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RESEARCH PAPER

Technical stakeholders' perspective of solar photovoltaic system failure in Sub-Saharan Africa: The case of Ghana

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Abstract. In many parts of sub-Saharan Africa, grid-connected electricity is unreliable and frequently unavailable in rural locations. Alternative electricity-generation fossil-fuel sources are prohibitive. Solar energy photovoltaic systems have great potential in bridging the energy gap in electricity off-grid locations in sub-Saharan Africa and contribute to the region's energy portfolio at utility and/or domestic levels. Most installed PV systems in sub-Saharan Africa have often not achieved their anticipated functionality and/or fail frequently. Take-up of PV systems consequently remains low, with long pay-back times. In this study, we have investigated the barriers and challenges associated with PV system operation and probable causes of failure of installed systems within the sub-Saharan Africa region from the perspective of technical stakeholders. We undertook a broad consultation of technicians (installers), engineers, project supervisors, and other technical stakeholders via questionnaires and interviews in a typical sub-Saharan African setting, namely Ghana. Our results show that component quality, cost, availability, and customer preferences are dominant factors considered by the technical stakeholders in component selection during the planning and execution of PV projects. The survey analysis revealed that inverters and batteries are components that account for the most malfunctioning and failures in installed PV systems, while PV panels account for the least. Low product quality, user errors, natural/environmental incidents, and poor sizing/installation errors are identified as key causes of components' failure.

Keywords: Photovoltaic Systems; PV Failure; Technical Stakeholders; System components; Sub-Saharan Africa; Ghana

1. Introduction

The vast majority of the world's population with the least access to electricity is located within the sub-Saharan African (SSA) region. Indeed, in many parts of sub-Saharan Africa, grid-

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connected electricity is unreliable and frequently unavailable in rural locations. Alternative electricity-generation fossil-fuel sources are prohibitive (Nwanya et al., 2016).

It has been projected that by 2040, about one billion people within the SSA region will have access to electricity, but because of population growth, around 530 million people within the same region, largely rural dwellers, will still live without electricity by the year (International Energy Agency, 2014). Currently, nearly 600 million people live without electricity (International Energy Agency, 2019). This lack of access to electrical energy has had a debilitating effect on development in the region. Under such conditions, renewable energy systems will become increasingly attractive and a viable alternative. Within the last decade, many countries within sub-Saharan Africa have articulated policies with set targets towards universal access to electricity (Ozoegwu et al., 2017; Obeng-Darko, 2024). A popular approach to the actualization of these targets is to employ, largely, decentralized systems in areas where the grid connection is unavailable. National agencies within the region and some international organizations have made a commitment to support this agenda, and some reasonable levels of accomplishment have already been realized in this regard (Salihu et al., 2020; Kabeyi & Olanrewaju, 2022; Ojong, 2022).

Solar energy photovoltaic (PV) systems lend themselves readily as viable and attractive options for captive power supply. PV systems have great potential to bridge the energy gap in electricity off-grid locations in sub-Saharan Africa and contribute to the region's energy portfolio at utility and/or domestic levels, accordingly reducing uncertainties surrounding the continued availability of fossil fuels, and the provision of affordable energy to the developing countries. Moreover, this would enhance the actualization of the United Nations Millennium Development Goals on green energy, thus reducing concerns about climate change.

PV installations within the region are largely capacity-based autarkic units, some captive-power installations are anticipated, but grid integration has not even been conceptualized. Take-up remains low, with long pay-back times. Solar PV is projected to contribute over 60% of the world's energy supply by 2100, leading to a 50% reduction in the carbon footprint. To achieve these targets, PV technology, which ensures reliability in the over 25-year designed life, is required.

Indeed, certain key considerations need to be addressed to achieve significant solar PV technology deployment. Two broad factors that possibly influence PV technology deployment in Africa have been identified, namely: attractiveness of PV in the country and attractiveness of the country for PV investment. Sub-Saharan countries' performances on these two factors are illustrated in Figure 1 (Detollenaere et al., 2019). By mapping the two factors' scores for particular countries on the graph, it can be readily predicted how well the PV technology would perform in a country. The location of a country on the graph determines the overall level of PV technology investment potential. The higher a country's attractiveness, the more preferred it will be for technology investment.

Several indicators define the attractiveness of a country to PV investment, these include political stability, ease of doing business, economic stability, and robust national policies. Beyond the PV investment attractiveness indicators of economic stability and business structures, investors are equally interested in the attractiveness of PV systems in a country that is characterized largely by the level of energy access and solar resource availability. Very important is the availability of renewable energy policies that allow easy installation within the countries. These policies go beyond awareness creation, but focus also on systems acquisition, installation, and maintenance as key factors that can influence PV system failures or successes.

Among several policy documents developed by countries in line with sustainable development goals, support for the development of clean energy to locations without electricity grid connection in developing countries, particularly within the sub-Saharan region through standalone or decentralized systems, has been of interest (International Energy Agency, 2019). Where resources and active policies are available, organizations have been willing to support solar

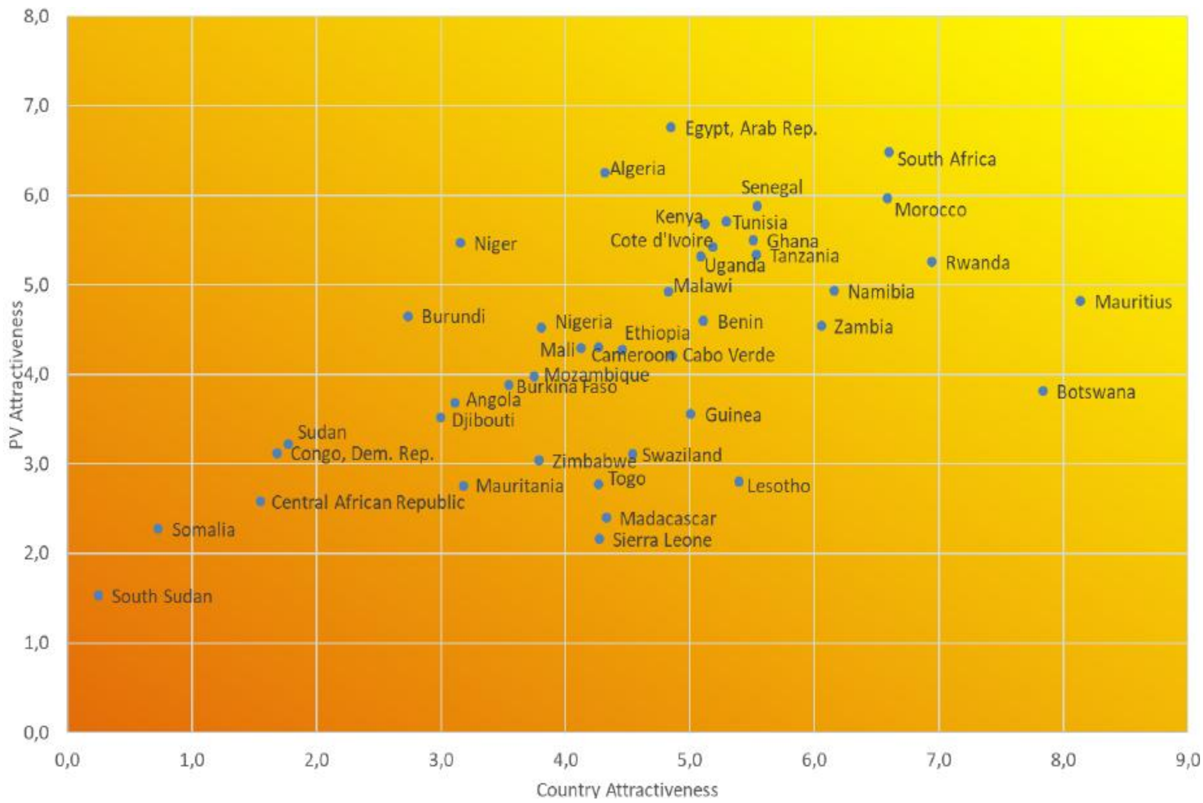

Figure 1. PV attractiveness by country (Detollenaere et al., 2019)

energy deployment (International Energy Agency, 2015). Documented reports on several public and private solar PV projects within the sub-region exist (Hankins, 2017; Gyamfi et al., 2015). However, most of these installed systems have either not been functioning properly or have failed and shut down completely (Hankins, 2017; Acquah et al., 2017). It has also been observed that several major PV projects are abandoned over time as a result of a lack of financial continuity and/or government involvement (Adenle, 2020). Consequently, many people have developed a lack of confidence and negative attitudes towards PV technology. Accordingly, it has become increasingly necessary to investigate the barriers and challenges associated with PV system operation and the probable causes of installed system failure within this region.

Studies on PV system failures have been undertaken, and these have employed a variety of methodologies with a focus on different aspects of PV technology. Some of these studies have focused on the technical causes of failure, including the degradation and failure of PV modules alone (Kumar & Kumar, 2017), the technical challenges associated with integrating PV into local electricity networks (Jamal et al., 2017; Ferrara & Philipp, 2012), and details of specific component failures (Kim et al., 2017; Dunlop & Fahri, 2001; Narayan et al., 2018), but not on the whole system or other non-technical factors. It has been noted that several total system failures can be attributed to the overemphasis on technical failures at the expense of other critical non-technical issues (Rahman et al., 2013) the neglect of which has rendered most projects inefficient. Some non-technical considerations such as socio-cultural and end-user perceptions are thought to be major causes of system and technology failure (Hirmer & Cruickshank, 2014). It has been observed, for example, that outdated national energy policies and the lack of trained personnel were part of the major setbacks in PV projects in Cameroon (Njoh et al., 2019). It has also been noted that in undertaking PV poverty alleviation programs in China, stakeholders' behaviour, which was considered key to the success of the program, was neglected in favor of a focus on literature reviews and project evaluations (Shan & Yang, 2019). Consequently, a tripartite evolutionary game model to deal with PV poverty by engaging relevant stakeholders was developed. Some studies on PV system failures in sub-Saharan Africa have employed methodologies that included experimentation, review of literature, authors' knowledge and experiences, or field visits (Tetteh, 2014; Quansah et al, 2016; Quansah & Adaramola, 2018; Hankins, 2017).

2. Material and method

2.1. Study area

Solar PV technology is gradually gaining popularity within the sub-Saharan region and particularly in Ghana, even though there are still challenges to overcome. In this study, which focuses on the perception of technical stakeholders on PV technology development across the country, care was taken to engage professionals in various parts of the country to give it a fair representation. In selecting respondents, factors such as geographical locations, solar resource availability, and the rate of PV technology penetration were considered. The study engaged professionals from the three major geographical subdivisions in Ghana as defined by this study, namely: the Northern sector (Upper East, Upper West, and Northern regions), the middle sector (Ashanti and Bono regions), and the Southern sector (Greater Accra and Central regions). These particular regions were chosen because the climatic conditions and PV penetration levels are representative of the entire nation.

2.2. Study design

This study employed a mixed-method approach in gathering and analysis of data. As explained by Creswell and Clark (2017), this method uses both quantitative and qualitative data collection techniques within a particular study. They further explain that there are different types of mixed-method approaches, and these include triangulation design, explanatory, and embedded style (Creswell & Clark, 2017). However, this study employed the triangulation design style. As discussed by Borrego et al (2009), this design method brings together both qualitative and quantitative information to help eliminate the weaknesses in each and to provide different perspectives on the same subject (Borrego et al., 2009). Here, data will be collected together, and results will be compared to understand the research objectives.

2.2.1. Population and sample size

The population comprised both male and female adults who worked or played key roles within the solar PV industry. As a relatively new and emerging technology within the energy market, it was expected that the sample would be smaller since the study targeted individuals in the PV industry with particular knowledge and skills. Samples were carefully selected across the country and from different companies/institutions to avoid repetitions and redundancy. Fifty questionnaires were administered to technical people within the PV sector across different companies and regions. Out of these, a total number of 47 questionnaires were filled and considered valid for analysis. This represents 94% of the total questionnaires administered.

2.3. Data collection

Data were collected across 7 regions of Ghana which covered all the 3 geographic sectors of the country. Structured questionnaires were administered to participants of the survey and were immediately followed by semi-structured interviews. Most of the data collected were done in-person, with a few conducted over the telephone as that was the most convenient means for respondents. Structured questionnaires were used to obtain exact answers from participants while the semi-structured interviews allowed respondents to freely share their experiences and perceptions on different sub-themes. The interactive nature of the interviews gave content-rich data which was very useful in discussing the results obtained.

An extensive desktop review was conducted to observe the responses from other studies as well as patterns within other developing countries, especially in the Sub-Saharan Africa region.

This information acquired through the literature review also compensated for the relatively lower number of responses from technical stakeholders from Ghana.

2.4. Data analyses

This study employed largely descriptive statistics in the data analysis. This method helped to describe and summarize respondents' results in a more meaningful way so that patterns, inferences, and conclusions could be made. Two statistical tools, namely: IBM SPSS Statistics 20 and Microsoft Excel were employed for the data entry, analysis, and results representation. Interview notes and recordings (where access was granted) were manually analyzed, and the results were utilized under the discussion section of the study.

3. Result and discussion

3.1. Demographics and categorization of respondents

In our survey, we consulted forty-seven technical stakeholders comprising 39 (83%) males and 8 (17%) females. The remarkable involvement of females in the technical sector in the solar PV industry is laudable. We characterized the respondents according to their levels of education, technical responsibilities, and experience in the industry. All the respondents were educated up to at least the high school level which ensured that they all could understand, interpret, and make valid judgments on the desired information in the questionnaire. Under the responsibilities, the technical administrators and marketing engineers were grouped under the category "other". The marketing engineers' responsibilities are distinct from those of the regular engineers; whereas the traditional engineers focus on the design, installation, supervision, commissioning, and monitoring of projects, the marketing engineers are responsible for sales of technical products and/or offering investment advice to clients regarding PV system type, specifications, sizing, and financial decisions. The marketing engineers, thus, have the role of convincing potential customers of the technical viability and economic benefits of the PV technology energy solution choice but are not involved in the actual installation. The majority of respondents (79%) have substantial experience (above 5 years) in the PV industry which meant that they had a deep understanding of component and system failures and client perception, thus ensuring the reliability of desired information. Table 1 presents the summary of the respondent's demography and categorization.

3.2. Categorization of regular solar PV system configurations

We identified and categorized the types of regular solar PV system configurations commonly available in the study area. These systems include integrated grid connection (GC), mini-grids, solar street-lighting systems (SSLS), residential/commercial standalone (R/C-SSS), and solar home systems (SHS). The majority of respondents worked on more than one configuration or type of system. This was to enable us to identify the types of systems that our survey respondents

Table 1. Respondents' demography and categorization

Gender	Responses
Male	39 (83%)
Female	8 (17%)

Technical Responsibilities	
Project Supervisor	9 (19%)
Engineers	16 (34%)
Technicians	13 (28%)
Others	9 (19%)

Educational Level	Response
Uneducated	0
Basic	0
High/Tech/Vocational	6 (13%)
Diploma/HND	19 (40%)
Degree and above	22 (47%)

Yrs. of Experience	Response
< 5 years	10 (21%)
5 – 10 years	19 (40%)
11 – 15 years	6 (13%)
16 – 20 years	5 (11%)
> 20 years	7 (15%)

regularly install, repair, and/or consider in the course of their job description. Figure 2 also shows that the majority of the respondents were involved frequently with a combination of system types.

3.3. Components procurement

The study revealed that procurement of solar PV system components was a very essential consideration for the respondents. Where and how system components are procured has an impact on the overall cost and the system performance. It can be observed (Figure 3) that 17 respondents representing 36.2% of the total survey size, sourced all the components exclusively from local markets. Components available in the local market are imported largely from a variety of foreign countries and not necessarily manufactured locally. About 19% (9) of the respondents indicated that they import their components in bulk, directly from their foreign client manufacturers, which reduces component unit prices and consequently the overall project cost. In their perspective, this creates project confidence as their sources are trusted more than the local market supply. Stakeholders who indicated that they have affiliate companies overseas that supply them with desired components as and when needed constituted 8.4% of the respondents. About 21% of respondents procure their components from both the local market and direct importation from overseas when their desired components are not available on the local market, while 14.9% of respondents indicated that they sourced their components from the local market, direct importation and/or from local manufacturers as appropriate.

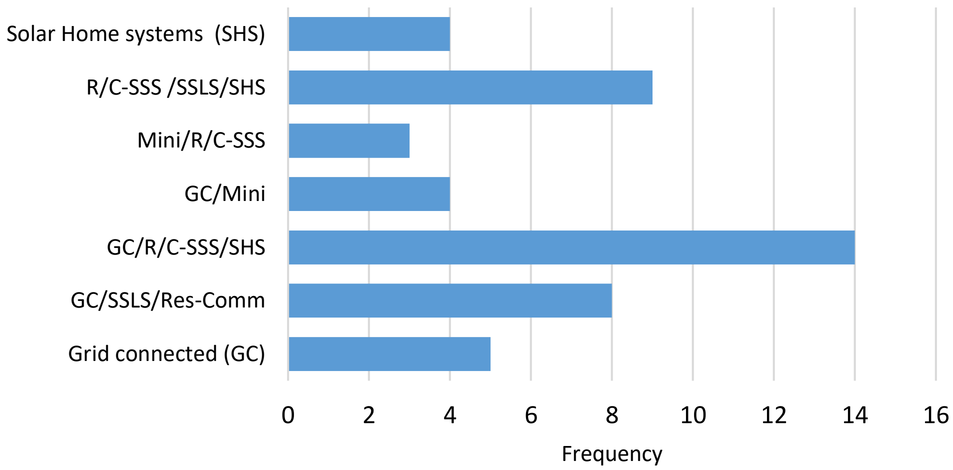

Figure 2. System configurations operated by the respondents

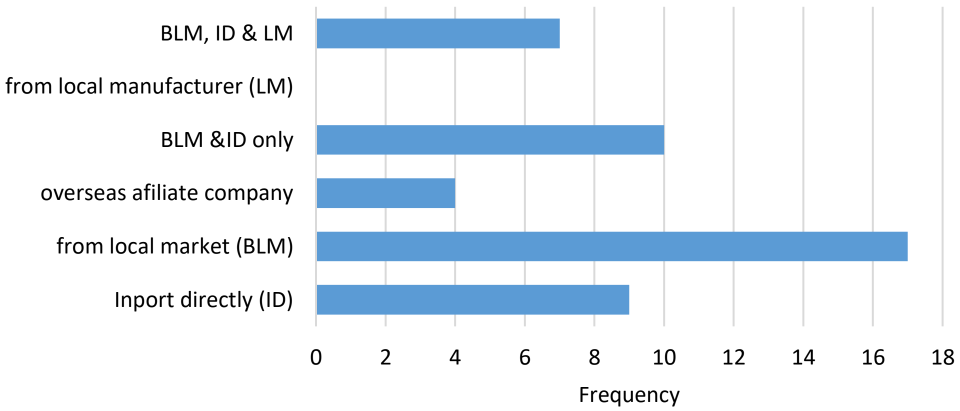

Figure 3. Sources of component procurement

3.4. Factors influencing choices of PV system components

Decisions on the appropriate selection of components for specific PV projects are regularly technical challenges faced frequently by project managers and other technical stakeholders. Indeed, several factors ideally influence the choices made by project implementers on component selection and decisions are dictated largely by prevailing realities. Such identified factors include availability, cost, quality, customer preferences, and other related issues. Survey respondents were then required to rank each of these factors according to how they influence their choices using the Likert standard five-point categorical scale (1 to 5) for measuring respondents' perception about the factors (as in Table 2) (Krabbe, 2017). The responses to the questions were grouped so that respondents with more favorable perceptions would have the highest score, and vice versa. For each system component, the frequencies recorded for the various scale measures are multiplied by their weighting values. Then the average for each factor is computed, and the factors are consequently ranked from most to least influential.

3.4.1. Choice of photovoltaic modules

Solar cells production facilities and commercial manufacturing of PV modules are generally lacking in sub-Saharan Africa; they are available only in a few countries such as South Africa (Moner-Girona et al., 2006). However, a few solar module assembly plants exist and are clearly inadequate to supply the needs of the local market. Consequently, stakeholders rely, for various PV projects, largely on foreign sources for module acquisition which are influenced by factors already identified above. Figure 4 shows the rankings of these factors considered by respondents in their choices of PV modules during independent projects planning. As can be seen, PV modules quality markedly (at 36% average) is the factor that mostly affects respondents' choices. Customers preferences on average are the next most important factor (at 22%). An instructive observation we gathered from the respondents during the course of our interviews was that customer's preferences are indeed almost always influenced by cost. Consequently, if customers preferences and cost are treated as a combined effect, they would clearly have been the most dominant factor. In the absence of any detailed technical assessment, almost all the customers would make the choice for cheaper modules. Though module prices have reduced in recent years, the prices still remain prohibitive for many users. Availability (at 21% average) closely follows the discrete customers preferences. The separate cost consideration constitutes 15% average influence on respondents' choice. Other factors such as proximity and country of origin were least considered at 6% average.

3.4.2. Choice of inverter

From the interview responses, most installers depend almost entirely on the local market to source their inverters. As shown in Figure 5, the availability of the inverters was the factor that mostly affects respondents' choices; ranked at an average of 27%. Since the majority of the installers rely on the local market for the procurement of the inverters, irrespective of the desirability of options, availability within the market becomes influential. The quality of the

Table 2. Weighting values for Likert scale (Krabbe, 2017)

Scales	Weighting Value
Always	5
Often	4
Sometimes	3
Occasionally	2
Rarely (Never)	1 (0)

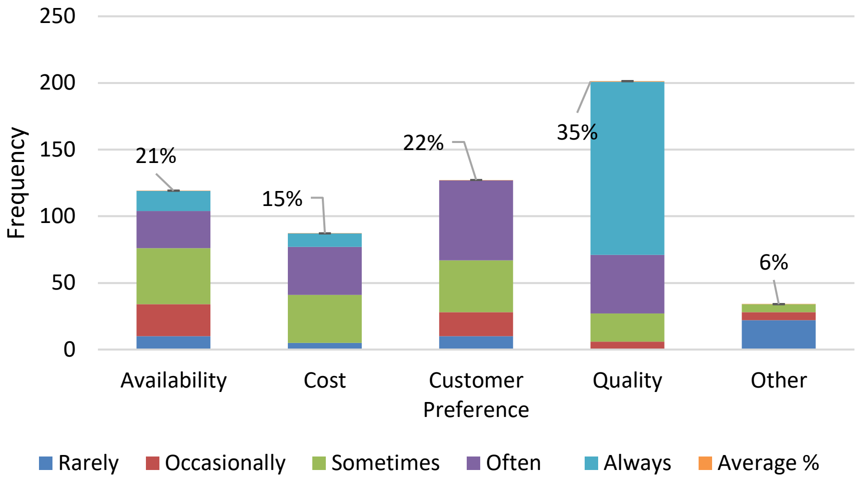

Figure 4. Ideal ranking of factors considered by installer on choice of module

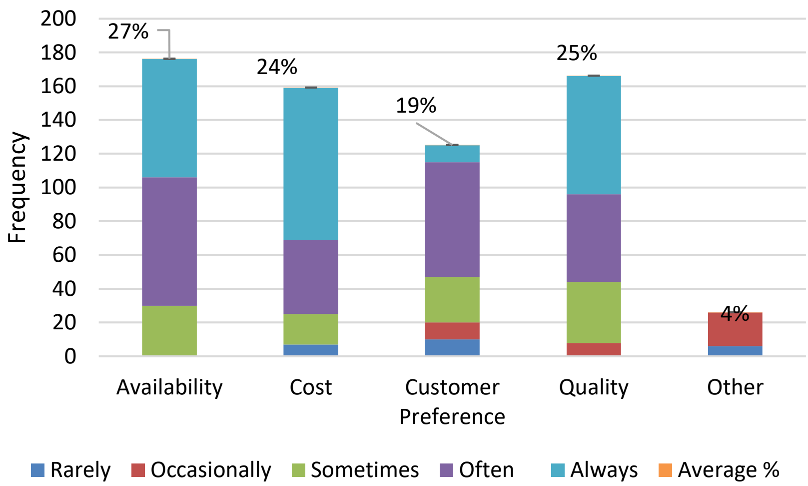

Figure 5. Ideal ranking of factors considered by installer on choice of inverter

inverters, with an average ranking of 25%, is the next most considered factor by the respondents in their choice. With an average ranking of 25%, cost is also a very important consideration. Customer preference was 19% while other marginal factors had average preference of 4%. Because the inverter cost is not a dominant factor in a PV system project planning, these factors that influence the choice of inverters are evenly distributed.

3.4.3. Choice of battery

Batteries frequently have the shortest lifespan of PV system components and indeed degrade most rapidly under unfavourable and usually strict operating conditions. Batteries are regularly the most expensive component. Consequently, if battery quality is compromised, the entire system efficiency is increasingly affected adversely. Figure 6 shows markedly that battery quality, at 31% average consideration, as anticipated, is the factor that influences mostly the respondents' choices. Cost, at 25% average consideration, is the next most important factor. This is so and as also expected because batteries are easily the most expensive PV system components. More so, costs become increasingly critical as customers seek to reduce their overall capital investment on PV systems. Cost considerations and concomitantly costumer preferences; the next most important factor considered by technical stakeholders in battery selection (at 22% average rating) have been observed to generally affect the integrity PV systems.

3.4.4. Choice of charge controller

During our survey, we also assessed the factors influencing respondents' considerations in charge controller selection as shown in Figure 7. Charge Controller quality, with an average of 30% preference, was the most important consideration by project implementers. From our interviews, respondents also indicated that occasionally, charge controllers preferred by technicians may not be readily available in the local market. Because controllers are frequently imported into the local market, costs and availability are observed to be critical factors also.

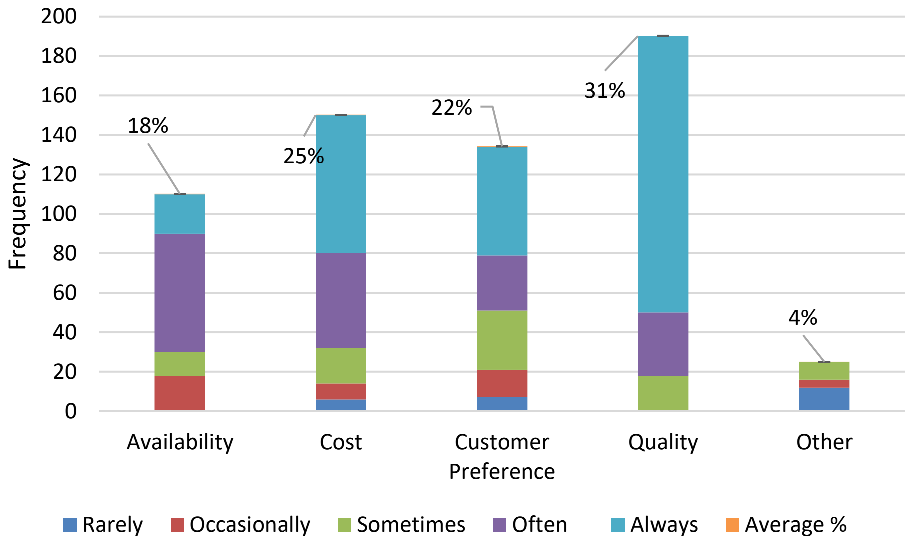

Figure 6. Ideal ranking of factors considered by installer on choice of battery

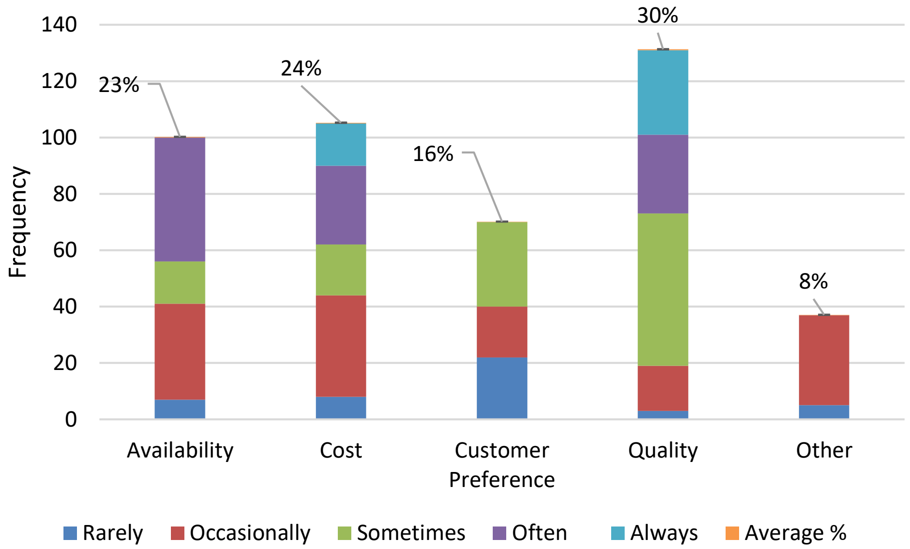

Figure 7. Ideal ranking of factors considered by installers on choice of charge controller

3.4.5. Choice of cable

Good quality cables are equally crucial in PV system installations, particularly for system safety considerations. Cable quality is the dominant factor considered by installers in cable selection, with an average preference of 36% as shown in Figure 8. Other factors of significance considered in cable selection include cost, customer preference, and availability, with average preferences of 22%, 19%, and 18%, respectively.

3.4.6. Overall components selection factor preferences

The combined preferences of the factors that influence the choice of PV system components for project implementers are shown in the Pareto chart in Figure 9. It can be seen markedly that component quality is the most dominant factor considered by the technical stakeholders in the planning and execution of PV projects. It has been observed previously by Karakaya and Sriwannawit (2015) that quality is largely influenced by government political policies and financial incentives put in place, as well as the circumstances of the local users (Karakaya & Sriwannawit 2015). It is instructive that our findings agree with a previous study conducted with

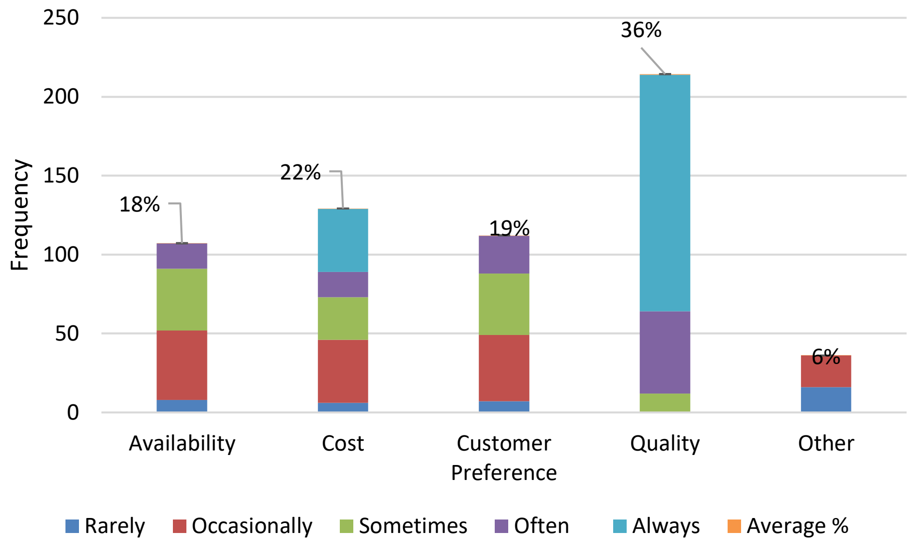

Figure 8. Ideal ranking of factors considered by installer on choice of cable

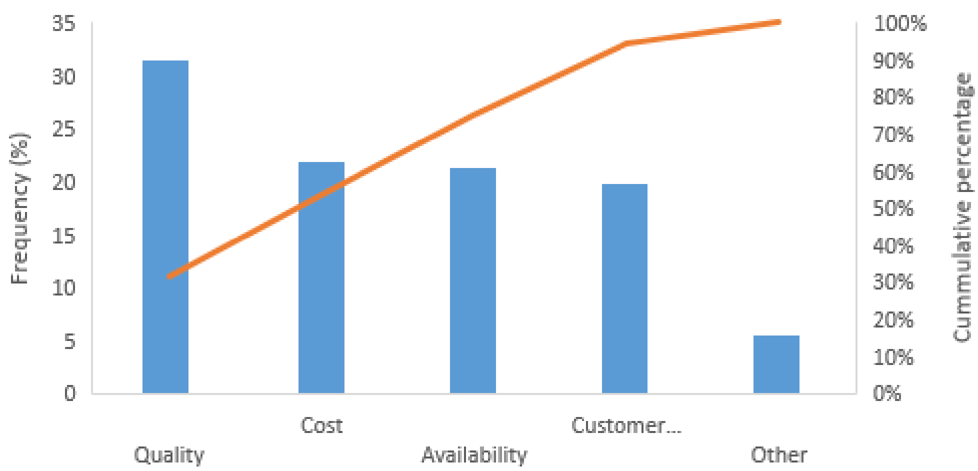

Figure 9. Overall ranking of choice of PV system components

PV users in Australia (Arthur et al., 2017), which also showed from an extensive interview that quality was the most important factor that was considered in component type selection. However, the ideal technical considerations and decisions of project planners, technicians, and/or installers are frequently altered during the actual implementation of the project. In a previous survey in China (D'Agostino et al., 2011), the feedback from interviews with users, compared with those of technicians and PV components sales shops in the same locality, was different. Users' decisions on product choice were motivated mainly by price consideration rather than quality.

Our study also investigated if respondents' ideal choices were often altered by other factors during the contract bidding and implementation stages. We observed that for most projects, whether private or public, the quality of components is often compromised in favour of cost and customers' budget. Customer preferences override many technical considerations regularly. Installers rarely insist on technical quality considerations only, for fear of losing businesses. Components readily available in the local market are designed to meet the customers' budget, and even where they fail to meet national standards, they are frequently available in the local markets within sub-Saharan Africa (Barau et al., 2020). Consequently, installers who rely largely on the local market are constrained to choose from the "best" available quality that is within the budget range.

We also observed that other factors, such as component country of manufacture or proximity, are rarely considered significant factors in component selection as shown in Figure 9. Although most of the stakeholders are skeptical about components from certain countries that are generally considered inferior (Müggenburg et al., 2012), this has been observed not to significantly influence installers' choice in practicality. Most respondents claim that, based on their experiences, consideration of component quality is not necessarily determined largely by country of origin but by whether they meet requisite standards.

3.5. Customer interaction and system failure

3.5.1. Customer feedback

A very important issue in post-installation assessment of PV systems is the existence of a users' feedback mechanism, i.e. a channel of communication and reporting between users and project implementers after the completion of the project. From our study, about 13% of respondents have lost contact with their clients, while 30% and 57% retained some partial and full interaction with their clients, respectively. Furthermore, 66% of the respondents have no schedule for interaction with clients, but only attend to their requests whenever complaints are reported. Only about 19% of our technical respondents have a planned post-installation schedule for interaction with clients, usually between 10–12 months, while 9% have a schedule for about 3 months, and 6% for every 4–6 months.

3.5.2. Post-installation inspection and maintenance

For most of the projects sponsored by NGOs and government institutions, technical managers indicated that there are regularly no in-built post-installation inspections and maintenance procedures in the contracts. Consequently, a major challenge ensues: a number of the projects accounted as functioning systems, may indeed have failed. We observed that most PV projects within the sub-region are only revisited if there is exists occasional national or international funding to undertake project evaluation. Accordingly, data on PV projects are frequently unreliable or unavailable, with the attendant encumbrance of the promotion and development of the technology.

3.5.3. Frequency of component failures

Our survey ranked the frequency of failure per component from the point of view of technicians and experts. Each respondent ranked the major component failures encountered using the Likert scale. The results were then computed to obtain the overall failure percentages for each component, as shown in Figure 10.

The survey analysis revealed that inverters account for the major failures within the entire PV system. This finding corroborates the results of previous studies elsewhere (Kim et al., 2017; Cristaldi et al., 2014), and of note, a study conducted on several PV systems in Ethiopia (Woldeyes, 2017). However, a study on some off-grid PV systems in Tanzania showed that batteries failed the most, on account that these systems were often overloaded, resulting in frequent draining of the batteries within shorter periods than anticipated (Hankins, 2017).

3.5.4. Causes of component failures

Remarkably, the significant reasons why system components fail and lead to an entire system shutdown are worth noting. This is more so for new investors wishing to establish PV businesses, particularly in sub-Saharan Africa. It would also provide relevant details for already established firms and project managers on how to monitor and maintain their systems. We have, in this study, categorized the key causes of component failures as follows: low product quality, sizing/installation errors, natural/environmental incidents, and user errors as shown in the Pareto chart in Figure 11. The chart, which shows the relative contributions of the key failure causes, also indicates, from the cumulative line graph, that generally, all these factors are essential and must be addressed holistically to ensure considerable take-up of the PV technology in sub-Saharan Africa.

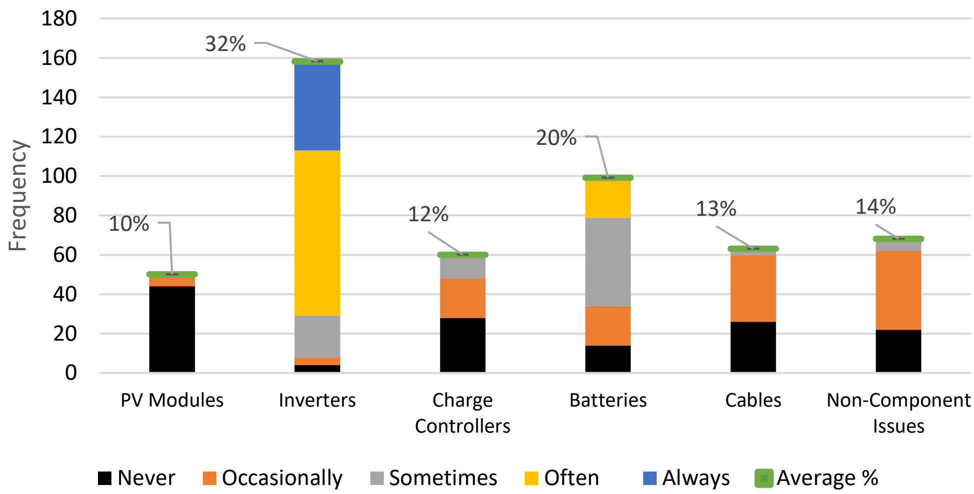

Figure 10. Frequency of faults per component

Figure 11. Causes of component failure

Low-quality product is the leading cause of PV system failures (as observed by 31% of the respondents). This corroborates our earlier finding that most respondents indicated that customer influence, cost, and unavailability of certain components in the local market frequently led to a compromise on quality. Imported pre-used components, referred to in local parlance as "home use" in Ghana or "tokunbo" or "follow-come" in Nigeria, are commonly available in the local market (Bruijn & Dijk, 2012). In Nigeria, for example, pre-used PV system components such as batteries, panels, and inverters are advertised online regularly (jiji.ng, 2020). Such pre-used components, albeit from reputable manufacturers, lack established shelf-life or warranty but are commonly promoted by the local traders (and often accepted by users and technicians) as of higher quality than new components from less fancied manufacturers. One of the online advertisements for fairly used solar batteries and inverters read, "…tested and approved, buying this is like buying brand new pack." (jiji.ng, 2020). With technicians and installers often constrained to use such components, failures, consequently, result frequently, as shown from our survey. Other previous studies within the sub-region have also identified poor-quality components as a significant cause of failure (Painuli & Fenhann, 2002; Baschel et al., 2018; Duke et al., 2002). The problems associated with the use of inferior PV components have also been reported in other developing countries outside of the sub-Saharan Africa (Li, et al., 2018).

User errors (commonly arising from lack of knowledge) account for 27% of the observed causes of component and system failures. From our interviews, the respondents indicated that customer education, understanding, and/or responsiveness to essential routine component monitoring and maintenance practices are low. PV systems are load-sensitive and overloading routinely drains the battery and drastically reduces anticipated life span. In one instance, for example, a technician responding to a repair call observed that the customer had connected a 2 kW refrigerator to his 1 kW solar inverter on his solar home system. Most of the technicians reported customers' lack of understanding of system capacity and matching load. For many of the users, once the system is installed, every electrical device can be connected. This, indeed, has been a common cause of many system failures. Basic and routine panel cleaning is frequently ignored, consequently reducing panel transmissivity and attenuating designed solar radiation availability. Our finding agrees with other reported observations from studies within the sub-Saharan region indicating that user errors are significant causes of system failures (Admasu, 2011; Mgonja & Saidi, 2017; Hansen, 2018).

Our results show that natural/environmental incidents account for 24% of component failures. The naturally occurring and environmental incidents are unanticipated occurrences that cause component failures but are not, readily, uniquely identifiable. PV system inverters, for example, are highly susceptible to unexpected environmental effects. Many of the technician respondents who have encountered inverter failures are usually unable to identify the exact causes that may indeed be attributable to, say, thunderstorms during tropical rainy weather conditions. High temperature and high humidity conditions are prevalent in tropical climates and are known to be unfavourable conditions for adequate battery and inverter performances. Under such prevailing environments, batteries degrade rapidly, reducing significantly the anticipated lifespan and causing failure (Narayan, et al., 2018; Brito, et al., 2018). Extra remedial protective measures are considered exorbitant by most investors resulting in frequent inverter board and prohibitive unscheduled battery replacements and/or ultimately the abandonment of projects.

Inaccurate system design and sizing and/or unsuitable installation are also significant observed reasons for system malfunction and/or failure, accounting for 19% of recorded causes. PV system designs and sizing are complicated. Load requirements have to be matched to appropriate component ratings, and most importantly, linked to solar radiation availability and associated intricate orientation and tilt of panels for optimal reception of solar radiation. Rarely are solar energy engineers consulted during project design and planning. Most clients employ only technicians for system design, sizing, and installation. These technicians have very limited knowledge of PV design principles, relying frequently on rule-of-thumb methods. Accordingly, poorly designed PV systems would malfunction and/or fail. Our observation is corroborated by an earlier study in Tanzania, which reported that during project evaluation, it was observed that most projects were poorly sized, resulting in system overload and consequent failure (Hankins, 2017).

The major problem identified by respondents in the installations of PV systems is that quacks and unlicensed installers are frequently available in the PV business in sub-Saharan Africa. These quarks are cheap to hire but do not understand or adhere to standards. Some of our respondents observed that several regular electricians with little knowledge of PV technology entered the venture with inadequate or no training in PV systems. Conversely, there are practitioners in the PV venture, who, though they have fairly good knowledge of the industry, but do not have a strong background in electrical wiring and installations. Our findings indicate inadequate collaboration between the various skilled experts in the installation venture in the sub-region. This is particularly so for freelance practitioners who are not employed in established firms. It is usual for a single technician to be engaged who does everything by himself. It is also not unusual to find poor installations undertaken by established firms, owing largely to inappropriate customer/political influences (especially for government projects).

4. Conclusion

Solar energy photovoltaic systems have immense potential in bridging the energy gap in electricity off-grid locations in sub-Saharan Africa and in contributing to the region's energy portfolio at domestic and/or utility levels. The sub-Saharan African region has, consequently, in recent years, become a very attractive center for PV technology deployment. Although several solar PV projects have been undertaken within the region, the take-up of the technology remains low owing to initial capital outlay and frequent malfunctioning, component, and/or system failures. In this study, we have identified major causes of malfunctioning and failures in installed PV systems, typically within the sub-Saharan Africa region, from the point of view of the technical stakeholders, using Ghana as a case study. Quality of PV components, costs, availability, and customer preferences are dominant factors considered by the technical stakeholders in component selection during the planning and execution of PV projects. Inverters and batteries are components that account for the most malfunctioning and failures in installed systems, while PV panels account for the least. Low product quality, user errors, natural/environmental incidents, and poor sizing/installation errors are identified as key causes of components' failure. Client influence leads regularly to quality compromise due to cost considerations. The prevalence of pre-used components in local markets affects quality adversely. Inadequate user education on PV system usage and basic maintenance leads frequently to user errors.

Findings from our study provide veritable information to a variety of stakeholders–policy makers, private clients, investors, organizations, governments, technicians, engineers, project planners, etc. – involved in the PV technology deployment in Ghana and the sub-Saharan African region at large. If adequate measures are taken to address key issues observed by our study, we anticipate that PV system breakdowns and failures would be significantly ameliorated and take-up greatly enhanced.

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