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Drivers of Sustainability Education and Green Vocational Education and Training in Africa's Solar Sector: A Case Study of Nigeria, Ghana, and Uganda

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Although 43% of Africa's population (amounting to about 600 million people) have no access to electricity, Africa still has 40% of the global potential for solar power. In 2022, Africa produced 12 641 MW of electricity from solar energy, amounting to 1.2% of the global production of solar electricity. Of this, 11 516 MW was from solar photovoltaic (PV) cells. The massive deployment of solar PV technology in Africa to address energy access also poses a challenge of lack of skilled manpower in the sector. What factors drive and influence Africa's solar sector manpower provision and in what ways are African stakeholders addressing this? Using mixed-method research, interviews (individual and focus group), and published literature and policy documents, we considered Nigeria, Ghana, and Uganda as our focus countries of study. Our study revealed (1) the complexity of the existing regulatory and governance frameworks and how they impact solar skills training, (2) the challenges of greening solar technical and vocational education and training in Africa, and (3) best practices in solar technical education delivery within the African continent that other stakeholders could learn from. We conclude by highlighting how addressing the identified challenges can lead Africa toward a more sustainable energy transition path.

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I. INTRODUCTION

Energy and electricity access are a priority for Africa. At present, 43% of its population (amounting to about 600 million people) have no access to electricity, most of them in sub-Saharan Africa [1]. Africa has 40% of the global potential for solar power. In 2022, Africa produced 12 641 MW of electricity from solar energy, amounting to 1.2% of the global production of solar electricity [2–4]. In the same year, 11 516 MW of the solar electricity produced in Africa was from solar photovoltaic (PV) cells [5]. These facts point to the essential role of solar photovoltaic systems in addressing Africa's energy crises and the need to develop associated technical skills to address the growing need for decentralized electricity. The adoption of green vocational education and training (VET) programs in solar energy across Africa plays a pivotal role in addressing the continent's energy needs, while promoting sustainability and economic growth.

Nigeria is the most populous country and the largest economy in Africa. With a population of more than 200 million people and an installed electricity generation capacity of about 15 000 MW [6,7], Nigeria has a clear energy deficit that needs to be addressed to unlock greater economic potential and job opportunities particularly for the youth, with a positive effect on the climate [3,8,9]. Only about 60% of Nigeria's population have access to electricity, meaning there are more than 85 million Nigerians who do not have access [10–12]. Nigeria has tried to address this challenge through the promotion of renewable energy development projects, particularly for solar energy [6].

Ghana, a country in West Africa with a population of approximately 33 million people, has a very vibrant and dynamic energy sector. With an energy access rate of approximately 89%, Ghana has one of Africa's best energy security scenarios [13,14]. With an installed electricity generation capacity of 4500 MW consisting of hydropower (29%), thermal sources (68%), and solar power (approximately 3%) [15,16], Ghana has continued to pursue and enhance its renewable energy potential, driven primarily by the 2030 target of having 10% of the energy mix from renewable energy sources, particularly solar energy [17]. Ghana has also made giant strides in technical and vocational education and training (TVET) to support the energy and industrial sectors through some TVET delivery reforms.

Uganda, a country in East Africa with a population of approximately 47 million people, is actively developing its energy sector to support its growing economy. The

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country had an installed electricity generation capacity of around 1346 MW as of 2023, with about 80% sourced from hydroelectric power plants and only 4.5% from solar PV plants [18]. Major facilities include the Bujagali Dam (250 MW), the Isimba Dam (183 MW), and the Karuma Dam (600 MW). Despite the efforts in increasing electricity generation, there is a significant energy deficit. Only about 42% of the population have access to electricity [19]. To address these challenges, the Ugandan government intends to increase its generating capacity to 41 738 MW, with 12% of this capacity coming from solar PV plants.

The growing emphasis on solar energy deployment to address the dire energy needs also provokes growing concern and emphasis on renewable energy education and training, particularly in the field of solar energy [20–23]. Understanding the regulatory and governance frameworks [24,25], challenges in greening solar TVET [26,27], and some best practices in solar technical education delivery is paramount in ensuring there is a steady stream of skilled manpower for the sector. In this paper, we present some of these salient issues that can serve as a basis for addressing the identified challenges.

II. MATERIALS AND METHODS

We used a mixed-method approach, combining a desk literature review of publicly available academic and policy documents with semistructured interviews (individual and focus group) of various stakeholder groups.

To ascertain the various drivers and issues impacting solar system training, adoption, and use in Africa, we embarked on study tours of three African countries—namely, Nigeria, Ghana, and Uganda. We engaged with diverse stakeholders in each country to understand, from their lived experiences, the salient issues that have impacted the solar training landscape in Africa's solar energy sector. Table I provides a summary of the stakeholders we engaged with and the dates of the study tours.

Our choice of the three countries was primarily a result of an agreement with the project funder. The choice of the three countries provides an opportunity for comparative analysis and cross-country comparison and learning. In particular, the choice of the three countries provides opportunities for comparison between countries with a large population (Nigeria) and a moderate population (Uganda

TABLE I. Summary of stakeholder groups interviewed and the dates of interviews.

Country	Stakeholder groups interviewed	Date
Nigeria	National Board for Technical Education National Power Training Institute of Nigeria Nigerian National Assembly (House of Parliament) with House Committee on Renewable Energy and House Committee on Climate Change Rural Electrification Agency Renewable Energy Association of Nigeria German Agency for International Cooperation Vocational education and training schools Industry players and dealers and distributors of solar products Solar system installers and maintenance personnel Energy advocacy groups and other energy think tanks	April 2024
Ghana	Energy Commission of Ghana Commission for Technical and Vocational Education and Training Ghana Technical and Vocational Education and Training Service Representatives of electrical engineering and renewable energy skills sector board Industry players, including installers, importers, designers, and their association representatives German Agency for International Cooperation Ghana Renewable Energy Association Brew-Hammond Energy Centre, Kwame Nkrumah University of Science and Technology Regional Centre for Energy and Environmental Sustainability, University of Energy and Natural Resources	July 2024
Uganda	Directorate of Industrial Training Ugandan Business and Technical Examinations Board Centre for Research in Energy and Energy Conservation, Makerere University Uganda Solar Energy Association Some technical and vocational institutions offering solar training Industry players, including installers, importers, designers, and their association representatives	June 2024

and Ghana), and regional comparison of West Africa (Ghana and Nigeria) and East Africa (Uganda). Furthermore, we chose the three countries in order to understand two important connections:

- How the energy access level of a country impacts or influences solar system adoption, use, and (sustainability) education. Ghana has an energy access rate of 89%, Nigeria has a rate of 60%, and Uganda has a rate of 42%.
- The regional nuances (within the African continent) impacting increasing manpower demand in Africa's solar sector and how they impact (solar) sustainability education.

The study was conducted by representatives of each project partner from ten countries [10] represented on the project. Each country partner prepared the groundwork for the country-level stakeholder engagement and study tour. We divided ourselves into groups to ensure all stakeholders were adequately engaged in the interview process for data collection. Within each stakeholder group for each country, we had a combination of individual and focus group interviews. We had at least seven focus group interviews [7] per country for the diverse stakeholder groups we engaged with. We also had a minimum of ten individual interviews per country.

For the individual interviews, we used codes to designate interviewees from different countries. For example, "N1" means the first individual interviewee from Nigeria, "G3" means the third individual interviewee from Ghana, and "U7" means the seventh individual interviewee from Uganda. This is important as we reference some quotes by some interviewees from the different countries in Sec. VI using the stated nomenclature for the country-level interviewees.

Transcribed notes from the stakeholder interviews and engagements were analyzed by pen and paper coding to ascertain the key drivers of solar system adoption and use and how they impact solar training needs in the countries we studied. The analysis and coding session was done as a workshop among the project partners. The subsequent section presents the findings of our field work and their implications for developing skills for Africa's solar sector.

III. TVET IN THE AFRICAN EDUCATIONAL SYSTEM

In this section, we present the key findings for the TVET landscape in Nigeria, Ghana, and Uganda.

A. TVET in the Nigerian educational system

TVET forms part of the formal education system in Nigeria, and it is clearly incorporated into the three tiers of the educational system (primary, secondary, and tertiary).

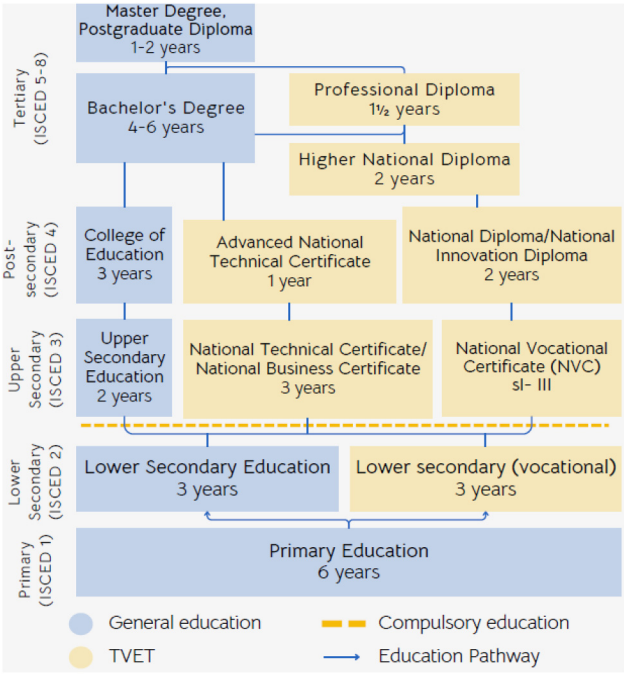

FIG. 1. TVET in the Nigerian educational system. ISCED, International Standard Classification of Education. From Ref. [28].

In Nigeria, education is compulsory up to lower secondary level. Afterwards, there are two possible pathways that can be followed: one proceeds either to the upper secondary level or to an equivalent TVET institution that offers the National Technical Certificate in a chosen discipline. While the universities offer the pathway for further general education leading to the award of a bachelor's degree, monotechnics, innovative enterprise institutions (IEIs), and polytechnics offer a TVET pathway that leads to the progressive award of the National Diploma, the National Innovative Diploma, and the Higher National Diploma. Figure 1 provides a snapshot of the available pathways in the Nigerian educational system and where TVET lies within the system.

Within the Nigerian educational system, there are no clearly defined qualifications relating to solar energy. Most solar energy courses are embedded as modules within a broader renewable energy program. At the TVET level, there is no clearly defined program that is focused exclusively on solar technologies. At university level, in 2023 the Nigerian Universities Commission released the Core Curriculum Minimum Academic Standard, which now includes a compulsory course on renewable energy systems and technologies for all engineering disciplines. Within that course, solar technology is treated only as a module among other technologies. The same pattern also exists for postgraduate programs in renewable energy.

B. TVET in the Ghanaian educational system

Like other African country contexts, Ghana's educational sector has the traditional progressive general education system and the TVET system as shown in Fig. 2. There are three main forms of TVET system in Ghana:

(1) The *formal TVET system*, which comprises institutionalized, intentional, and planned programs offered in public or private recognized educational establishments. They are aimed at providing access to structured lifelong learning resources, and these training programs (and the institutions offering them) are often regulated by a constituted government authority. Most solar training programs in Ghana offered in universities, research institutes, and energy centers [such as the Research Centre for Energy and Environmental Studies at the University of Energy and Natural Resources, Sunyani, and the Brew-Hammond Energy Centre at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi] and TVET institutions (such as Don Bosco Technical Institute, Sunyani, and Suame Technical Institute, Kumasi) follow the formal system.

(2) The *nonformal TVET system*, which exists outside the formal school system, comprises those training arrangements that have some sort of structure, have no structured curriculum, but are more flexible. They often take place in workplaces and community-based settings through activities of trade associations, nongovernmental organizations, and civil society organizations. GREEN Solar Academy is an example of a nonformal TVET system offering solar training in Ghana.

(3) The *informal TVET system*, which comprises largely unstructured training programs and offers no structured or systematic approach to skills development. However, many informal-sector-provided training programs are driven not necessarily by the broader market assessments and needs but by the ability of people to solve some proximate short-term problems. Informal training in the solar sector in Ghana happens mostly among solar system designers and installers where they provide specific training to their trainees in an aspect that helps them fulfil their job functions.

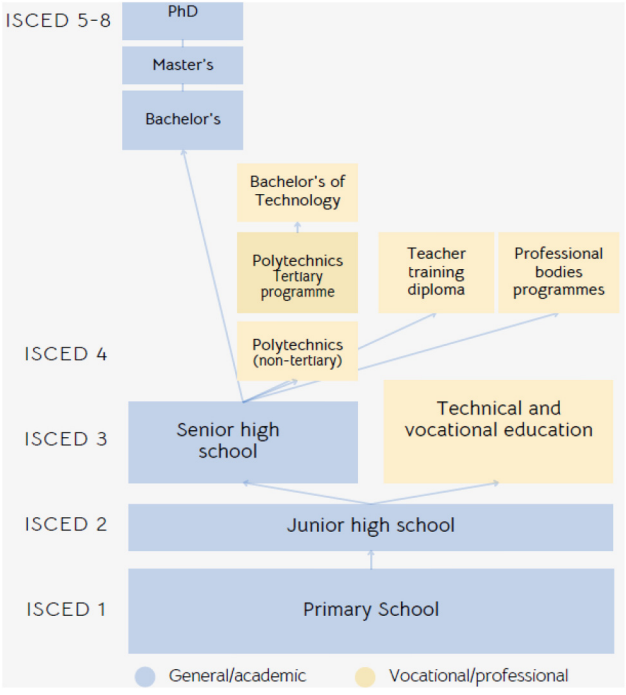

FIG. 2. Education pathway for general academic education and TVET in Ghana (from Ref. [29]).

Within the Ghanaian context, there has been an intentional move to formalize the skills gained through the informal and nonformal systems by means of the competency-based test (CBT) and assessment system. This has proven to be very effective in certifying the skills gained, while also helping people to know where they are deficient and need further training. The CBT system was formally incorporated into the TVET system and is clearly reflected within the educational cycles of the Ghanaian educational system. Solar training is now being incorporated into the existing curriculum of the electrical installation courses at the TVET level. This is the case for Don Bosco Technical Institute in Sunyani and Suame Technical Institute in Kumasi. A corresponding solar system CBT assessment and certification models has also been developed and is being implemented.

There are three educational cycles in Ghana as shown in Table II : cycle 1 concerns basic education, which is compulsory for all Ghanaians; cycle 2 consists of secondary education with two pathways—either conventional senior high school education or TVET; and cycle 3 consists of tertiary education The Ghanaian educational sector offers 11 years of compulsory education at nursery (2 years), primary (6 years), and junior secondary (3 years) levels, all offered within the first cycle of basic education. However, there has been a growth in enrolment of students in secondary education TVET due to the recent introduction of the free education policy by the Ghanaian government at the secondary and tertiary levels. Most solar training programs in Ghana happen in cycles 2 and 3, mostly in TVET institutions and universities.

C. TVET in the Ugandan educational system

The Ugandan educational sector has the traditional progressive general education system leading to the award of degrees, and the TVET system. In Uganda, a pathway

TABLE II. Educational cycles and pathways in Ghana for TVET and conventional education (adapted from Ref. [30]).

Cycle	Level	Age (guide)	Qualifications	
			Conventional academic	TVET
3 (tertiary education)	University Technical university Training college Specialized institute	18 years and older	Doctorate Master's degree Postgraduate diploma Bachelor's degree Diploma	Doctor of technology degree Master's degree Bachelor of technology degree Higher National Diploma Full Technological Certificate *Apprenticeships
2 (secondary education)	Postsecondary, nontertiary		Ordinary National Diploma	Technician Part 1 Certificate *Apprenticeships
	Senior high school	15–18 years	West Africa Senior School Certificate	National Certificates (I and II) Intermediate crafts Technician grades *Apprenticeships
1 (basic education)	Junior secondary	12–15 years (3 years)	Junior high school certificate	Junior high school certificate *Apprenticeship
	Primary	6–12 years (6 years)	No formal qualification	Proficiency II
	Nursery, kindergarten	4–6 (2 years)	No formal qualification	Proficiency I

*The Apprenticeships include formal and non-formal apprenticeship programs.

toward TVET exists immediately after the primary education level, which provides further progression within the educational system. As in the case of Ghana, there are three main forms of TVET systems in Uganda. These are the formal TVET system; the informal TVET system, and the nonformal TVET system.

The formal TVET system in Uganda offers structured training and has an overlapping three-tier system comprising craftsman-level training offered by technical schools and institutes, technician-level training offered by technical colleges, and graduate-engineer-level training offered by universities. The formal TVET segment is largely dominated by private TVET providers, with more than 1000 institutions representing about 80% of all TVET providers in Uganda [31]. There are limited institutions offering formal training in solar system technologies in Uganda.

Within the nonformal TVET system in Uganda, solar training programs are often provided in workplaces and community-based settings through the activities of trade associations, nongovernmental organizations, and civil society organizations. The informal TVET system, accounting for more than 50% of employment in the nonagricultural sector, remains a stronghold of employment in Uganda. The formal TVET system has largely neglected addressing the specific skill needs of those in the informal sector. Indeed, there is no structured or systematic approach to skills development for people in the informal sector. However, many informal-sector-provided solar training programs are driven not necessarily by broader market assessments and needs but by the ability of people to solve some proximate short-term problems,

The Ugandan educational system is structured, beginning with 7 years of primary education, followed by 6 years of secondary education (divided into 4 years of lower secondary school and 2 years of upper secondary school) and 3–5 years of postsecondary education as shown in

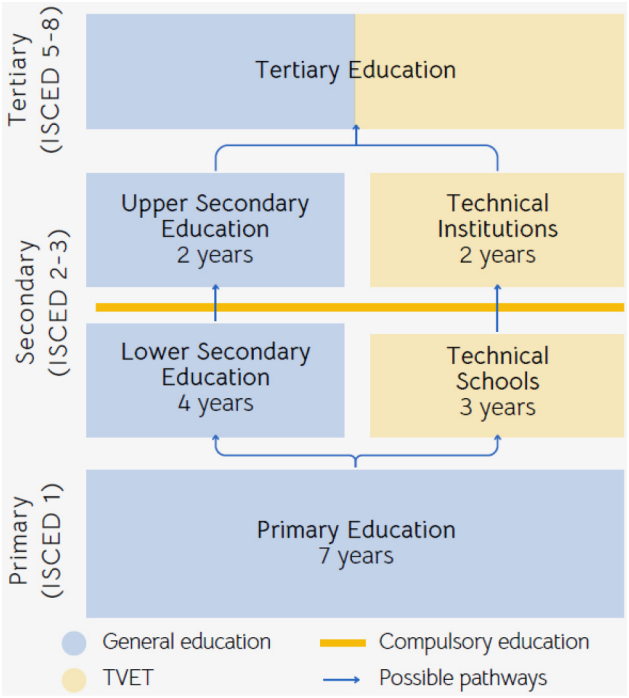

FIG. 3. TVET within the Ugandan educational system (from Ref. [31]).

Fig. 3. Most solar training programs are often provided within the secondary and tertiary education system.

IV. GOVERNANCE FRAMEWORKS DRIVING SOLAR TRAINING PROGRAMS IN AFRICA

In this section, we delve into the salient governance frameworks within each country of focus that shape the TVET landscape for solar training programs in each country.

A. Governance frameworks driving solar training in Nigeria

Three agencies of the Nigerian government have played vital roles in the development of TVET and related policies. These are the Federal Ministry of Education, the Federal Ministry of Science and Technology, and the Federal Ministry of Labour and Productivity. The governance system for TVET in Nigeria follows a decentralized structure with different actors playing different roles. However, there are two important actors involved in the governance of TVET in Nigeria:

(1) The *National Board for Technical Education* (NBTE), which is responsible for supervision and regulation of TVET institutions in Nigeria, as well as providing the minimum guidelines for the curricula for different TVET programs in the country. The NBTE was established in 1977 with the aim of developing a critical manpower base to execute the national development plans initiated in the 1970s. The NBTE regulates activities of monotechnics, polytechnics, colleges of education, and IEIs. There are a few innovative enterprise institutions approved by the NBTE that have National Innovative Diploma programs in renewable energy with an extensive focus on solar technologies. An example is Asteven Energy Institute, which offers a diploma program in solar technology.
(2) The *National Business and Technical Examinations Board* (NABTEB), which is an examination board that issues and validates certificates, and conducts examinations in the technical and business disciplines. There is currently no defined examination and certification for solar system installation and maintenance from NABTEB. NABTEB offers a modular trade certificate in solar system installation for short flexible programs (ranging from a few weeks to months). This is a stand-alone certificate that is awarded to successful candidates who have passed a written and practical assessment offered by NABTEB. However, many informal solar technology training providers are not aware of the possibility of a national certification in solar technology offered by NABTEB.

While these institutions play critical roles in fulfilling their mandate, there are salient challenges (which are more peculiar to Nigeria than the other countries studied) that are confronted by the different stakeholders they regulate:

(1) *Predefined curricula that give very little or no room for innovation in curriculum assessment and delivery*. The NBTE have provided a minimum benchmark document that defines the courses and modules within each program. Even though this is defined as a minimum benchmark, it has become overly prescriptive over time, such that additional course modules (aimed at addressing industry needs) become burdensome to the students on the programs. This also affects the quality of solar training delivery.
(2) *Rigid curriculum structure that does not address industry needs*. The existence of a minimum benchmark document that defines the curriculum at every point for every program makes it excessively rigid. To respond to industry needs, some TVET institutions (by choice) decided to add some training courses or modules to their existing programs to address industry needs. John Bosco Institute of Technology and the Institute for Industrial Technology are examples of technical institutions that have incorporated solar system training into their existing electrical installations curriculum.
(3) *Exclusive focus on technical skills with little emphasis on digital, entrepreneurial, and soft skills*. There is a claim that entrepreneurial skills have been added to many programs; however, they are taught mostly as theoretical courses with very little practical appreciation. There is an urgent need to incorporate entrepreneurial skills in solar training delivery.

Some relevant policies and governance frameworks aimed at developing the TVET landscape in Nigeria include

(1) The development of the *Nigerian Skills Qualification Framework*, which is a system for the development, classification, and recognition of skills, knowledge, understanding, and competencies acquired by individuals, irrespective of where and how the training or skill was acquired. This framework recognizes the skills acquired by individuals through a formal means in the classroom, on the job, or informally [32]. With this new framework, solar training programs offered in nonformal and informal settings can be formalized through the modular assessment and certification system offered by NABTEB.
(2) Introduction of *digital literacy competency* for TVET teachers aimed at providing practical applications of digital tools and strategies to enhance teaching and learning in vocational education. This

also includes the development of online tools and e-learning pathways for TVET. Digital competencies provide additional opportunities for online and hybrid solar skills training for teachers and students.

B. Governance frameworks driving solar training in Ghana

The Ministry of Education primarily manages and governs the TVET system. Before the reorganization of the TVET system in Ghana, several ministries and agencies were involved in TVET program development and delivery, which resulted in an uncoordinated system that made it difficult for quality assurance management. They include the Ministry of Employment and Labour Relations; the Ministry of Trade and Industry; the Ministry of Health; the Ministry of Local Government and Rural Development; the Ministry of Gender, Children and Social Protection; the Ministry of Food and Agriculture; and the Ministry of Youth and Sports. The Pre-Tertiary Education Act, 2020, established and empowered two institutions of government tasked with the responsibility of managing the TVET system in Ghana. These are

(1) The *Commission for Technical and Vocational Education and Training* (CTVET). The CTVET has the primary responsibility for promoting, administering, and regulating TVET in Ghana. The CTVET is responsible for the coordination and supervision of the TVET system, with the mandate to plan, coordinate, and support all aspects of TVET at the national level [33]. The Council for Technical and Vocational Education and Training (COTVET) is supported by five standing technical committees—namely,

   (a) The National TVET Qualifications Committee, which is responsible for the prequalification and inclusion of new TVET programs;
   (b) The Sector Skills Committee, comprising different skills sector boards representing different industrial and professional disciplines;
   (c) The Quality Assurance Committee, with primary responsibility for quality assurance in TVET;
   (d) The Ghana Skills Development Fund Committee, which is responsible for seeking innovative ways to fund TVET and delivery;
   (e) The Enforcement Committee, which is responsible for the enforcement of TVET regulations and policies.

(2) The *Technical and Vocational Education and Training Service* (TVET Service), which is responsible for overseeing, managing, and implementing approved national policies and programs relating to pretertiary technical and vocational education and training. This includes

   (a) Construction, maintenance, and equipping of TVET institutions;
   (b) Implementing the curriculum for TVET programs in collaboration with industry and regulatory bodies;
   (c) Updating the register of TVET institutions and trainers;
   (d) Providing recommendations for TVET policies and programs.

The CTVET has developed a curriculum for solar system installation and maintenance that is embedded within the electrical installations course at TVET level. There is also a stand-alone course on solar systems that follows the CBT assessment and certification models at levels 1 and 2. The TVET Service works closely with TVET schools and other relevant stakeholders (including the relevant skills sector boards) to ensure the effective implementation of the program in approved TVET schools in Ghana.

C. Governance frameworks driving solar training in Uganda

In Uganda, the TVET landscape is governed by several regulatory and governance frameworks managed by key stakeholders to improve the quality and relevance of vocational education in the country. A major intervention in vocational education in Uganda (which also includes solar training) was the "Skilling Uganda" strategic plan of 2011–2020, which had four major critical areas of TVET reform intervention [34]:

(1) Building a comprehensive public-private partnership;
(2) Ensuring a strong and focused TVET management controlled by all major stakeholders;
(3) Defining the requirements of the world of work as the benchmark for all TVET programs and qualifications;
(4) Reforming the system of financing TVET in order to achieve long-term sustainability.

TVET governance and regulation in Uganda is the primary responsibility of the Ministry of Education and Sports, which is responsible for formulating policies, regulations, and guidelines that govern TVET institutions and programs. It is also responsible for program implementation, monitoring, planning, budgeting, and annual reviews. This is achieved by collaboration with other government agencies, educational institutions, and stakeholders to effectively implement TVET policies and standards. These standards cover the legal, institutional, operational,

financial, and stakeholder engagement standards across all relevant sectors, which includes the solar sector [35].

Within the Ugandan TVET solar training landscape, there are two important institutions that play a pivotal role:

(1) The *Directorate of Industrial Training* (DIT). DIT is a Ugandan quality assurance directorate offering nationally, regionally, and internationally recognized quality assurance services for business, technical, and vocational education and training. DIT's focus is to promote employability skills. It operates under the Ministry of Education and Sports and promotes quality and relevance in industrial training through accreditation, certification, and regulation. DIT facilitates industry partnerships and apprenticeships to enhance practical skills development. DIT has contributed greatly in the development and recognition of some solar training initiatives in Uganda offered by private sector players, including courses such as on solar drying technology and solar PV installation.

(2) The *Uganda Business and Technical Examinations Board* (UBTEB). UBTEB is a national examinations board of the Ugandan government that is mandated by law to streamline, regulate, coordinate, and conduct examinations leading to the award of certificates and diplomas in the technical and business disciplines in Uganda. It plays a pivotal role in validating and certifying skills of people who have passed through the formal TVET system through the national examinations it provides [36]. While recognizing the skills gap within the solar sector, UBTEB has recently developed some basic assessment and certification schemes for solar system technologies.

While we acknowledge the role of these institutions in developing TVET in Uganda, another important institution is the *National Council for Higher Education* (NCHE). Although focused primarily on higher education, the NCHE regulates universities and other higher education institutions offering higher-level vocational programs. It ensures that these institutions meet quality standards and adhere to prescribed curriculum development, delivery, and assessment guidelines. The key drivers of these developments include the following:

(1) The *Ugandan TVET Policy 2019*. Uganda has implemented policy initiatives to address the challenges and improve the quality of vocational education. The TVET Policy 2019 aims to reform the TVET system by enhancing access to, equity in, the relevance of, and the quality of vocational training. It emphasizes integration of practical skills development, entrepreneurship education, and industry partnerships to meet labor market demands [35]. This policy has had a direct impact on solar training in Uganda by allowing more private sector stakeholders to play an active role in the training and development of the solar workforce.

(2) The *Skills Development Fund* (SDF). The SDF, established by the government of Uganda, provides financing and support for TVET programs and initiatives. It aims to address critical challenges such as inadequate funding and infrastructure by investing in skills development projects, capacity building, and modernization of training facilities for several trade disciplines (including solar training). The SDF encourages innovation and collaboration among stakeholders to increase the effectiveness and sustainability of TVET interventions.

V. KEY DRIVERS IMPACTING SOLAR ENERGY TVET, ADOPTION, AND USE IN AFRICA

There are key initiatives driving increased demand for skills in the solar sector in Africa, including the following:

(1) *Agenda 2063*. Agenda 2063 has four main themes: economic development; political integration; improvements in democracy and justice; and the establishment of security and peace on the entire African continent. It aims to birth the ideals of African growth underpinned by science, technology, and a hub for opportunities, and the requisition of the African Renaissance [37]. At the heart of Agenda 2063 is the promotion of the energy transition in Africa. This would require building a skills base to support this transition.

(2) *Solar energy potential*. Africa is home to 60% of the best solar resources globally [1]. It boasts abundant solar resources, making solar energy a workable and sustainable solution for meeting the continent's energy needs. Green VET programs capitalize on this potential by preparing a skilled workforce to harness solar energy efficiently.

(3) *Job creation and economic development*. Investing in green VET programs creates employment opportunities and stimulates economic growth. Solar energy projects require skilled technicians, engineers, and installers, driving the demand for trained professionals in the renewable energy sector. In Africa, between 8 million and 14 million energy transition jobs could be created through to 2030, driven primarily by government spending and investment in energy transition technologies [38].

(4) *Climate change mitigation*. Solar energy contributes to reducing greenhouse gas emissions and mitigating climate change impacts. Green VET programs

focus on building a workforce equipped with the knowledge and skills to deploy solar technologies effectively, thereby supporting Africa's commitment to climate action.

(5) *International support and partnerships*: Various international organizations, governments, and nongovernmental organizations recognize the importance of promoting renewable energy education and training in Africa. The African Development Bank, through an initiative organized at COP27, was able to attract $35 million to the Sustainable Energy Fund for Africa to catalyze private sector investments in renewable energy in Africa [39]. Power Africa has also established relationship with key stakeholders and development partners in Africa's energy sector (including technical agencies, development finance, governments, and multilateral organizations) to address Africa's energy needs [40].

A. Key drivers and barriers impacting solar system training, adoption, and use in Nigeria

The key barriers to and drivers of solar training in Nigeria are summarized in Table III. These identified drivers influence (and are influenced by) the educational governance structure. For example, the fact that different stakeholders in Nigeria's solar industry are working in silos makes it difficult for educational institutions to know which stakeholders to engage with for industry-relevant input in curriculum development. This in turn widens the skills gap, leading to insufficient technical knowledge on the part of both the teachers and the students. This lack of long-term vision has been a major contributor that

TABLE III. Drivers and barriers impacting the adoption and use of solar systems in Nigeria.

Drivers and barriers	Description
Addressing the energy access challenge	There is a huge energy need in Nigeria, necessitating alternatives in electricity generation, which includes solar technology. Solar PV technology is viewed primarily as a technology to address energy access and not just to address the energy transition challenge. Only 60.2% of Nigerian have access to electricity, meaning there are still more than 85 million Nigerian without electricity access [41]. These challenges point to the need for increased skilled manpower in the solar sector for provision and maintenance of solar electricity infrastructure.
Governance challenges	Lack of long-term vision for the solar industry poses a challenge to achieving full industry potential [25,42]. Different stakeholders in the industry are working in silos that create a challenge around addressing the specific interests of diverse stakeholders regarding manpower needs in the solar sector.
Financial constraints	Financial constraints are limiting the adoption of solar systems. Limited funding is available to support teacher training and manpower development in the solar sector [43].
Solar skills and training deficit	Solar training is viewed as a way of addressing the existing multidimensional poverty in Nigeria. Training is needed in designing solar PV systems for various uses.
Insufficient technical knowledge	There is a lack of knowledge of how to integrate solar infrastructure into existing systems in an economic way. This is primarily due to a lack of knowledge that (unfortunately) is contributing to the bad image of solar energy as an unreliable energy infrastructure [27]. Safety training must be incorporated into solar training to reduce installation and maintenance safety risks. The skills and competencies of trainers must be enhanced for greater impact.
Lack of defined technical standards	Lack of defined design, installation, and operational standards poses a challenge in the Nigerian solar market. There is a need for an enhanced and good maintenance culture to ensure optimal efficiency of solar installations.
Market risks	There is a need for users and installers to be more risk aware. Security of the physical solar infrastructure is important to avoid infrastructure sabotage [44]. There is less supply of labor than the actual demand in the solar market.
Behavioral challenges	There is a need for behavioral change since solar energy pays in the long run. There is a need for a change of commercial strategy for those involved in the solar value chain to help users see the benefits both now and in the future.

makes many Nigerians view solar training as just a way of addressing the existing multidimensional poverty. This issue is also compounded by a lack of defined technical design, installation, and operational standards. Lack of defined standards has resulted in difficulty for educational institutions to prepare their students for the growing complex solar design, installation, operation, and maintenance requirements, thus leading to mismatch of available skills with the actual skills requirement of the Nigerian solar industry.

B. Key drivers and barriers impacting solar system training, adoption, and use in Ghana

The key drivers and barriers impacting the solar system training ecosystem in Ghana are summarized in Table IV. Unlike Nigeria, Ghana has a much better educational governance structure that supports the solar industry training ecosystem. The existence of the CTVET, which is responsible for setting up policies governing TVET in Ghana, and the existence of the TVET Service, which is responsible for the implementation of TVET policies (including supporting institutions, teacher training, and institutional funding), makes the Ghanaian case unique. Stakeholders are not only knowledgeable, they actively contribute to curriculum development through the various sector skills boards for different disciplines and trades. Some of the prevailing challenges (such as financial, infrastructure, market, and attitudinal issues) can be easily addressed with the existence of a robust educational governance structure that encourages interaction between diverse stakeholders in addressing the common challenges.

C. Key drivers and barriers impacting solar system training, adoption, and use in Uganda

The key drivers and barriers impacting solar system training in Uganda are summarized in Table V. Uganda and Nigeria have some similarities with respect to challenges in the educational governance structure. UBTEB, after its establishment, was mentored and guided by NABTEB of Nigeria. Lack of cohesive policies and coordination of stakeholders poses a challenge in getting

TABLE IV. Drivers and barriers impacting the adoption and use of solar systems in Ghana.

Drivers and barriers	Description
Addressing energy access challenge	There is a high level of electricity access (89%) in Ghana. Solar adoption and use is largely viewed as a way to reduce energy cost since grid electricity is very expensive, hence the need for more skilled manpower in solar system installation and maintenance. Government investment in the solar minigrid has targeted isolated communities that grid electricity may take some time to reach. This further highlights the need for skilled solar technicians who can maintain the solar infrastructure in isolated communities.
Governance challenges	There are good policies and targets favoring solar adoption; for example, the 2030 target that sets renewables as 10% of the total energy mix (mostly to be achieved with solar energy). There is also a net metering policy whose pilot implementation would begin in early 2025. Stakeholders are very knowledgeable about what to do and they are taking the necessary action. Government actions are viewed as slow with respect to implementation of some policies that favor solar adoption; for example, the delayed implementation of net metering policy. TVET governance structure (comprising national, regional, and local directors or heads) is viewed as effective in addressing emerging issues (particularly solar training) much faster.
Financial constraints	There are limited funding opportunities for solar projects and solar training programs. The high initial cost of solar infrastructure hinders widespread adoption.
Skills gap persists	There is insufficient training in solar energy technologies for both teachers and students. There is a lack of skilled trainers and teachers for solar training. Solar training is not yet incorporated into the existing curriculum.
Infrastructure deficit	Many technical institutions still do not have the necessary infrastructure and equipment for solar training.
Attitudinal barriers	Since the TVET reforms, there has been high enrolment and better perception of TVET programs among parents, students, and communities. This is also resulting in increased interest in solar training programs. TVET solar training is perceived as a better and faster pathway to employment and economic empowerment. TVET student motivation is very high with regard to solar training.
Market risks	The security of solar installations in isolated areas needs to be improved. Market uncertainties affect the rate of adoption of solar systems.

TABLE V. Drivers and barriers impacting the adoption and use of solar systems in Uganda.

Drivers and barriers	Description
Addressing the energy access challenge	Solar technology is perceived as a viable option to address the high demand for reliable energy solutions, especially in underserved areas and island communities. Solar technology is viewed as a way to address the energy access problem and not just the energy transition challenge, hence the need for more skilled solar system manpower and training. Approximately 60% of Ugandans have access to electricity [45].
Governance challenges	Lack of a cohesive policy and coordination of stakeholders poses a challenge in getting high-level stakeholder commitment and involvement in solar system training and manpower development.
Financial constraints	There is limited funding for solar projects, thus limiting the growth potential of solar technology. The high initial costs of solar PV installation hinder widespread adoption. Very limited financial support is available for solar system training.
Skills gap persists	There are insufficient training programs in solar energy technologies. There is a lack of skilled trainers and teachers for solar system training
Infrastructure deficit	Poor infrastructure, including inadequate workshops and outdated equipment for training, hinders good solar training delivery
Attitudinal barriers	Negative perception of TVET among parents, students, and communities hinders the greater acceptance of solar TVET programs. TVET is perceived as a pathway for dull and economically disadvantaged people. This also impacts solar training programs.
Market risks	The security of solar installations and market uncertainties affect adoption rates, which in turn slows down solar market growth and the corresponding demand for solar skills.

high-level stakeholder commitment and involvement in solar system training and manpower development, leading to stakeholders working in silos, as is the case in Nigeria. This lack of stakeholder cooperation has further entrenched and widened the existing skills gap both for teachers and for students, posing a great challenge for people development for the Ugandan solar sector.

VI. KEY CHALLENGES IMPACTING THE DEVELOPMENT OF SOLAR TRAINING PROGRAMS IN AFRICA

Our analysis revealed important challenges impacting the development of solar training programs in Africa. These challenges were largely similar for Nigeria, Ghana, and Uganda in many ways. However, there are some specific challenges that are peculiar to Nigeria. These were highlighted in Sec. IV A.

Following a cross comparison of the three country case studies, and desk research done for other African countries, we have identified the following challenges impacting the development of solar training programs in Africa:

(1) *Skills shortage and poor training quality*. There is a gap between the skills acquired through traditional education systems and the needs of the renewable energy industry. Green VET programs must align their curricula with industry requirements and ensure the quality and relevance of training to produce competent professionals. Africa currently lacks more than 4.3 million engineers and technicians to aid its development agenda [46].

"*It's a shame that there is such a misalignment between what we need and what the institutions provide. The disconnect is huge and this has to be corrected."*

Interviewee N4

(2) *Inconsistencies in regulatory and policy frameworks*. Inconsistent regulatory frameworks and policy environments across African countries create uncertainty for investors and educators in the renewable energy sector. Harmonizing policies, streamlining regulations, and providing incentives can foster a conducive environment for green VET programs.

"*Many African countries are trying to have a national qualifications framework that can help tackle this issue. However, the major issues are around implementation challenges. Many are confused. The confusion is real and this poses a lot of challenges to educators and similar institutions."*

Interviewee U2

(3) *Access to funding and financing*. Sustainable funding mechanisms are essential for the sustainability and scalability of green VET programs. Securing *adequat*e funding for infrastructure development, curriculum development, faculty training, and student scholarships remains a significant challenge.

"*We receive limited support. We need training equipment. Teachers need to be trained. We need training consumables and the funding is so small."*

Interviewee N7

(4) *Poor awareness and perception of solar energy*. Limited awareness of the benefits of solar energy and misconceptions about renewable energy careers hinder the uptake of green VET programs. For example, there are narratives that solar energy cannot power commercial and industrial facilities. There are also ideas that certain solar installations are for the rich due to their high initial installation cost Addressing misconceptions and raising awareness of the opportunities in the solar energy sector is essential to attract more students to these programs.

"*It's a fallacy that solar energy cannot power industry-scale machineries. I am happy you are here and you can see it for yourself. You just have to plan to make the most of it. We do not run night shift but we work on weekends. We try to make the most of it and limit what we consume from the grid because it is very expensive."*

Interviewee G5

(5) *Limited training infrastructure and resources*. Many African countries face infrastructure gaps and resource constraints, hindering the establishment and expansion of green VET programs in solar energy. Insufficient funding, inadequate training facilities, and a lack of modern equipment pose significant challenges.

VII. KEY REGIONAL DIFFERENCES AFFECTING DEMAND FOR AND SUPPLY OF MANPOWER IN AFRICA'S SOLAR SECTOR

As stated in Sec. II, one important connection we intend to highlight in this paper is the regional nuances (within the African continent) impacting increasing manpower demand in Africa's solar sector and how it impacts (solar) sustainability education. The particular country-level cases studied provided us with an opportunity to dive deeply into specific details and how these country-level nuances affect regional initiatives and projects in the solar sector. For example, are there connections between country-level solar energy interventions in Ghana and Nigeria and the initiatives of the Economic Community of West African States (ECOWAS) Centre for Renewable Energy and Energy Efficiency? Are there regional initiatives that have resulted from country-level interventions? What regional megaprojects are impacting increased manpower demand in the solar sector?

There are key regional peculiarities within the African continent that affect demand and the eventual supply of skilled manpower within Africa's solar energy sector. Some key regional differences impacting the different subregions of Africa are highlighted below:

(1) *North Africa*. Countries such as Egypt and Morocco have made significant progress in the addition of renewable energy to their energy mix. Between 2015 and 2019, Egypt added 25.5 GW of new electricity generation capacity, which also includes 1 GW of solar PV capacity and 840 MW of wind capacity. This took Egypt out of energy shortage to having a 25% energy surplus [47]. Megaprojects such as Egypt's Benban solar farm and Morocco's Noor solar project are poised to address the region's energy and export needs, thus showcasing the immense potential of the region's solar resources.

(2) *East Africa*. About 140 million people in East Africa lack access to electricity. In 2021, Kenya and Ethiopia accounted for 30% of global home solar systems and solar appliance sales [2]. Recognizing the immense potential of solar energy for development, East Africa is witnessing significant progress. Initiatives such as the East African Renewable Energy Training Centre are fostering education and training in the region.

(3) *West Africa*. Mirroring North Africa's sunny disposition, West Africa prioritizes solar power due to its abundant sunshine and rising energy demand due to its large population. Regional collaboration through ECOWAS tackles shared challenges, paving the way for a sustainable energy future. Leading countries such as Nigeria and Ghana showcase the region's potential, inspiring a collective journey toward a brighter, solar-powered future.

(4) *Central Africa*. While boasting rich renewable energy resources, Central Africa faces infrastructure limitations. Building capacity and securing funding access are crucial for the region's progress. In Central Africa, more than 109 million people lack access to electricity [48]. This will necessitate increased need for more off-grid solar solutions and more skilled manpower in the solar industry.

VIII. BEST PRACTICES TO ENABLE SCALE-UP OF SKILLS IN AFRICA'S SOLAR SECTOR

As stated in Sec. II, a major connection we intend to highlight in this paper is the regional nuances (within the African continent) impacting increasing manpower

demand in Africa's solar sector and how it impacts on (solar) sustainability education. In line with this objective, some best practices in solar training in Africa can be better understood and appreciated through three main dimensions:

(1) Solar training programs offered by universities and research institutes;
(2) Solar training programs offered by TVET institutions;
(3) Solar training programs offered by nonformal training academies.

A. Solar training programs offered by universities and research institutes in Africa

In southern Africa, South Africa leads with a robust presence in vocational solar training, where about 50% of its 26 institutions offer solar programs at both undergraduate level and postgraduate level. Institutions such as Nelson Mandela University, the University of Johannesburg, and the University of Cape Town provide specialized courses in photovoltaic engineering, energy storage, and technoeconomic modeling. These training programs typically last between 1 year and 2 years. Furthermore, the University of Cape Town's Energy Research Centre, funded by the African Climate and Development Initiative, conducts research and provides short-course training to help enhance skills via a multidisciplinary approach. However, the need for more advanced research facilities often drives students abroad for further studies.

North Africa, particularly Egypt, boasts a strong TVET solar training sector, with graduate programs spanning 1 to 3 years, covering topics such as solar cell materials and energy storage. Cairo University and the German University in Cairo collaborate with German institutions to offer a dual master's degree in renewable energy and energy efficiency.

In West Africa, Nigeria and Ghana are at the forefront of solar training. Nigerian institutions such the University of Nigeria, Nsukka, and Usman Danfodiyo University offer advanced degrees in renewable energy, focusing on solar power generation. Ghana's KNUST and Ghana Technology University College are key players. KNUST's master of science program in renewable energy technologies is a notable example. Both Nigeria and Ghana offer programs ranging from 18 to 24 months, with KNUST also providing short courses through its Brew-Hammond Energy Centre.

In East Africa, Kenya and Uganda are leading the way in solar training. Kenya's Kenyatta University and Moi University, in partnership with Kibabii University, offer postgraduate programs in sustainable energy, supported by international partnerships and lasting up to 3 years. Uganda Martyrs University and Uganda Christian University (UCU) are also advancing in this field, with UCU launching a postgraduate diploma in sustainable business and renewable energy, supported by the European Union's DALILA project. Makerere University's Centre for Research in Energy and Energy Conservation (CREEC) in Kampala further contributes through research and solar training workshops.

Overall, Africa's solar education landscape is thriving, with institutions across the continent increasingly offering specialized programs and training to meet the growing demand for renewable energy expertise.

B. Solar training programs offered by TVET institutions in Africa

There has been significant progress in Africa's TVET landscape in solar training, with significant focus on enhancing the skills of technicians across the continent. In North Africa, Tunisia leads with numerous vocational institutions. The Sfax Vocational Training Centre, managed by the Tunisian Agency for Vocational Training, now features a solar photovoltaic training laboratory funded by the Turkish Cooperation and Coordination Agency. Egypt's Don Bosco Technical Institute offers renewable energy training, with courses certified by both the Italian Embassy and the Egyptian Ministry of Foreign Affairs.

In East Africa, Kenya's solar PV regulations require compliance across the solar industry. Nairobi Technical Institute, in collaboration with the Kenya Renewable Energy Association, offers class T1 and class T2 licenses for solar PV installation, with courses lasting from 3 weeks to 6 months. Uganda's Nakawa Vocational Training Institute (NVTI), in partnership with the German Agency for International Cooperation (GIZ), provides solar PV short courses and electrician courses, spanning 6 to 8 months.

South Africa's Nkangala TVET College offers solar-specific courses with 6-month internships through partnerships with companies such as Enel Green Power South Africa. False Bay College also offers advanced solar technician training, including diploma programs.

In West Africa, Nigeria's TVET sector integrates solar energy training into broader programs. The Institute for Industrial Technology and John Bosco Institute of Technology include renewable energy systems in their curricula. Specialized solar training is offered by institutions such as Asteven Academy, the Renewable Energy Technology Training Institute, and Wavetra Energy Academy. In Ghana, institutions such as the Accra Technical Training Centre and Koforidua Technical University provide comprehensive solar training, while programs such as Green People's Energy for Africa, organized by GIZ, further support this initiative.

C. Solar training programs offered by nonformal training academies in Africa

South Africa boasts numerous nonformal training academies due to its thriving solar industry, offering short courses to quickly upskill the labor force in the solar sector. Notable institutions include the Green Building Council for South Africa, Terrafirma Academy, the South African Energy Efficiency Confederation, Ashrae, and GREEN Solar Academy. These courses, ranging from 1 week to 3 months, focus on practical, hands-on training in solar PV technology, system design, and installation, although they are outside the formal educational framework.

In North Africa, the Global Horizon Centre in Sharm El-Sheikh offers 2-week nonformal solar training courses. Additionally, Infinity's Women in Renewable Energy Committee provides vocational training programs to increase female participation in renewable energy, particularly in rural areas.

West Africa's approach differs, with Ghana emphasizing collaboration with TVET institutions and government plans to certify artisans and technicians, reducing industry-driven training needs. Conversely, in Nigeria, companies such as Gennex Academy, Green Academy Africa, Ecowatt Nigeria, and Rubitec Academy offer short courses, ranging from 1 week to 6 months, for recruitment and corporate social responsibility purposes.

In East Africa, the Toolkit Hub in Kikuyu, Kenya, partners with more than 50 TVET centers to provide short, dedicated solar PV courses. Initiatives such as those at Sigalaga National Polytechnic in Kakamega, Kenya, in partnership with Strathmore University, focus on equipping trainers with the skills needed to teach solar PV system design, installation, and maintenance.

D. Key challenges and best practices in greening TVET in Nigeria's solar sector

In this section, the best practices in solar training in Nigeria are presented through three main dimensions: solar training programs offered by universities and research institutes; solar training programs offered by TVET institutions; and solar training programs offered by nonformal training academies.

1. Solar training programs offered by universities and research institutes

Several universities in Nigeria have introduced *specialized postgraduate programs* to equip students with the skills needed for the national energy transition. Examples of these universities include the University of Nigeria, Nsukka, which offers advanced degrees in renewable energy systems through its Renewable and Alternative Energy Research Group, focusing on solar drying, heating, and power generation, and Obafemi Awolowo University and Usman Danfodiyo University in Sokoto, offering master's degrees in energy systems and renewable energy. The Federal University of Technology Akure, Bayero University Kano, the University of Ibadan, and the University of Port Harcourt have also embraced renewable energy studies. Their programs, typically lasting 18–24 months, require candidates to have a bachelor's degree in engineering or physical sciences. The curriculum covers essential topics such as renewable energy studies and environmental sustainability, preparing students to contribute to Nigeria's sustainable energy goals.

In Nigeria, only a few universities run *short courses* in solar system installation and maintenance. These include Pan-Atlantic University, through its School of Science and Technology, and Lagos State University, through its Open and Distance Learning and Research Centre. These programs, ranging from 1 week to 4 weeks, provide practical skills for professionals and individuals seeking hands-on experience in solar energy without committing to full-time studies. These educational initiatives underscore Nigeria's commitment to advancing renewable energy, making it more accessible and practical for a broader audience.

2. Solar training programs offered by TVET institutions

The TVET sector in Nigeria is characterized by institutions that offer both diploma certificates and certificates of proficiency. These institutions prioritize practical skills over theoretical knowledge, with program durations ranging from 3 to 24 months. Within this framework, some institutions have incorporated solar energy training into their existing curriculum. For example, the Institute for Industrial Technology offers robust programs in electromechanics and electrotechnics, with solar renewable systems as one of the modules offered in both programs. Similarly, John Bosco Institute of Technology has included solar system training as a module in the 3-year electrical installation program.

There are also institutions that provide specialized solar training programs as stand-alone courses, with durations ranging from 1 week to 3 months. Notable examples include Asteven Academy, the Renewable Energy Technology Training Institute, Wavetra Energy Academy, and Green Academy Africa. These programs focus on equipping individuals with the specific skills needed for careers in the solar energy industry.

3. Solar training programs offered by nonformal training academies

Several companies in Nigeria are actively involved in providing solar training programs to enhance the skills of the labor force in the solar energy sector. These programs, which serve both recruitment needs and the drive for corporate social responsibility, range from 1 week to 6 months depending on the company's objectives. Notable among

these companies are Gennex Academy, Green Academy Africa, Ecowatt Nigeria, and Rubitec Academy.

Rubitec Academy has been a pioneer in renewable energy training since 2004, specializing in the design, installation, and maintenance of off-grid solar systems. To foster future leadership in the sector, Rubitec Africa partners with Nigerian universities and polytechnics in delivering solar training by selecting ten top graduates in the electrical and electronic engineering, environmental science, and related fields for the training. This initiative is part of Rubitec Africa's broader mission to collaborate with academic institutions both in Nigeria and abroad to develop leaders in renewable energy and environmental sciences.

E. Key challenges and best practices in greening TVET in Ghana's solar sector

In this section, the best practices in solar training in Ghana are presented through three main dimensions: solar training programs offered by universities and research institutes; solar training programs offered by TVET institutions; and solar training programs offered by nonformal training academies.

1. Solar training programs offered by universities and research institutes

Most universities and research institutes within universities offer two types of training program concerning solar technologies:

(1) *Postgraduate programs* in the form of master and doctoral programs in renewable energy where solar technology is treated as a module in the program.

Ghana's postgraduate education in renewable energy, particularly solar technology, is led by KNUST and Ghana Technology University College. KNUST's master of science program in renewable energy technologies, launched in 2011 with international support, has trained more than 100 engineers and scientists, solidifying KNUST's leadership in this field. The program lasts approximately 18 months and includes a comprehensive curriculum covering the entire renewable energy spectrum.

To pursue a master's degree in renewable energy engineering or related fields in Ghana, applicants must meet specific requirements. Academically, a minimum of a second-class lower-division degree in relevant fields such as engineering or physical sciences from a recognized university is required. Applicants with a third-class degree may be considered if they have 2–5 years of substantial industry experience. Professional experience is crucial, with candidates needing 1–2 years of relevant experience in the renewable energy industry or related industries.

(1) *Short courses in solar technology* targeted at people without any prerequisite knowledge or skills. These training programs often last 1 week and are targeted at upskilling those already working in the solar sector or those who are interested in entering the solar system design and installation business.

Institutions offering short courses to accelerate training in solar energy often obtain funding support from partner European organizations. The Brew-Hammond Energy Centre, for example, provides essential training, research support, and expertise in energy management and policy analysis. This is vital for sustainable energy usage to meet Ghana's developmental needs and achieve ECOWAS targets and the Sustainable Development Goals.

2. Solar training programs offered by TVET institutions

In Ghana, TVET institutions play a crucial role in the development of skilled labor for the renewable energy sector, particularly in solar energy. The growth of the solar industry in Ghana has led to increasing demand for technicians and engineers who are well-trained in the installation, maintenance, and management of solar energy systems. Institutions in this space include Accra Technical Training Centre, Koforidua Technical University, and Don Bosco Training Institute. Most solar training programs in TVET institutions are often embedded in existing 2–3-year electrical installation and maintenance programs.

Institutions such as GREEN Solar Academy organize their programs as dedicated short courses that run for a duration of between 3 weeks and 3 months. Other programs, such as those run by Green People's Energy for Africa, are organized with the support of GIZ. GIZ partners with some companies and institutes to help sponsor short courses aimed at upskilling participants to work in the solar space.

There are other partnerships and collaborations that have aided the development of more solar training opportunities in Ghana. For example, DSTC Solar Training Centre was established in 2009, in technical cooperation with Global Sustainable Energy Solutions of Australia and the Department of Mechanical Engineering and Agriculture of KNUST at Kumasi. This partnership provided a framework that has helped train hundreds of trainees fit for the industry.

3. Solar training programs offered by nonformal training academies

Nonformal training academies offering short-term solar training programs are not very prominent in Ghana. However, there are a few companies that would rather train their participants in partnership with a recognized TVET institution so as to aid the process of assessment and certification of the learners. An example is GREEN Solar

Academy, whose aim is to create Africa's largest network of solar installers and to make renewable energy accessible for all. It focuses on providing the needed solar training by upskilling before getting the trainees into companies.

F. Key challenges and best practices in greening TVET in Uganda's solar sector

In this section, the best practices in solar training in Uganda are presented through three main dimensions: solar training programs offered by universities and research institutes; solar training programs offered by TVET institutions; and solar training programs offered by nonformal training academies.

1. Solar training programs offered by universities and research institutes

Uganda has limited postgraduate programs in renewable energy, trailing behind other African countries in academic development in this sector. However, institutions such as Uganda Martyrs University and UCU are making notable progress. UCU, for instance, recently launched a postgraduate diploma in sustainable business and renewable energy, supported by the European Union's DALILA project and approved by the NCHE. This program introduces six new courses focused on renewable technologies and green business, such as energy and sustainable development, renewable energy technologies, energy efficiency, and renewable energy enterprise management, positioning UCU as a key player in advancing renewable energy education in Uganda.

Meanwhile, Makerere University, one of Uganda's oldest universities, contributes to the renewable energy sector through its CREEC. CREEC conducts research and offers solar training programs, focusing on thematic areas such as rural electrification, energy efficiency, energy testing, energy for productive use, household energy solutions, and energy entrepreneurship.

2. Solar training programs offered by TVET institutions

The government's overall objective is to provide electrification for 80% of the country's population by 2040. This rural electrification process has to be accompanied by skills transfer, capacity building, and technical training around renewable energy sources. NVTI stands out in the provision of solar training done in partnership with GIZ and HWK Goblenz. NVTI operates two systems of solar training delivery: solar PV short courses and the solar PV electrician course. The former runs for about 6 months, while the latter runs for 8 months.

In Palabek, the Don Bosco Vocational Training Centre also has a training program that is part of the broader electrical installations program. This training also helps support refugees from South Sudan located in Uganda. These programs run for 6 months to 18 months.

3. Solar training programs offered by nonformal training academies

There are not too many solar training initiatives in the nonformal sector in Uganda. However, the Stiftung Solarenergie (Solar Energy Foundation) spearheads one such solar training program. It has a dual-training concept that combines theoretical training in solar technology with internships in a local solar company. It also works closely with the Ugandan Cooperative Sendea. Sendea organizes and coordinates the training courses open to the entire Ugandan solar industry. SolarNow, a Ugandan-based company manufacturing and selling home solar systems, also offers nonformal training programs in solar systems.

IX. CONCLUSIONS AND KEY TAKEAWAY MESSAGES

To achieve Agenda 2063's objectives of job creation and economic development, it is important that all stakeholders realize that energy is pivotal to these development objectives, and achieving increased decentralized solar deployment would necessarily lead to increased demand for solar training programs in Africa. With the potential of between 8 million and 14 million energy transition jobs that could be created through to 2030, driven primarily by government spending and investment in energy transition technologies, this would not only address the energy access challenge of Africa's large population but also open the path for a more sustainable and inclusive development for Africa. Indeed, regional differences and subcontinental energy priorities within the African continent play a major role in solar system deployment and the corresponding sector skill needs.

In Nigeria, there is a huge energy need, necessitating alternatives in electricity generation that includes solar technology. Solar PV technology is viewed primarily as a technology to address energy access and not just as a means to address the energy transition challenge. With only 60.2% of Nigerians having access to electricity, meaning there are still more than 85 million Nigerian without electricity access, there is a need for a long-term vision for the solar industry to achieve the full industry potential. Indeed, a lack of defined design, installation, and operational standards poses a challenge in the Nigerian solar market. Many solar training programs in universities and TVET institutions are implemented either as short courses targeted at addressing specific skill needs or as modules embedded in a broader program. A more targeted approach is required to ensure we prepare the required skilled manpower for the growing opportunities that the future of the Nigerian solar industry presents.

In Ghana, solar adoption and use is largely viewed as technology to reduce energy cost since grid electricity is very expensive, hence the need for more skilled manpower

in solar system installation and maintenance. With solar system training happening at cycle 2 (senior high school or TVET) and cycle 3 (universities and research institutes) of the Ghana education system, it is important for stakeholders to give priority to the provision of necessary infrastructure and equipment for solar training to help support the future of that industry.

With only 42% of Ugandans having access to electricity, solar technology is perceived as a viable option to address the high demand for reliable energy solutions, especially in underserved areas and island communities. A lack of cohesive policy and coordination of stakeholders poses a challenge in getting high-level stakeholder commitment and involvement in solar system training and manpower development. Negative perception of TVET among parents, students, and communities hinders the greater acceptance of solar TVET. TVET is perceived as a pathway for dull and economically disadvantaged people. This also impacts solar training programs. Poor infrastructure, including inadequate workshops and outdated equipment for training, hinders good solar training delivery.

It is important to draw lessons from what different African countries are doing to address the manpower preparation challenge for the solar industry. Ghana has a robust educational governance system that supports the development of the various industry sectors, including the solar industry, that other countries can learn from. Its robust industry sector skills boards that serve as an avenue for stakeholder engagement and contribution to defining the industry skills requirements for each sector are something that should be emulated by other countries. This initiative of the Ghanaian government and its mode of implementation has drastically reduced the silo mentality of Ghanaian industry stakeholders, forcing them to work together in the interest of all. The dynamism of the Nigerian solar industry sector is something to be emulated. The focus on addressing the incessant challenges by different stakeholders (in the way they know best) despite the regulatory and governance challenges is phenomenal. Openness to learning from the others is a major takeaway message from the Ugandan case. Their openness to learn from their counterparts in Nigeria on how to address the skills assessment and certification challenge is commendable.

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DATA AVAILABILITY

The data that support the findings of this article are openly available [49].

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