20], which makes it highly vulnerable for any disruption of supply chains. One of the key reasons for the supply chain disruptions of renewable energy technologies in the world during the COVID-19 is due to the halt of production at the sources [21]. China being the epicenter of the Pandemic showed a decline of the production of solar modules by 20–25% within the months of January-February 2020 [22]. Examples of disruptions include delays of equipment for the construction of Africa's largest Grand Ethiopian Renaissance Dam (GERD) in Ethiopia [23]; restriction in the mobility of people, shortages of labour supply, and disruption to businesses and government services in several African countries [24]. A survey conducted in Nigeria on off-grid related businesses showed that more than 80% face delays in importing solar related technologies and local demand shocks for off-grid based electricity from clients [25]. Similar studies in Uganda indicated delays in product delivery [26]. Haverhill synergy was affected its smooth operation because of the lack of equipment resulting from the closure of ports in Nigeria [27]. Such disruption of supply chains has slowed development of the energy sector in the African continent possibly leading to shortages of electricity supply [28].

Effects on the development of energy infrastructures and related businesses

Energy related businesses have been largely dependent on the importation of technologies. A survey conducted by the Global Off-Grid Lighting Association (GOGLA) mainly on Off-grid businesses indicated that the pandemic led to huge financial challenges [29]. Similar study in Ethiopia indicated that the country's dependence on imported solar technologies from China, United States and Germany affected the growth of local businesses [30]. Delaying of technology procurement, restrictions of both local and international mobility, social distancing, and delays in project implementation was typical examples of the impact on the development of energy infrastructures [30].

Other impacts include the cessation of negotiations on infrastructure projects [8]; challenges of the off-grid businesses to borrow funds and reduction of stock level due to the disruption of supply chains [31]; limitations on the availability of workers for energy projects, demand shocks, cancellation of agreements of energy projects, and procurement process [32]. According to a report by ILO [33], Africa is expected to face nearly 19 million job losses resulting from the closure of businesses by the pandemic. Solar-based businesses have also faced shortage of cash flows affecting their financial resilience facing continuity threat [25]. Studies in Uganda and Rwanda showed limited company operations and delays in procurement because of complete lockdowns, business closures, public transport bans and border closures [26].

The COVID-19 crisis is having huge impact particularly in the expansion of off-grid energy systems threatening to reverse the progress mad so far. A report by the International Energy Agency indicated that nearly 30 million people in the Sub-

Saharan Africa (SSA) could fall back into energy poverty [34]. Many off-grid solar companies across the East African region are struggling to continue their businesses threatening the 3.9% African workforce employed by the solar PV jobs [35]. A study by Amir and Khan [36] indicated that the pandemic has slowed the development of renewable energy because of the lack of capital investments. These impacts could have been minimized if there was local development of solar technologies within the continent.

Mixed signs of flow of investment into the energy sector

Investments in the energy sector in the African continent have largely been in the development of infrastructure by utilizing imported technologies. Though the investments and related large scale energy infrastructure development varies among the African countries, some of the existing developments still continues amid the pandemic such as the Grand Ethiopian Renaissance Dam (GERD) though at slow pace [37]. Other examples include the renewed commitment to continue the Inga 3 project in the Democratic Republic of Congo that have resistance from social organizations because of its impact on access to fresh water for local community [38,39]. Success stories related to investments in the off-grid energy systems include acquiring nearly 200,000 new customers by Engie Energy Access (EEA) in nine sub-Saharan countries; nearly 12 million investment in new mini-grid project in Uganda and Sierra Leone by French based company called NEoT Off grid Africa (NOA) [31].

Such signs of progresses during the pandemic are very limited but generally the indication is that investments in large-scale hydropower projects are affected because of the lack of interest from the private sector [20]. A recent survey conducted by the African Business showed that more than 50% of the 176 professionals participated from developers, investors, policy makers, technologies, legal and regulatory staffs believe that the pandemic has affected their investment strategy. According to the survey, 40% of the respondents believe that the pandemic would reduce investments in the sector with only 23% of the respondents hopeful of increasing investments [40]. Other impacts include interruptions and disruptions of investment processes [27]; shrinking of investment flows predicted by the off-grid solar-based businesses in Nigeria [25].

Africa's performance in combating the COVID-19 crisis

The use of technology in the energy sector

Africa's utilization of technology in combating the impact of COVID-19 in the energy sector is largely limited. A study in the Sub-Saharan African countries indicate that the impact of COVID-19 on value added in the energy sector is sever compared to the impact on other sectors with the result showing nearly 21.55% deviation from the reference scenario [41]. However, a study by GOGLA showed an increase of demand for off-grid applications in Africa [27]. Despite the increased demand the disruption of supply chain, lockdowns, and social distancing has impact on the development of off-grid energy systems largely because of Africa's dependence on imported technologies.

The use of technology in other sectors

The pandemic has thought us Africa's high vulnerability to any major crisis such as the COVID pandemic because of its weak infrastructures and its inability to make innovative and disruptive technologies within short period of time. It has long been lagging behind in technology development and innovations. Africa's dependence on foreign knowledge, skills and innovations has been a norm for generations. However, all is not doom when it comes to the COVID pandemic with few African countries showing strong and positive response to the crisis through innovation and technology albeit with often foreign technologies but with fast adaptation to local context. Examples include Tunsia's initiatives of deploying Artificial intelligence and natural language processing through local start-ups to overcome the crisis and reshape future economy of the country [42].

Digital platforms have been used to educate students in Ugandan schools. Information about COVID symptoms, prevention tips and testing has been given in South Africa. Nigeria used digital platforms to provide information on symptoms and infection avoiding mechanisms. Kenya, Ghana, Nigeria, and Togo adopted mobile cash services to minimize physical contact reducing the COVID-19 transmission [3]. The performances shown in these sectors by some of the African countries can be considered as an opportunity to look on how local energy innovation and technology development could help shape the future of African energy sector.

Experiences of African industries and academics in the development of energy technologies

Experiences of academics and industries from other continents

Experiences from the developed world show that academics are the center for generating new ideas that have the potential for technology transfer to industries for scale up and production [43]. Though contribution of academics differs from sector to sector, research outputs from Universities have had pivotal role in enhancing knowledge for manufacturing process, product innovation, and experimental techniques [44]. This is mainly done by the spillover of new research outputs and delivering skilled human capital to make local firms competitive [45,46]. Universities are considered as "*creators, interpreters of ideas and innovation, source of human capital, and key components of social infrastructure and social capital*" [47]. Universities also play critical role in creating and transforming industries through industry transplantation, diversification of old industry into related new, and upgrading of mature industries [48]. Universities in the modern world are actively changing their policy towards commercialization of their research outputs in the form of licensing, patents, and spinoffs. These policies are supported by laws enacted for example in the US and Europe giving them the right to exploit the intellectual property rights of their research [49].

The industrialized world has successfully exploited the collaboration between academics and industries to develop low carbon energy technologies as a strategy to mitigate climate change [50]. Examples include the explosive solar PV production trajectory of China from 2% global production in 2003 to 64% global production capacity by 2012 making it the largest producer by overtaking Japan and Germany [51]. Saudi Arabia has been traditionally an oil exporter but has moved to reduce its dependence on oil by developing vision 2030 plan to diverse its energy mix and has focused in the development of local renewable energy technologies [52]. As a result, Saudi Arabia has several industries that are focusing on the manufacturing of solar PV components making it a potential exporter. In light of these world experiences, we look the historical experiences of the African academics and industries and their collaboration in innovation and technological development within the continent.

Experiences of the African academics

Development of Africa's human capital is crucial to sustain the economic growth and to become internationally competitive in the areas of Science, Technology, Engineering, and Mathematics [53]. However, a study conducted by the Royal Academy of Engineering in 2012 showed that there is a chronic lack of indigenous capacity in Engineering and technology. More importantly, the study provided stark reality that the shortage was not related to the number of graduates. The problem was rather that the engineers who graduated lacked the necessary skills and experience according the needs of the labor market. Another study indicated that African academics have been facing various challenges in developing scientific research, education and technologies in renewable energy tailored to local conditions [54]. This study on four Sub-Saharan Universities showed capacity deficits and the need for capacity building strategies particularly on renewable energy doctoral programs. Studies in several African Universities indicate that their respective government's financial contribution to research and technology development is negligible such as in the case of the University of Nairobi [55].

The World Economic Forum has backed up the lack of graduates with the necessary knowledge and skills from African Universities. This study has indicated that many employers in Sub-Saharan Africa could not fill job vacancies despite high unemployment rate due to skills mismatch of graduates in technical and generic skills [56]. This gap is directly related to the lack of practice-oriented competence-based curricula in engineering, access to industry-grade equipment and the lack of proper training after graduation. There have been several efforts to change the current situations in the African academics. The document presented by Brown and Chiguvare [57], highlighted the need for developed countries to mobilize resources for capacity building and applied research in accelerating development, dissemination of technologies, and innovative mechanisms for financing renewable energy developments. This has been translated into action with examples of the European Union and Africa establishing a partnership focused on Renewable Energy Cooperation Programme (RECP). The RECP initiative supports introduction of renewable energy projects and capacity building in education, technical and vocational training institutions; the setting up of policies related to renewable energy; and development of political and legal framework for renewable energy market. The Ethio-German cooperation for engineering capacity building has taken curriculum revision as one of its focus areas, supported by state-of-the-art laboratory facilities. Innovate UK has launched the Energy Catalyst Africa programme in South Africa to accelerate the development of energy technologies to end energy poverty and provides financial support for commercialization that can improve lives in Africa and Asia [58].

There are also national legislative efforts in support of fulfilling the increased demand for skilled human power in technology. We see an increase from 30 to 70% of undergraduate enrolment in science and engineering via governmental directive in Ethiopia [59]. Ugandan policy is focused on a stronger industrial base according to the vision 2040 [60], in ICT, mining, engineering, oil & gas, Hydropower [61]. Tanzanian government adopts various employment and poverty reduction strategies such the National Development Vision and Higher Education Development Programme (2000–2025) to improve the supply of qualified science and engineering students [62]. Tanzania in the quest for developing a middle-income economy by 2025 developed Industrial Development Strategy 2025 considering human resource development as one of the key strategic areas with an emphasis on competency-based education and training for the manufacturing industries [63].

Several African academics are developing strategic plans to make their research outputs impactful. Examples include the University of Nairobi with its research policy focusing on strengthening research outputs in collaboration with industries in terms of contributing towards economic development goals and linking research activities to commercialization of products via the establishment of science and technology parks [55], Mekelle University's efforts in establishing technology incubation centers to support the innovation and technology development and commercialization. The University of Pretoria recently established various carefully selected multidisciplinary and trans-disciplinary research ideas, which are appropriate to South Africa's economic growth and development. According to the report by Lalk [64], the research focus areas include Energy production, Energy optimization, Energy distribution, Smart grids, and Policy, economics and society. The university has given an emphasis on the localization of energy technologies.

Several researches show that the South Africa's Renewable Energy Independent Power Producers Procurement Programme proposed to alleviate South Africa's carbon emissions depends on the availability of qualified human resource [65–67]. The same researchers reported that the government of Botswana assessed the training in renewable energy in technical schools of Botswana to tailor towards achieving the training needs. However, there is no prove that all these efforts by the Universities, development partners, local governments, and financing institutions are bringing impact in the academics' ability to produce skilled human power and impactful research outputs based on the needs of the African industries. A combination of the incapability of academics to deliver skilled human power and the lack of proper investment in their research to innovate and develop technology is something that requires attention and focus by policymakers. This could make the African academics a center of knowledge and technology development similar to their counterparts in the rest of the world. For academics to deliver successful impact-oriented research outputs and skilled human power, African universities need to develop the technical capabilities to innovate and develop renewable energy technologies and produce skilled human power that can influence governments, policymakers and local industries [68].

Experiences of the African industries

A combination of the increasing energy demand and the requirement for de-carbonization of the energy sector has pushed governments in the African continent to shift their focus to the development of the abundant renewable energy resources. This has led to an increased investment paving the way for the establishment of local renewable energy component manufacturing facilities within the continent [69]. Examples include the establishment of twenty solar industries in Nigeria, South Africa, Algeria, Egypt, Kenya, Tunisia, and Ethiopia [70]. Wind turbine component manufacturing plants are also available in Kenya, South Africa, Morocco and Egypt [71,72]. The Strategic Security Systems International plant established in Ghana is manufacturing 150W, 250 W, and 300W sizes of PV modules [73]. A Kenya based Solinc Manufacturing company produces 20W and 250W size solar panels albeit with several challenges such as VAT and duty regulations [74].

However, detailed reports on several other initiatives indicate that the actual local manufacturing of full or partial components of renewable energy technologies is very limited. An assessment of the local manufacturing of off-grid solar technologies in Nigeria, Ethiopia, Tanzania, Zambia and Rwanda revealed that the off-grid related companies are focused mainly on assembling of foreign technologies [75]. Same report shows Rwanda's attempt to provide investment for two foreign companies to engage in local manufacturing, with Nigeria and Ethiopia still at early stages to establish local manufacturing industries. Similar study in Ethiopia also showed that there is limited capacity and interest by companies to engage in local manufacturing of solar and wind energy technologies [76].

It is anticipated that there will be huge challenge for the very limited manufacturing industries in the continent to respond to the increasing demand. The continent will largely require the up scaling of the local manufacturing industry in-terms of skills, design capability, engineering management, manufacturing process and other related issues.

Experiences of collaboration between the African academics and industries

The study conducted by Bolo [77], has tried to assess the relations between research players and industry players focusing on the models that have been implemented in Africa. Technology and knowledge transfer and commercialization of scientific research discoveries are a big issue for innovation experts, governments, development partners, and the local industries. Though new knowledge is generated from the public institutions and demanded by the private sector, connection points for technology and knowledge transfer between the demanding sector and the academics research output has remained a challenge.

There have been several initiatives in the African continent to strengthen the link and interaction between the academics and industries. According to a study by Creso [78], some of the initiatives include:

- A three-year program of Education partnership in Africa funded by the UK government to build institutional capacity and quality to improve employability of graduates.
- Corporate graduate link at the University of Zambia funded by the German Federal Ministry for Economic Cooperation and Development to improve the skill of graduates based on the industry requirements.
- The Annual Civic Camps in Senegal to improve conditions of local communities using students.
- Incubator INNODEV at the Polytechnic Dakar, Senegal, established by five Senegalese Universities with the support of French Research Institute for development in order to commercialize research results through partnership with local industries.
- Establishment of partnership between Kenyatta University and Equity Bank to support communities through community service by students.

Appreciating these initiatives, they are drop in the ocean considering the large number of academics and industries in the continent and are not sufficient to support high level technology transfer and innovation among these key actors. The poor knowledge and technology transfer between research institutions and the industry stems from numerous challenges. These challenges include but not limited to: inadequate investments in innovation/knowledge generation; unequal information access and exchange; weak capacities for knowledge and technology uptake; and organizational culture and procedures [77]. Another study revealed that academics independently set the research projects with no consultation with industries and governments and thus do not actively promote engagement with prospective end users and policymakers [54].

African led pathways to localize energy technologies

One of the five priority areas included in the African Union's post COVID green recovery action plan is to support renewable energy, energy efficiency and national Just Transition programmes [6]. In order to achieve this action plan and support the post COVID recovery and growth, several stakeholders have to synergize their knowledge, skills, and resources to localize energy technologies to develop resilient energy infrastructures that could provide reliable, affordable, sustainable, and modern energy systems. In order to make a paradigm shift, governments in the continent shall promote the localization of energy technologies through African led pathways and approaches. Development of enabling policies, research, and local capacities based on the context of respective countries in the African continent are critical to shape its future energy development [79].

Pathways and approaches for capacity development

Academics and industries can play critical role in the innovation and development of energy technologies. The question is: what does it take for such potential stakeholders to be heavily involved and be pioneer of innovation and technology development in the continent? Details of the pathways and the approaches required to develop capacity to localize energy technologies are given in Table 1.

Enabling policies to support localization of energy technologies

International experiences indicate that well designed policies and regulations such as import tariffs and strong quality standard controls, preparing infrastructures (special economic zones and industrial parks), ensuring market demands for locally manufactured technological components can stimulate investments by the private sector in the energy industries [75]. For this reason, strong engagement of the African governments is important to effectively implement the recommended pathways and approaches. Investment return in innovation and technology development takes time and the interest of the private sector is focused on investments that have short-term returns. We are witnessing an increase in investment by the private sector in the African continent though it is focusing on the development of the energy sector using imported technologies.

Therefore, governments' support in developing enabling policies and allocation of sufficient funding is crucial for the success of renewable energy technology development and deployment [81]. This will have huge implications both in reducing the high unemployment rate in the post COVID recovery and growth of the continent. Several studies indicated that the sector has an employment potential of 14% in the manufacturing process, 36% in the module assembly, and 49% during installation [82,83]. In order to effectively implement and accelerate the recommended African led pathways and approaches detailed in section 7.1, implementation of the following policies by adapting to each African countries specific context is required. It is understood that such policies already exist in some of the African countries but there is lack of effective implementation. These policies require huge commitment and readiness by all African countries to introduce and translate them into action.

Policy #1: Strengthening public-private partnership

The public-private partnership (PPP) is becoming a powerful tool to strengthen the University-industry collaborations but requires strong regulation that can incentivize both parts to collaborate in their knowledge exchange to develop technologies at a local level. Strong institutional capacity at both institutions is critical in order to develop effective collaborations to avoid the existing ineffective experiences of their collaborations. Though there are still African countries that have no national policies [78], the performances of the countries that implement University Industry partnership are ineffective. This requires urgent rethinking by all stakeholders in order to exploit their innovation and technology development potentials that could be instrumental to alleviate dependence of the continent on imported energy technologies.

Policy #2: Strengthening the University-Industry-Government (the triple helix) partnership

University-Industry-government, the Triple Helix Model, is considered as one of the effective way of producing and disseminating organized knowledge for the economic development of countries [84]. This model provides the opportunity to synergize resources of the three actors in order to facilitate innovation and technology development activities [85]. This policy is becoming a powerful tool to support innovation and technology development [86,87].

Policy #3: Introducing intellectual property rights in the academic systems

As proved by Universities in the US and Europe with the support of laws [49], shifting policies of academics towards commercialization of research outputs in the form of licensing, patents, and spinoffs through intellectual property rights is one of the effective ways to change the traditional academic businesses. Most of the African academics have no clear intellectual property rights because of the lack of focus by governments and the university managements. This has to be changed and both stakeholders enact a policy to introduce clear intellectual property rights to support research outputs to be commercialized in partnership with industries.

Table 1
Pathways and approaches for capacity development to localize energy technologies.

No	Pathways		Approaches/Actions
1	Revitalizing the Academics	Need based education and training	■ Tailoring the development of curriculums based on requirement of industries ■ Develop partnership with universities in the developed nations to promote shared education facilities ■ Building and upgrading education facilities that provide practice oriented teaching learning environment ■ Disseminate knowledge through short and long term training to industries and communities to strengthen their technological capacity
		Contributing to fundamental and applied research	■ Promote joint research proposals with international institutions to substantially increase chances for successful applications and increase the quality of research output ■ Explore new materials and develop new technologies
		Creating space for open fertilization of ideas	■ Create a platform for open-ended discussions with industries about technological developments ■ Establish seminars, regular meetings, workshops with any one interested to contribute to the technological development and improvement of businesses ■ Encourage cross-fertilization of ideas from different disciplines
		Establishing incubation centers and science and technology parks	■ Incubate new ideas and businesses for promoting start -ups ■ Use the platform to commercialize research outputs ■ Use the platform to synergize resources and be a center of discussions, exhibitions of new products ■ Use the platform to bring cross-disciplinary knowledge to develop new ideas and technologies
2	Phased approach of establishing energy industries	Phase I: Establishment of Assembling companies	■ Support local assembly programmes to stimulate interest of the companies for local manufacturing as this is a proven technic used in other countries such as Bangladesh [80] ■ Use the platform as a learning curve to develop knowledge and skills about the technologies
		Phase II: Promoting the Assembling companies to manufacturing companies	■ Provide financial and legal support to shift the assembly companies to local manufacturing companies ■ Arrange free import duties to import machineries that help to manufacture local energy technologies ■ Support in finding suitable land to establish the manufacturing companies
		Establishing African and foreign joint venture companies	■ Develop suitable policies to attract foreign companies ■ Develop legal framework that can be introduced as part of the agreement between the parties for knowledge and technology transfer ■ Use the joint venture as a way of efficient knowledge and technology transfer platform to develop local capacity
3	Fostering partnerships	Forging local partnerships	■ Develop institutional capacity to successfully implement university industry linkages ■ Combine existing knowledge to create new product, process and policy ■ Build trust between academicians and industries through joint research and outreach activities ■ Enhance effective communication by jointly setting up knowledge transfer offices, aiming to improve collaboration and exploitation of research results and their uptake by the industries ■ Closely work in tailoring of knowledge and skills to the societies demand, developing and exploiting new technologies, promoting technologies and innovations, and transferring technology ■ Exchange relevant research and training through internships and externships
		Forging international partnerships	■ Strengthen international collaboration in research, knowledge sharing, capacity-building, technology development, and policy learning

Policy #4: Developing incentive packages

Development and manufacturing of energy technologies requires huge investment and has long-term return. The private sector has no appetite to invest in such long-term returns. In order to attract investments into this sector, Governments in the African continent shall develop incentive packages based on the context of their specific countries. According to a study by Gebreslassie [76], the effective incentive mechanisms that can promote local development and manufacturing of energy technologies are: providing land at nominal prices for potential industries; government support for training of the industrial workforces; providing free worker recruitment services; reduction of income Tax; Tax deduction for labor cost; developing targeted customs duties for importing few critical components; and financial incentives for research and development both at the academics and R&D departments in the industries.

Policy #5: Developing conducive utility procurement

Utility procurement policy has the potential to encourage users to buy locally manufactured technologies [88]. For example, the Made in Rwanda policy makes easier for local producers to be competitive with the imported technologies using 15% preferential prices [75]. This will have huge implications for market expansion in return attracting the private sector to enter into the local manufacturing businesses. The African governments are therefore encouraged to develop Conducive procurement policy in order to attract private investors to invest in the development and localization of energy technologies.

Policy #6: Localization of the energy development value chains

Localization is not only for the manufacturing of technologies but also includes localization of the entire value chain of the energy sector in order to develop sustainable energy for all. Localizations such as enabling local environment, localization of finance and involvement of locals in the design, development and marketing value chain are considered crucial factors to support local capacities in the development of the African energy sector [89]. Therefore, governments should work towards embedding the concept of localization in their efforts to develop resilient energy infrastructures in their respective countries.

Policy #7: Renewable Portfolio Standard

The Renewable Portfolio Standards policy have been experimented in several developed countries to ensure and enforce electricity supply companies to generate specified fraction of their electricity from renewable energy resources. Exercising such obligations in the African continent could promote and facilitate the adoption and localization of renewable energy technologies within the continent.

Conclusions

This study has focused on the assessment of the impact of COVID-19 in the context of the development of the energy sector in the African continent and its performance using technology in combating consequences of the crisis. We have also looked on the historical contribution of the African Academics and Industries in the innovation and technological development in the energy sector. The findings show that the Pandemic has generally negative consequences on the development of the African energy sector with signs of continued development in few countries. We found that Africa's dependence on imported energy technology was the main factor that affects development of the African energy infrastructure. The contribution of Academics and Industries has shown similar weaknesses in the technological development because of lack of proper knowledge and skills. We have looked at the lessons learned during the pandemic and the inability of academics and industries in the innovation and technological development of the continent and recommended pathways and approaches that can help in minimizing Africa's dependence on imported energy technologies. These recommended pathways include revitalization of the academic sector through need based training and education; contributing to fundamental and applied research; creating space for open fertilization of ideas; and establishing incubation centers and science and technology parks. Phased establishment of energy industries with first promoting the establishment of assembling industries followed by the promotion of these companies into full fledged manufacturing industries could be critical to develop stage by stage capacity building in the energy sector. Establishment of joint ventures with foreign companies is also another pathway to develop local capacities. In this process, fostering the collaboration between academics and industries is critical to develop the necessary capacity for localization of energy technologies. The contribution of African governments by developing enabling policies such as strengthening public-private partnership; strengthening university-industry-government partnership; introducing intellectual property rights; incentive packages; Conducive procurement policy; and localization of the energy development value chains are few but effective tools to implement the recommended African led pathways and approaches to facilitate localization of energy technologies within the African continent. These are few but instrumental policies to strengthen the contribution of academics and industries in the localization of energy technologies within the African continent in order to support Africa's future energy development.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] UNCTAD, (2022). Science, technology and innovation efforts to address COVID19, United Nations Conference on Trade and Development, Commission on Science and Technology for Development. United Nations Conference on Trade and Development. Available at: https://unctad.org/topic/commission-on-science-and-technology-for-development/covid-19.
[2] H.A. Patrinos & T. Shmis, (2020). Can technology help mitigate the impact of COVI-19 on education systems in Europe and Central Asia?, World Bank Blogs, Eurasian perspectives, 2020. Available at: https://blogs.worldbank.org/europeandcentralasia/can-technology-help-mitigate-impact-covid-19-education-systems-europe-and.
[3] N. Jiang & J. Ryan, (2020). How does digital technology help in the fight against COVID-19?, Wolrd Bank Blogs, let's talk development. Available at: https://blogs.worldbank.org/developmenttalk/how-does-digital-technology-help-fight-against-covid-19.
[4] A. Sampson Kofi, 3 ways tech and innovation can push Africa to the next level of economic growth, World Econ. Forum (2022) Available at https://www.weforum.org/agenda/2022/02/3-ways-tech-and-innovation-can-push-africa-to-the-next-level-of-economic-growth/. Accessed: 2022-09-20.
[5] V. Olabi, T. Wilberforce, K. Elsaid, E.T. Sayed, M. Ali, Impact of COVID-19 on the renewable energy sector and mitigation strategies, Chem. Eng. Technol. 45 (4) (2022) 558–571.
[6] AUAfrican Union Green Recovery Action Plan 2021-2027, African Union, 2021 Available at https://au.int/sites/default/files/documents/40790-doc-AU_Green_Recovery_Action_Plan_ENGLISH1.pdf.
[7] WBReport: COVID-19 Slows Progress Towards Universal Energy Access, World Bank, 2022 Available at https://www.worldbank.org/en/news/press-release/2022/06/01/report-covid-19-slows-progress-towards-universal-energy-access Accessed: 2022-09-19.
[8] I.M. Bugaje, Renewable energy for sustainable development in Africa: a review, Renew. Sustain. Energy Rev. 10 (6) (2006) 603–612.
[9] J. Ambrose, UK could tap into Africa's 24bn market for off-grid solar power, Guardian (2020) Available at https://www.theguardian.com/environment/2020/jan/21/uk-africa-off-grid-solar-power. Accessed: 2022-10-04.
[10] A.D. Mukasa, E. Mutambatsere, Y. Arvanitis, T. Triki, Development of Wind Energy in Africa Working paper series No 170,,African Development Bank Group, 2013 Available at https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Working%20Paper%20170%20-%20Development%20of%20Wind%20Energy%20in%20Africa.pdf.
[11] ADBStrategic Plan for Wind Energy Development in Africa, African Development Bank, 2004.
[12] L. Munyengeterwa & S. Whittaker, (2021). Powering Africa's sustainable development through wind, development and a changing climate, World Bank Blogs Available at: https://blogs.worldbank.org/climatechange/powering-africas-sustainable-development-through-wind.
[13] UNECA, (2014). Energy access and security in Eastern Africa. Status and Enhancement Pathways, United Nations Economic Commission for Africa. Available at: www.uneca.org/.../energy_access_and_security_in_ea_eng_fin_lowres_27dec2013.pdf. [Accessed: 2022-10-14].
[14] K. Stecher, A. Brosowski, D. Thrän, Biomass Potential in Africa, International Renewable Energy Agency (IRENA), 2013.
[15] IEA, (2009a). "2009 energy balance for Africa",International Energy Agency www.iea.org/stats/balancetable.asp?.COUNTRY_CODE=11. Accessed: 2022-09-10.
[16] P. Viebahn, Y. Lechon, F. Trieb, The potential role of concentrated solar power (CSP) in Africa and Europe—a dynamic assessment of technology development, cost development and life cycle inventories until 2050, Energy Policy 39 (8) (2011) 4420–4430.
[17] UNEP, (2014). South-South trade in renewable energy: trade flow analysis of selected environmental goods, United Nations Environment Programme. Available at: https://www.greengrowthknowledge.org/sites/default/files/downloads/resource/-South-South%20trade%20in%20renewable%20energy%20a%20trade%20flow%20analysis%20of%. Accessed: 2022-09-11.
[18] R. Lema, R. Rabellotti, P. Gehl Sampath, Innovation trajectories in developing countries: co-evolution of global value chains and innovation systems, Eur. J. Dev. Res. 30 (3) (2018) 345–363.
[19] A. Balabanyan, Y. Semikolenova, D. Hankinson, S. Nash, C. Parcels, African Utilities during COVID-19: Challenges and Impacts, World Bank, 2021 Topical paper, International bank for reconstruction and development, the.
[20] W. Shen and S. Ayele, (2020). COVID-19 and the African energy sector, EEG energy insight, energy and economic growth, Oxford Policy Management. Available at: https://www.energyeconomicgrowth.org/sites/default/files/2020-10/EEG%20EI_COVID-19%20and%20the%20African%20energy%20sector.pdf.
[21] A.T. Hoang, S. Nižetić, AI. Olcer, H.C. Ong, W.H. Chen, C.T. Chong, S. Thomas, SA. Bandh, X.P. Nguyen, Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: opportunities, challenges, and policy implications, Energy Policy 154 (2021) 112322.
[22] IRENAThe post- COVID Recovery: An Agenda for Resilience, Development and Equality, IRENA, Abu Dhabi, 2020 Available at https://irena.org/publications/2020/Jun/Post-COVID-Recovery.
[23] Brook Abdu, (2020). COVID-19 delays GERD material delivery, The Reporter, 2020. Available at: https://www.thereporterethiopia.com/9384/ (Accessed: 2022-08-20).
[24] UNECA, (2020). The impact of COVID-19 on Africa's energy sector and the role of RE to empower a long term and sustainable recovery, United Nations Economic Commission for Africa. Available at: https://hdl.handle.net/10855/43786 (Accessed: 2022-09-20).
[25] A. Isah, (2022). How is COVID-19 pandemic affecting electricity access in Africa? evidence from Nigeria. Available at: https://aec.afdb.org/en/papers/how-covid-19-pandemic-affecting-electricity-access-africa-evidence-nigeria-399.
[26] T. Kukeera, A. Brophy, Supporting the East African off-grid energy industry post COVID-19, Climate Compatible Growth, University of Oxford, 2022.
[27] Sun-connect, (2020). The impact of COVID-19 on the off grid energy sector. available at. https://sun-connect.org/the-impact-of-covid-19-on-the-offgrid-energy-sector-2/ (Accessed: 2022-10-05).
[28] M. Boulle & A. Dane, (2020). The impacts of COVID-19 on the power sector in sub-Saharan Africa, and the role of the power sector in socioeconomic recovery, Konrad Adenauer Stiftung. Available at: https://www.kas.de/documents/282730/8327029/Covid_Energy_SSA_publication.pdf/efc74763-8f85-39c6-53e4-de16cb75f71d?t=1594778811782.
[29] M.M. Akrofi, S.H. Antwi, 'COVID-19 energy sector responses in Africa: a review of preliminary government interventions, Energy Res. Soc. Sci. 68 (2020) 101681.
[30] M.G. Gebreslassie, Comparative assessment of the challenges faced by the solar energy industry in Ethiopia before and during the COVID-19 pandemic, Wiley Interdiscip. Rev. Energy Environ. 418 (2021) e, doi:10.1002/wene.418.
[31] I. Lewis, (2021). Sharp sales growth predicted for Africa's off-grid solar energy, Africa Business.
[32] OECDCovid-19 and a New Resilient Infrastructure landscape, OECD Policy Responses to Coronavirus (COVID-19), OECD, 2021.
[33] ILOCOVID-19 Causes Devastating Losses in Working Hours and Employment, International Labour Organization, 2020 Available at www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_740893/lang--en/index.htm Accessed: 2022-10-5.
[34] IEAThe Covid-19 Crisis is Reversing Progress on Energy Access in Africa – Analysis, IEA, 2020 Available at https://www.iea.org/articles/the-covid-19-crisis-is-reversing-progress-on-energy-access-in-africa.

[35] IRENA, (2019)Renewable Energy and Jobs: Annual Review, International Renewable Energy Agency. Available at https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019. Accessed: 2022-09-12.
[36] M. Amir, S.Z. Khan, Assessment of renewable energy: status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa, Energy Built Environ. 3 (3) (2022) 348–362 Environ, doi:10.1016/j.enbenv.2021.03.002.
[37] K. Salam, The Blue Nile is Dammed, Foreign Policy, 2020 Available at: https://foreignpolicy.com/2020/07/24/the-blue-nile-is-dammed/ Accessed: 2022-09-30.
[38] I. Rivers, (2020a). 'South Africa and DRC plan to press ahead with Inga 3 in the midst of the COVID-19 pandemic', International Rivers, available at: www.internationalrivers.org/news/press-release-southafrica-and-drc-plan-to-press-ahead-with-inga-3-in-the-midst-of-the-covid-19-pandemic/.
[39] I. Rivers, (2020b). 'Covid-19 impacts in the democratic republic of Congo: crisis to opportunities series', International Rivers, available at: www.internationalrivers.org/news/blog-covid-19-impacts-inthe-democratic-republic-of-congo-crisis-to-opportunities-series/.
[40] A. business, How is COVID-19 impacting energy investment: African business surveys market, Afr. Bus. (2020) Available at https://african.business/2020/08/energy-resources/covid-19-impacts-investors-energy-strategies-in-africa/. Accessed: 2022-09-20.
[41] O. Gharbi, COVID-19: Using Innovative Technology to Overcome the Crisis and Reshape the Future of the Economy, Mobile for Development, GSMA, 2022.
[42] Power for All, (2022). Delivering clean and affordable energy to Africa faster, Race for resilience. Available at https://climatechampions.unfccc.int/delivering-clean-and-affordable-energy-to-africa-faster/ (Accessed: 2022-09-20).
[43] R.W. Hawkins, C.H. Langford, K.S. Sidhu, University research in an innovation society, Science, Technology and Innovation Indicators in a Changing World: Responding to Public Needs, OECD, 2007.
[44] D.C. Mowery, The bayh-dole act and high-technology entrepreneurship in U.S. Universities: Chicken, Egg, or Something Else? Paper Presented at, Entrepreneurship Education and Technology Transfer, University of Arizona, 2005.
[45] M. Feldman, The locational dynamics of the US biotech industry: knowledge externalities and the anchor hypothesis, Ind. Innov. 10 (3) (2003) 311–329.
[46] J. Goddard, P. Vallance, A. Pike, A. Rodriguez-Pose, J. Tomaney, Universities and regional development, in: Handbook of Local and Regional Development, Routledge, London, 2011, pp. 425–437.
[47] R.K. Lester, (2005). Universities, innovation, and the competitiveness of local economies. A summary report from the local innovation systems project - phase I. MIT industrial performance center working paper 05-010: Cambridge.
[48] R. Levin, A. Klevorick, R. Nelson, S. Winter, Appropriating the returns from industrial R&D, Brook. Pap. Microecon. 18 (3) (1987) 783–831.
[49] R. Grimaldi, M. Kenney, D.S. Siegel, M. Wright, 30 years after Bayh–Dole: reassessing academic entrepreneurship, Res. Policy 40 (8) (2011) 1045–1057.
[50] R. Quitzow, J. Huenteler, H. Asmussen, Development trajectories in China's wind and solar energy industries: How technology-related differences shape the dynamics of industry localization and catching up, Journal of Cleaner production 158 (2017) 122–133.
[51] U.E. Hansen, I. Nygaard, E. Davy, T.H. Larsen, C.W. Wabuge, Challenges to establishing and sustaining local production of renewable energy technologies in Sub-Saharan Africa. Kenya miniwind project report. https://www.researchgate.net/publication/337843417_Challenges_to_establishing_and_sustaining_local_production_of_renewable_energy_technologies_in_Sub-Saharan_Africa.
[52] Z.S. AlOtaibi, H.I. Khonkar, A.O. AlAmoudi, et al., Current status and future perspectives for localizing the solar photovoltaic industry in the Kingdom of Saudi Arabia, Energy Transit 4 (2020) 1–9 https://doi.org/10.1007/s41825-019-00020-y.
[53] G. Mohamedbhai, Engineering education in Sub-Saharan: The quest for quality, Int. J. Afr. Higher Educ. 2:1-24 (2015).
[54] S. Colenbrander, J. Lovett, M.S. Abbo, C. Msigwa, B. M'Passi-Mabiala, R. Opoku, Renewable energy doctoral programmes in Sub-Saharan Africa: a preliminary assessment of common capacity deficits and emerging capacity- building strategies, Energy Res. Soc. Sci. 5 (2015) 70–77.
[55] T. Bailey, N. Cloete, P. Pillay, Universities and Economic Development in Africa, Case study: Kenya and University of Nairobi, 2013 Available at http://erepository.uonbi.ac.ke/handle/11295/45937.
[56] K. Schwab (2015). World economic forum's global competitiveness report. Global Edge. Available at: https://globaledge.msu.edu/global-resources/resource/471. Accessed: 2022-09-29.
[57] Ed Brown, Z. Chiguvare (2016). How Africa-EU research cooperation is improving energy access in Africa, Devex. available at: https://www.devex.com/news/authors/ed-b-1206317. (Accessed: 2022-09-18).
[58] S. Burger, Energy Catalyst Africa launches in South Africa to Support Energy Technology Development, Creamer Media Senior Contributing Editor, 2022 Available at https://www.engineeringnews.co.za/article/energy-catalyst-africa-launches-in-south-africa-to-support-energy-technology-development-2022-06-27 Accessed: 2022-10-01.
[59] FDRE. (2015). Growth and transformation plan II (GTP II) (2015/16-2019/20) Volume I : Main Text, I, GTP II.
[60] NPA, Uganda Vision 2040, in: Proceedings of the Annual Meeting of the Midwest Political Science, 12, NPA, 2007, pp. 1–7, doi:10.1007/s11947-009-0181-3.
[61] MFPEDMinistry Policy Statement for Ministry of Finance, Planning and Economic Development, Ministry of Planning Finance and Economic Development, 2013.
[62] URT. (1999). The Tanzania Development Vision 2025, Ministry of Finance And Planning Tanzania, The United Republic of Tanzania. Available at: https://www.academia.edu/8775328/THE_TANZANIA_DEVELOPMENT_VISION_2025.
[63] MIT. (2010). Integrated industrial development strategy 2025. Ministry for industry and trade,Dar- es-Salaam.
[64] Jö Lalk, (2011). University launches new energy research initiative: Features innovate. Available at: https://www.up.ac.za/media/shared/Legacy/sitefiles/file/44/1026/2163/8121/universitylaunchesnewenergyresearchinitiative.pdf. Accessed: 2022-09-23.
[65] B. Msimanga, A.B. Sebitosi, South Africa's non-policy driven options for renewable energy development, Renew. Energy 69 (2014) 420–427.
[66] L. Baker, The evolving role of finance in South Africa's renewable energy sector, Geoforum 64 (2015) 146–156.
[67] P.K. Jain, E.M. Lungu, B. Mogotsi, Renewable energy education in botswana: needs, status and proposed training programs, Renew. Energy 25 (1) (2002) 115–129.
[68] A.E Ockwell, A. Mallett, O. Johnson, J. Watson, Low Carbon Development; the Role of Local Innovative Capabilities, University of Sussex, Brighton, 2009 STEPS Working Paper 31 STEPS Centre and Sussex Energy Group, SPRU.
[69] L. Thomas Hebo, H. Ulrich Elmer, Sustainable industrialization in Africa: the localization of wind-turbine component production in South Africa, Innocation and Development 12 (2020) 189–208 https://doi.org/10.1080/2157930X.2020.1720937.
[70] IRENASolar PV in Africa: Costs and Market, The International Renewable Energy Agency (IRENA), Abu Dhabi, 2016.
[71] J. Leary, A. While, R. Howell, Locally manufactured wind power technology for sustainable rural electrification, Energy Policy 43 (2012) 173–183.
[72] L. Kamp, L. Vanheule, Review of the small wind turbine sector in Kenya: status and bottlenecks for growth, Renew. Sustain. Energy Rev. 49 (2015) 470–480.
[73] T. Kenning, (2016). Inside Ghana's first module manufacturing facility. Available at: (https://www.pv-tech.org/author/tomkenning/). (Accessed: 2022-09-20).
[74] D. Mulupi, (2016). Manufacturing solar panels in East Africa: rising demand, but challenges remain. Available at: https://www.howwemadeitinafrica.com/manufacturing-solar-panels-east-africa-rising-demand-challenges-remain/53859/.
[75] ACETAF, (2021). Assessment of local manufacturing of off-grid solar in Sub Saharan Africa, African clean energy technical assistance facility and the world resources institute. Available at: https://www.ace-taf.org/kb/assessment-of-local-manufacturing-of-off-grid-solar-in-sub-saharan-africa/.
[76] M.G Gebreslassie, Development and manufacturing of solar and wind energy technologies in Ethiopia: challenges and policy implications, Renew. Energy J. 168 (2021) 107–118.
[77] M. Bolo, (2020). Strengthening research – industry collaborations in Africa, Foreign, Commonwealth & Development Office, UK Government. Available at: https://www.gov.uk/research-for-development-outputs/strengthening-research-industry-collaborations-in-africa-rapid-evidence-assessment.

[78] M.S. Creso, (2015). Perspective of industry's engagement with African Universities, African Association of Universities. Available at: https://www.heart-resources.org/wp-content/uploads/2015/09/Report-on-University-Industry-Linkages.pdf.
[79] Y. Mulugetta, Africa needs context-relevant evidence to shape its clean energy future, Nat. Energy (2022), doi:10.1038/s41560-022-01152-0.
[80] S. Sanyal et al, (2016). Stimulating Pay-As-You-Go Energy Access in Kenya and Tanzania: The Role of Development Finance, World resources Institute. Available at: https://www.wri.org/research/stimulating-pay-you-go-energy-access-kenya-and-tanzania-role-development-finance (Accessed: 2022-10-05).
[81] D.R. Walwyn, A.C. Brent, Renewable energy gathers steam in South Africa, Renew. Sustain. Energy Rev. 41 (2015) 390–401.
[82] J. Sawin, (2006). National policy instruments: policy lessons for the advancement & diffusion of renewable energy technologies around the world. Renewable Energy. A Global Review of Technologies, Policies and Markets. Oil, Gas & Energy Law Journal, Vol 2. Available at: https://www.semanticscholar.org/paper/National-Policy-Instruments-Policy-Lessons-for-the-Sawin/38258ea4bda505d270966d740a1505b8d96e5550.
[83] G. Ban-Weiss, D. Larsen, S.X. Li, D. Wilusz, Job Creation Studies in California for Vote Solar, University of California, Berkeley, 2004.
[84] I.A. Ivanova, L. Leydesdorf, Rotational symmetry and the transformation of innovation systems in a Triple Helix of university-industry–government relations, Technol. Forecast. Social Change 86 (2014) 143–156.
[85] D. Liu, X. Liu, W. Luo, The university-industry-government triple helix innovation model with innovation and entrepreneurship base as the node, in: Proceedings of the 5th International Conference on Education, Management, Arts, Economics and Social Science (ICEMAESS 2018), 2018 Advances in Social Science, Education and Humanities Research, volume 264.
[86] H. Etzkowitz, et al., The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm, Res. Policy 29 (2000) 313–330.
[87] L. Ranga, et al., Enhancing the innovative capacity of small firms through triple helix interactions: challenges and opportunities, Technol. Anal. Strateg. Manag. 20 (6) (2008) 697–716.
[88] UN, (2018). The role of science, technology and innovation in increasing substantially the share of renewable energy by 2030, economic and social council, Technical report. Available at: https://unctad.org/system/files/official-document/ecn162018d2_en.pdf.
[89] M. Veen, (2022). Localization is critical to reaching sustainable energy for all, SNV available at: https://www.google.com/search?q=Localization+is+critical+to+reaching+sustainable+energy+for+all.