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An Evaluation of Performance of Renewable Energy in Ghana Involving Operation and Maintenance Project Management Protocol

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Abstract

The Renewable Energy Master Plan of Ghana (REMP, 2019), reports that renewable energy usage will increase from 42.5MW in 2015 to 1363.63MW by 2030; mainly due to a joint collaboration between governments and corporate bodies to control the carbon footprint in the atmosphere. The deployment of solar Photovoltaics (PV) has grown at a faster rate from 2021 to 2025 than it did the years before and so, there is the need to properly operate and maintain the renewable systems in order for it to remain competitive in the market. This study presents a methodological protocol or checklist and mobile application for Solar PV Operation and Maintenance Protocol (OMP) for Ghana's solar PV projects. Results of a technical survey indicate that out of 31 solar technicians and engineers, only 19% of solar PV projects have single contractors on site to provide routine maintenance, 71% do not have a standard operating procedure and engineer for routine maintenance and 2 out of 4 companies across the country are not proactive on solar PV maintenance to prevent unplanned maintenance. Again, there was a deduction of poor operation and maintenance culture and is recommended that using solar PV and OMP could improve the current status quo for an invaluable optimizing of energy efficiency.

Keywords
Solar Photovoltaic, Energy Efficiency, Renewable, Maintenance, Protocol.

1. Introduction

Energy is a vital part of socioeconomic development and so ensuring the attainment of a dependable supply of clean, low-carbon energy is an important component of any sustainable development plan (Schwanitz et al., 2017).

Cities are economic engines, accounting for more than 80% of the global Gross Domestic Product (GDP) (Dombrovski, 2015). Transportation, industrial production, trade, building construction, public works, lighting, air conditioning, and countless other human activities like cooking, driving, education and the use of mobile phones and computers are all fueled by energy (Dombrovski, 2015). If not for the presence of Renewable Energy (RE) power production sources, the aforementioned activities will continue to increase the carbon footprint in the atmosphere leading to the world's dreaded fear in climate change.

However, the joint efforts by governments and corporate bodies have fostered the use of renewables in the past two decades. 173 nations had RE objectives in place since 2016, with 146 countries having supporting measures (Vidyanandan, 2017). Congruently, cities, communities, and organizations are at the forefront of the rapidly growing "100% renewable" campaign, which is helping to accelerate the worldwide energy transition (UN Climate Change, 2016). According to the International Energy Agency (IEA), the use of RE around the world is on the rise. Current statistics prove that in the past decade, RE sources of energy use have doubled and close to tripling.

Renewables are expected to raise their proportion of power generation to nearly 30% in 2021, the greatest level since the Industrial Revolution (IR) began, and up from less than 27% in 2019. The wind is expected to have the highest increase in renewable generation, increasing by 275 TWh, or roughly 17%, by 2020. Solar Photovoltaic (PV) electricity production is estimated to increase by 145 TWh, or over 18%, by 2021, reaching 1000 TWh (IEA, 2020). Considering these statistics, many countries, industry, and household need to consider a proper Operations and Maintenance (O&M) schedule for any project or system. The importance of O&M of solar PV systems has increased due to the escalating global market for solar energy technologies. Solar PV dependability and system performance optimization are critical to the technology's continued success and adaptability (Keisang et al., 2021).

Again, scheduled O&M will ensure maximum system power out for the lifespan of any project. In 2021, LNRG Technology published a research report on Global solar PV O&M. The report, states that the total market valuation for solar PV O&M is USD 9.8 billion, divided into 3.9 billion USD for distributed (residential and commercial) and 5.9 billion USD for solar fields (industrial and utility-scale) (LNRG Technology, 2021).

Ghana enacted Act 832 regarding the "Renewable Energy Act," to provide for the development, management, usage, and appropriate supply of renewable energy for heat and electricity generation, as well as other things (Government of Ghana,2011). Following the passing of this act by the parliament, in its 2021 published energy statistics, The Energy Commission of Ghana disclosed that, the overall power nearly doubled from 10,166 GWh in 2010 to 20,170 GWh in 2020, at 7.1 % annual growth rate. The overall generated electricity in 2020 was 20,170 GWh, with 7,293 GWh coming from hydropower, 12,820 GWh from thermal power, and 57 GWh coming from renewables. The installed and dependable capacity of energy from 2016 to 2024 is illustrated in Figure 1.

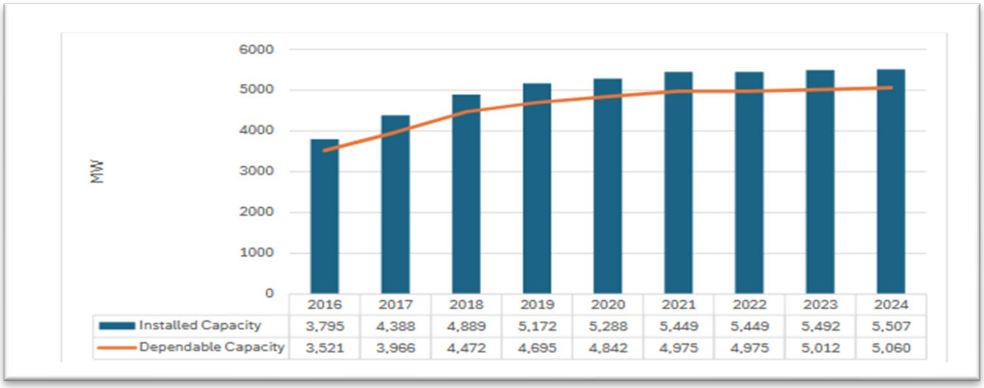


Figure 1. Installed and dependable from 2016 to 2024
Source: 2025 Energy Outlook for Ghana

Figure 1 clearly shows that there has been an increasing installed and dependable capacity of power in MW from 2016 to 2024. Also, reports from Ghana energy commission indicate that wind and solar energy production are in the lead globally. In Ghana, solar PV is in the lead with 7.3 MW Off-grid, 59 MW On-grid, and 0.3 MW Mini-grid.

Grid-connected renewable capacity has expanded dramatically in just six years - from 2.5 MW in 2014 to almost 59 MW in 2020 (Energy Commission, 2023).

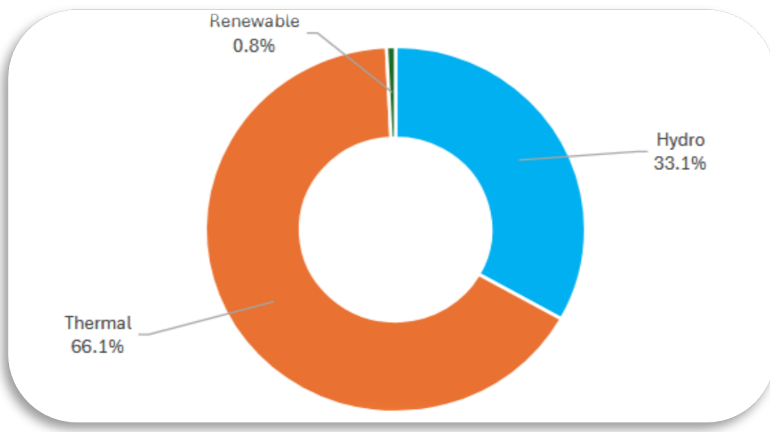


Figure 2. Share of Electricity Supply by Generation Source in 2025
Source: 2025 Energy Outlook for Ghana

To keep and improve this trajectory, solar PV should always be available in all sectors of the economy. Also, proper maintenance culture should be employed to ensure that investors have value for money. Solar PV systems, like any other product, have a lifecycle that begins with the acquisition, installation, operation, and maintenance and ends with the disposal. Figure 2 indicate Share of electricity supply by generation source in 2025 with an increase in supply from RE. It is worth noting that, the longest phase of a solar PV system's life cycle is operation and maintenance; without an effective maintenance management system and the application of best practices in the field, it will be difficult to achieve the system's reliability and cost-effectiveness during its designed operation lifetime (Mgonja & Saidi, 2017). Proper maintenance, adequate technical know-how, tailored financing package, and adequate training of end-users are very important in ensuring the maximum efficiency of a solar PV (Mgonja & Saidi, 2017).

Also, according to (Vidyanandan, 2017), battery health and capacity, the type of PV material, cell temperature, solar radiation intensity, parasitic resistances, shading effects, module orientation, inverter and charge controller efficiency, dust conditions on the solar panel, weather conditions, cable thickness, and geographical location are some factors that affect the power output of solar PVs. This work will demonstrate the importance of a maintenance culture on solar PV system installations to improve the systems' performance and availability or reliability. This is required now, since the solar PV system may be made financially appealing if properly deployed and maintained. It elaborates on when to maintain what part of the solar PV system.

Interestingly, solar Photovoltaics (PVs) have a minimum operating lifetime of approximately 20 years (Keisang et al., 2021). More often within two to five years most of these systems fail (Vidyanandan, 2017). According to Haney & Burstein (2013), most off-grid solar PV systems fail to achieve reliable operations during their lifecycle due to a lack of maintenance, and often fail two to three years after installation, well short of the projected service lifetime. Similarly, it is believed that maintenance practices in use (like breakdown and corrective) might lead to increased costs and overall lifecycle costs due to earlier and frequent replacement of some components and additional costs for extra maintenance work (Mgonja & Saidi, 2017). This will make solar PV project unattractive to cooperate bodies and individuals who want to invest. Thus, a well-outlined cost-effective Operation and Maintenance Protocol (OMP) to measure the performance of renewable energy can help mitigate the downtime of SPV projects across the country.

1.1 Problem Statement and Justification

Solar Photovoltaics (SPVs) have a minimum operating lifetime of approximately 20 years (Keisang et al., 2021). More often within two to five years, most of these systems fail (Vidyanandan, 2017). According to (Haney & Burstein, 2013), most solar PV systems fail to achieve reliable operations during their lifecycle due to a lack of maintenance, and often fail two to three years after installation, well short of the projected service lifetime. Also, it is believed that maintenance practises in use (like breakdown and corrective) might lead to increased costs and overall lifecycle cost due to earlier and frequent replacement of some components and additional costs for extra maintenance work (Mgonja & Saidi, 2017).

This will make SPV project unattractive to cooperate bodies and individuals who wants to invest. Thus, a well-outlined cost-effective operation and maintenance protocol (OMP) to measure the performance of renewable energy can help mitigate downtime of SPV projects across the Ghana.

1.2 Objectives

The specific objectives are,

- To review the existing procedure for the operation and maintenance project protocol for solar PVs in Ghana
- To assess the performance of solar PVs in Ghana based on its operations and maintenance culture
- To develop an improved procedure for the operation and maintenance project protocol for solar PVs in Ghana

2. Literature Review

2.1 A Review of Performance of Renewable Energy

According to Ibrahim et al., 2021, the achievement of the set objectives for the actualization of the United Nations (UN) sustainable energy for all, benefits such as green job creation, technology advancement, economic expansion, and international investors attraction can be achieved if policies are properly put in place and effectively enforced by authorities (Ibrahim et al., 2021).

Within the last few decades, there has been a global paradigm change in energy and associated topics due to its importance as an alternative to fossil-fuel-based electricity production and climate change mitigation; which has made RE research to be the forefront of energy and related sciences.

In many developing and growing economies, empirical evidence demonstrates a link between energy use, utilization, and pollution (Asumadu-Sarkodie & Owusu, 2016). RE has experienced rapid growth in investment in several countries throughout the world. The capacity of solar PV has grown from 3.1 GW in 2005 to 227 GW in 2015. Wind power capacity grew from 59 GW to 433 GW during the same period. Large hydropower has also maintained extremely high annual market quantities. Over the same period, bio-power, which is partly used as a cogeneration plant, doubled to a total global generation capacity of 106.4 GW. Again, various renewable technologies have also advanced significantly, with total annual biofuel output rising from 37 billion litres in 2005 to 128 billion litres in 2015 and continue to increase. This is translated into many technologies seeing significant cost reductions as manufacturing levels have increased (Energy Commission, 2019).

Similarly, RE accounted for about 18.1 percent of Total Final Global Energy Consumption (TFEC) in 2017. Modern renewables provided 10.6% of TFEC, representing a 4.4 percent increase in demand over 2016 and resulting in an increase in the use and feasibility of renewable electricity in end-use sectors and also in line with policymakers' interest and advocacy in sector integration and markets for supporting technology (such as battery storage, heat pumps, and electric vehicles) grew (REN21 & Century, 2011).

Despite gains in renewable energy adoption, energy efficiency, and access to energy, the world is still on track to miss the Paris Agreement and Sustainable Development Goal 7 targets. Due to rising fossil fuel, global energy-related carbon dioxide (CO2) emissions increased by 1.7 percent in 2018. Global subsidies for fossil fuel consumption climbed by 11% in 2018, while fossil fuel companies continued to spend hundreds of millions of dollars on lobbying and ads to delay, limit, or reject climate change initiatives.

International investment in renewable energy and fuels totaled USD 288.9 billion (USD 304.9 billion including hydropower plants larger than 50 megawatts, MW); this was down 11% from the previous year (largely due to a significant drop in China), but it was the fifth year in a row that investment surpassed USD 230 billion (REN21 & Century, 2011).

In 2018, the renewable energy sector employed over 11 million people worldwide (directly and indirectly). In early 2019, 175 businesses had signed up for RE100, pledging to 100% renewable energy targets, up from 130 the year before (REN21 & Century, 2011). Renewable energy policies in the transportation sector are currently mostly focused on road transport; however, the expanding usage of electricity and advanced biofuels in road transport, as well as increased attempts to decarbonize, has boosted support for renewables in rail, shipping, and aviation. By the end of 2018, biofuels have become a fundamental component of national renewable transportation policy frameworks, with blending regulations in place in 70 nations at the national or state level.

In terms of capacity growth and concentration of activity, the worldwide hydropower market in 2018 appeared relatively similar to the previous year. To reach a total installed capacity of roughly 1,132 GW, an estimated 20 GW was added. Hydropower generation was predicted to be 4,210 TWh worldwide, varying each year due to changes in weather patterns and other local circumstances. China, as in previous years, took the lead in commissioning new hydropower capacity, accounting for more than 35% of new installations in 2018. Brazil came in second (as it did last year), followed by Pakistan and Turkey, all of which added more than 1 GW of capacity (REN21 & Century, 2011). As shown in Figure 3, IEA proposed that by 2022, solar PV's net capacity technology addition for both main and accelerated cases will be 119 and 149 GW respectively.

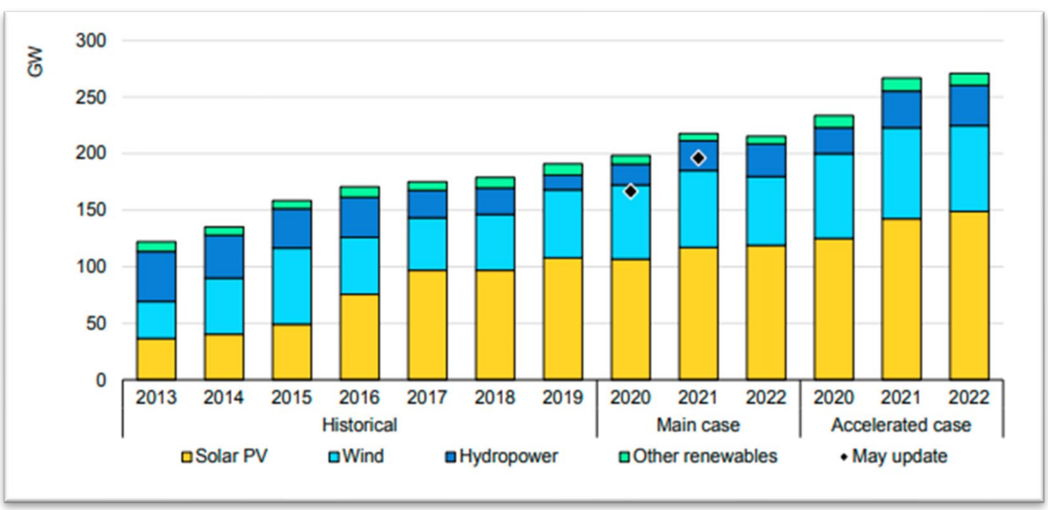


Figure 3. Renewable electricity net capacity additions by technology, main and accelerated cases, 2013-2022.
Source: IEA, 2019

Distributed renewable energy systems continue to play a significant role in linking families in remote areas to electrical services in developing and emerging economies. Through off-grid solar PV systems, an estimated 5% of the population in Africa and 2% of the population in Asia has access to power (REN21 & Century, 2011).

Over the years, the Ghanaian government, as well as the private sector, has launched numerous renewable energy projects, with outcomes demonstrating the impact of RE on poverty alleviation and socio-economic development. Going forward, a well-targeted plan with a clear roadmap for the long-term development and enhancement of different renewable energy sources is required (Energy Commission, 2019).

The Renewable Energy Master Plan (REMP) has been established in Ghana to achieve the following by 2030:

1. Increase the share of renewable energy in the national electricity production mix from 42.5 MW in 2015 to 1363.63 MW (with grid-connected systems amounting to 1094.63 MW);
2. Reduce reliance on biomass as the primary fuel for thermal power applications;
3. Provide renewable energy-based decentralized electrification options in 1,000 off-grid communities;
4. Encourage local content and involvement in the renewable sector.

As of December 2015, Ghana has an estimated installed renewable energy capacity as shown in Table 1.

Table 1. Estimate of installed capacity of RE systems in Ghana

Technology type	**Installed capacity/ No. of units (estimated)**	**Unit**
Utility-scale grid-connected renewables	23	MWp
Other grid-connected renewables (distributed generation)	15	MWp
Mini-grid (hybrid system)	0.2	MWp
Off-grid Solar (including street/community light)	>10	MWp
Solar Lanterns	>72,000	No. of Units
Biogas	9000	m^3
Biomass/Biogas (electricity and thermal)	5.6	MW
Solar dryers	50	Tonnes

Source: REMP, 2019

Over 10 MWp of stand-alone solar PV systems were deployed in Ghana by the end of 2015. Lighting, water pumping, computer powering for ICT teaching and learning, and vaccine refrigeration are among the many uses for them across the country. Solar lamps have now been distributed to over 70,000 people (Energy Commission, 2019).

Hydro generation, thermal generation, embedded generation, and renewable energy generation are all part of Ghana's energy mix. Ghana had a total installed generation capacity for grid power of 4,990 Megawatt (MW) in 2019, with a reliable capacity of 4,580 MW. In 2019, renewable energy installations totaled 78.9 MW, with 42.5 MW of solar PV installed at the distribution level. However, under the Renewable Energy Act of 2011, Ghana has set a goal of increasing renewable energy utilization in the country to 10% by 2020. This includes solar, wind, and thermal energy (Ghana Investment Promotion Centre, 2016). Yet, at the end of the year 2020, Ghana has an installed renewable energy capacity of 98.87MW. accounting for more than the 10% target. This translates into a constant increasing capacity of RE with a associated increasing demand for technicians to maintain and recover the system.

2.2 Project-Specific Review of and Maintenance Project Management Protocol

The PV Operations and Maintenance (O&M) best practices guide is one of the work products created by the Solar Access to Public Capital (SAPC) working group, which aims to expand the capital market for investment (Keating et al., 2015). This PV O&M best practices guide was created with three goals in mind:

1. to increase the transparency of solar assets for rating agencies and investors**. 2.** to establish an industry framework for quality management and**; 3.** to lower transaction costs associated with the securitization of solar assets.

In line with this, Jeff Hoy et al. (2018) created a checklist for both stand-alone and grid-connected solar PVs in their solar PV system users' maintenance guide. However, only the major components, such as the PV module, inverter, battery, and system balance, were given attention. In 2011, David Tan suggested that performing preventative maintenance and inspection tasks between six months and one year is recommendable. Again, his research focus was only on the major component including the PV module, Inverter, Battery, and balance of systems. (David T. 2011). Correspondingly, the United States Agency for International Development, (2013) designed a Solar PV System Maintenance Guide specifically for the Guyana Hinterlands Stand-Alone Solar PV Installations. Unlike this work, solar PV System Maintenance Guide was not comprehensive (for all components) but this was specifically for Batteries, PV modules, inverters and charge controllers, wiring and connections.

Table 2, 3, 4, and 5 show the maintenance checklists designed for some of the SPV components for the Guyana Hinterlands Stand-Alone project.

Table 2. Solar System Maintenance Schedule

Maintenance Task	**Daily**	**Weekly**	**Monthly**	**3 Months**
Visual Inspection of system wiring, Lights, and vaccine freezer		Yes		
Solar Panel Maintenance				Yes
Battery Inspection		Yes		
Battery Cleaning			Yes	
Wiring Inspection		Yes		
Inverter/ Battery Charger		Yes		
Charge Controller		Yes		
Battery “top-up”			Yes	

Source: USAID, 2013

In Table 2, almost all the maintenance tasks are generic. They are not specific. Every specific task has a duration of maintenance. This implies that ‘Solar panel maintenance’ for example, is too broad. Are we to wash the PV modules from dust and other particles, check hot spots using an infrared camera, check for missing or loosened panel clamps, etc.? For instance, waiting for 3 months to wash solar panels (in sub-Sahara countries like Ghana) will lead to very low output power due to dust accumulation.

Table 3. Panel Maintenance Log Sheet (every 3 months)

Date	**Name of Maintenance Technician**	**Module Clean**		**Array Frame**			**Array Cabling**	**Array Output Voltage**
		Yes	No	Good	Fair	Bad		

Source: USAID, 2013

Table 3 is the panel maintenance log sheet. As stated earlier, the panel maintenance checklist should be at least one month in this part of our world. Again, apart from the stated activity, middle and end clamps, and the mounting structure of the panels should have been included. That is, the state of the 'mounting structure' against wind should have been added.

Table 4. Weekly Inspection Log Sheet for "Deep Cycle Flooded" Lead-acid Battery

Date	**Battery Number**	**Specific Gravity**	**Terminals/ Connection Tight**		**Voltage**	**Water Level**			**Action Taken**
			Yes	No		Good	Fair	Low	

Source: USAID, 2013

The battery inspection log sheet in Table 4 is old and outdated when compared to the batteries in use today. Lithium and Gel batteries are the common ones used in Ghana and other parts of the world. These batteries are sealed and tight. It does not need checking and adding up water. Apart from the under-listed maintenance in Table 5, checking of battery and room temperature, and checking of breaker functionality could have been added.

Table 5. Weekly Battery Inspection Log Sheet for AGM and GEL Batteries Date

Date	**Battery Number**	**Terminals/ Connection Tight**		**Voltage**	**Action Taken**
		Yes	No		

Source: USAID, 2013

The checklists designed by David Tan (2011), Keating et al. (2015), Jeff Hoy et al. (2018) are only for major components of the solar PV. In effect, their works could be considered as recommendation for mainly site technicians to adopt. Thus, this research intends to enhance on their work by detailing areas like the lifespan of the components and the time or date for maintenance. Even though, consumer, building & occupational services consumer, (2021) designed a hardcopy checklist for both technicians and owners of solar PV projects to share, no lifespan of the components was added. The lifespan informs all stakeholders what component will be replaced at a particular time. Thus, the checklist appears to be more on inspection oriented than maintenance. Accordingly, 'Electrical characteristics' under the system component could have been added to the DC and AC side of the system for efficient O&M process. Again, Laboratory et al., (2018) maintenance checklist was complex but lacked some maintenance practices like maintenance under 'cables and conduits and frequency of maintenance, which is yearly and runs across all the aforementioned documentations.

Considering the failure rate of solar PVs, Costa Branco et al. (2020) and Halwachs et al., (2019) published respectively on failure rates in Photovoltaic systems: A Careful selection of quantitative data available in the literature and statistical evaluation of PV system performance and failure data among different climate zones for solar PVs shown in Figure 4 and Figure 5; owing to the fact that the health of all components is very important in ensuring that the system survives failure when it occurs.

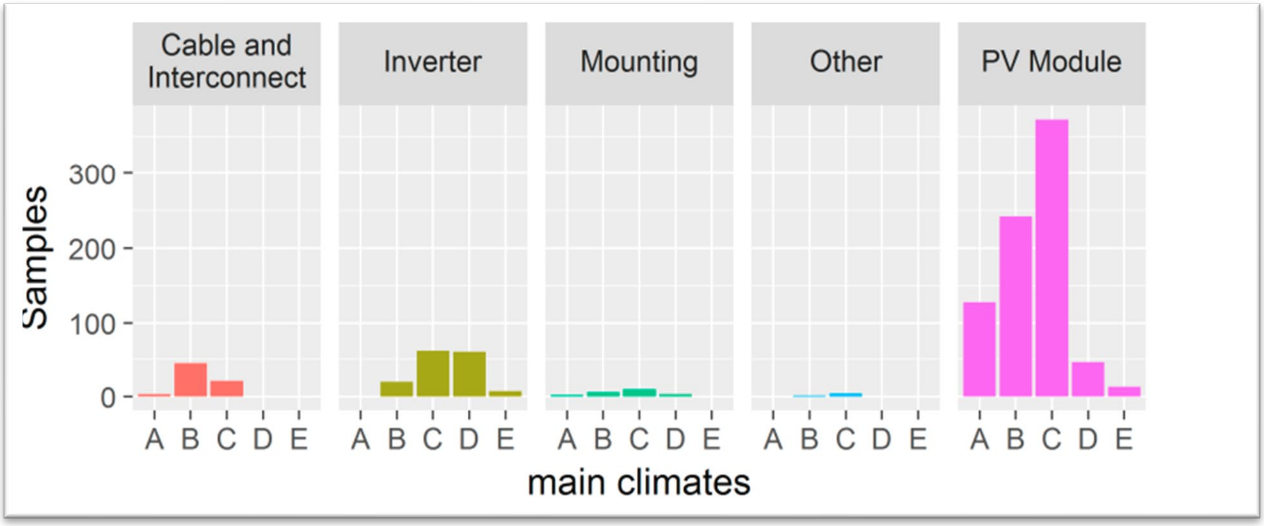


Figure 4. Distribution of collected data over main climate zones of Koppen-Geiger climate classification. (Source: Branco, 2020)

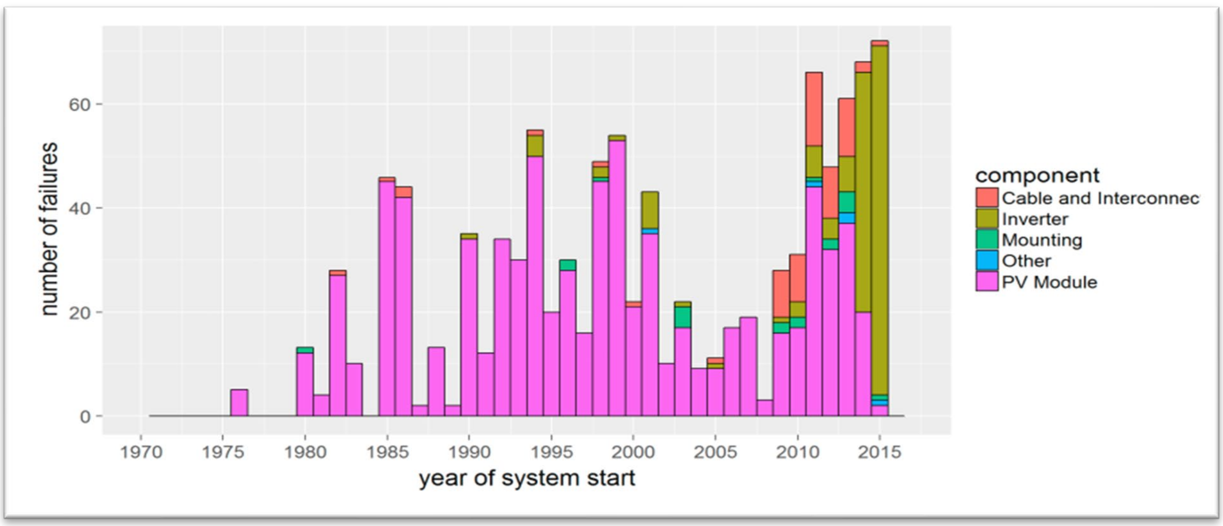


Figure 5. Collected Failures with their PV System's Installation Year (Source: Branco, 2020)

Costa Branco et al., (2020) discussed system failures as shown in Table 6. According to their work, the percentage of incidence linked with significant PV system components concerning all system failures recorded is the information provided in Ref. 1. It also details the proportion of occurrence of failure modes for the PV module, inverter, and cablings. The proportion of failures for the system's key components (mounting structure, PV module, and inverter), as well as for the subcomponents inside the PV module and inverter.

Table 6. Field Data and their Respective Failure Data Collection Characteristics

Ref.	No. for Systems	Sizes	Age	Location	Climate	Data collection
1	772	Diverse	Avg. 2.7 yrs	Europe	Diverse	Up to 2016
2	350	Few kW to 70MW	Up to 7 yrs	Worldwide	diverse	Jan/2010 to Mar/2012
3	63	0.2MW to 10MW	N/A	Italy and Spain	Medit.	2012 to 2016
4	57	N/A	N/A	Italy	Medit.	N/A
5	11	10kW to 600kW	4 to 18 yrs	Arizona, US	Hot dry	2009 to 2013
6	1	115kW	5 yrs	Serbia	Moderate	N/A
7	1242	Avg. 26kW	Up to 14 yrs	Japan	N/A	2006 to 2013
8	1	4.6MW	N/A	Arizona, US	desert	2003 to 2007
9	N/A	1.4 MW to 3.4 MW	2 to 7 yrs	N/A	N/A	N/A
10	1	20kW	N/A	Largely Canada	Moderate	2010

The Mean Time Between Failure (MTBT) for the inverter's internal parts and certain significant DC-side components, including the PV module, mounting structure, PV string cabling, and fuses, are provided in Ref. 3. The most important failure modes are listed in a portion of a Failure Mode Effects Analysis (FMEA) along with an explanation of the magnitude of their failure rate. The failure rates for a few key system parts—the PV module, inverter, and mounting structure.

The failure rate for the inverter as a whole, as well as for its internal parts and the PV array's individual PV modules, fuses, connectors, string cables, etc., is disclosed in 9. Table 6 organizes the data from the references that provide specific failure rate values (expressed in failure per unit per hour). We have assumed that the time to failure follows an exponential probability distribution if just MTBF is available.

In conclusion, no operation and maintenance protocol checklist are suitable for sub-Saharan Africa. Most of the SPV checklists are project specific which makes them undesirable for this region. Since it is clear that Ghana is gradually and steadily increasing the capacity of renewables in its energy mix, one way of increasing the capacity of renewables in Ghana's energy mix is to encourage owners of SPV projects in the country to comply with strict operation and maintenance protocol practices.

2. Methods

A mix research design method was adopted. It also applied both exploratory and confirmatory research approach to evaluate the performance of solar PV projects in Ghana based on their O & M culture. These aforementioned methods coupled with the use of the SPVOMP checklist and mobile app, facilitated the assessment of the effectiveness of the proposed procedure for maintenance of solar PV. Accra was chosen as the study area. Information and data were gathered from solar engineers and technician from 18 institutions in the renewable energy industry.

3.1 Data Collection

Survey and interview guides were the data collection tools used. Closed-end questionnaires were provided for solar engineers and technicians to collect data on the operation and maintenance activities of SPVs to ascertain how technicians and engineers relate and carry out maintenance and operational activities. The data from respondents was used as part of the information needed to design the SPV O&M checklist and also the development of mobile software.

Similarly, a review of the checklists of Akopong Energy, Energy Masters, and Macht Energy, on some of the limited existing local project-specific checklists was conducted. Interactions and interviews were used to review the various checklist and examine their limitations, as the study seeks to review and improve on the status quo.

Both simple random and purposive sampling methods were used. Out of a population of 200, 31 solar engineers and technicians responded appropriately to the online interview and questionnaires. These participants were from both educational and industrial institutions. Educators, both certified and non-certified technicians, and engineers were among the respondents. All participations were recorded as anonymous.

3.2 Solar Photovoltaic Operation and Maintenance Protocol (SPVOMP) Research Questionnaires

A total of 31 SPV's engineers, installers, and technicians responded to questionnaires administered. The response supports the claim that a comprehensive, general, and easy-to-use SPVOMP is imminent in the solar power industry. Amongst the questionnaires are very important questions as follows:

1. Do you have a single major contractor on site who routinely provides maintenance support services?
2. Do you have an operations/maintenance organization chart?
3. Are there standard operating procedures for each step of the maintenance process, and are they consistently followed?
4. Who can do maintenance?
5. How often does your company do maintenance?
6. Do you have a shutdown procedure displayed at your sites?

Also, the SPVOMP is a checklist and software app that is used to aid operators and technicians to undertake proper operation and (most importantly) maintenance to keep SPVs operational within their lifespan.

Microsoft Word (MS Word) from Microsoft Office Suite and JavaScript are the two software that were applied to produce this OMP. Whilst MS Word was used to produce the hard copy, the JavaScript programme was used to develop the virtual softcopy or software.

4. Results and Discussion

The results obtained from the questionnaire administered showed that, the selected companies under study have somewhat a guide that corresponds to the routine Operation and Maintenance activities for all their solar PV installations. However, the need for scheduling of Operation & Maintenance via monitoring is not practiced. It is clear from the response that over 83% either do not have or do not see the importance of Operation & Maintenance charts. This means most of the solar PV installations are only getting responded to only when there is a reported incident i.e., corrective maintenance and not preventive. As a result, this will affect the operational lifespan of the installation. Also, the financial benefits associated with green energy will not be realized in full.

Again, results indicated that most companies do not have a properly documented checklist and hence the question of being consistent was needless. A total of 75% of responses do not have a standard operating procedure for routine maintenance activities and operations. This implies that, most of these multiple subcontractors are performing maintenance activities based on their discretion. This will eventually lead to poor performance of these solar PV systems. The expected lifespan of these solar PV systems will be hugely impacted as well as the generation capacity will be affected. This indicates the need for a properly documented Standard Operating Procedures (SOP) document detailing all activities.

The response to the question "Do you have a single major contractor on site who routinely provides maintenance support services?" The goal was to know whether most EPCs companies in the sector are subcontracting to single or multiple companies to assist in Operation and Maintenance. A single contractor will have the maintenance history intact and would even have a major contribution to the efficient management of the solar PV project.

Unfortunately, only 19.4% of solar PV projects have single contractors on site to provide routine maintenance as shown in Figure 6. Most Energy Performance Certificates (EPCs) and finance institutions are using multiple subcontractors in the O&M of solar PV projects across the country. This implies that, there will be a lot of disjointed documentation of activities by different contractors and likely to lead to the loss of data on specific activities. Moreover, most EPCs and finance houses do not have their O&M chart as well as a properly documented operation and maintenance procedure, which may lead to the subcontractors performing the various maintenance activities in a disjointed manner and can affect the efficiency and generation of the solar PV projects.

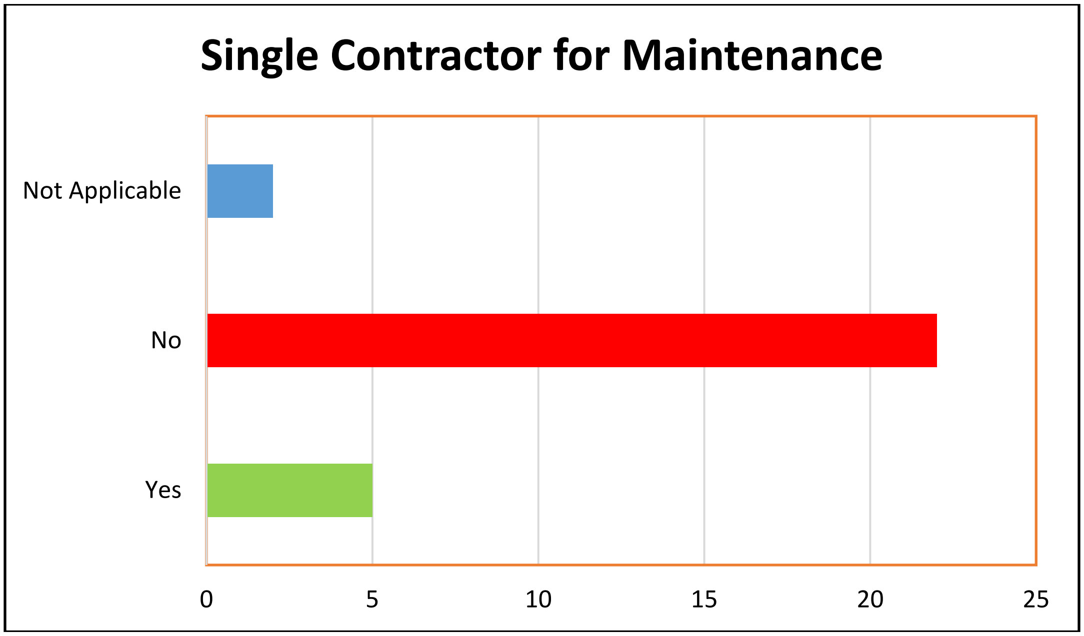


Figure 6. Response to a single major contractor on site who routinely provides maintenance support services

The Ghana Electrical Wiring Regulations 2011, (L.I. 2008) were passed into law by Parliament on Friday 24th February 2012 as one of the responses to the spate of electrical fires that had occurred in the country.
The key objectives of the regulations are to ensure that only properly qualified and certified professionals engage in electrical wiring and installation works, to well-defined standards that would promote the safety of persons, property, and livestock. Under these regulations, only Certified Electrical Wiring Professionals (CEWPs), qualified under the regulations, will be legally entitled to undertake indoor electrical wiring projects.
There are 2 classes of certification:
1. Certified Electrical Wiring Professional (CEWP)
   a. Domestic Electrical Installation
   b. Commercial Electrical Installation
   c. Industrial Electrical Installation
   d. Certified Electrical Wiring Inspector (CEWI)

Accordingly, results indicate that 55% of solar PV projects are being maintained by technicians and engineers who are not certified by the energy commission. These industry workers do not have the CEWPs which is a requirement for every industry worker in the electrical sector. This has lots of implications on the quality of installation and maintenance activities conducted and its effects on the lifespan and generation of the solar PV projects. In a worst-case scenario, a solar PV project could be in flames due to servicing and maintenance conducted by unqualified technician.

Likewise, approximately 2 out of 4 companies across the country; wait for an incident to occur on site before responding. It is also worth mention that 25%, 19.4%, and 19.4% have monthly, quarterly, and bi-annual maintenance activities respectively as shown in Figure 7. However, for a Solar PV project to perform efficiently, both corrective and preventive maintenance activities should strictly be adhered to. Also, to ensure the individual lifespan for the major components (panels, inverters, and batteries) is not compromised, corrective routine maintenance is the best approach. Finally, having a comprehensive operation and maintenance protocol will address this overall challenges.

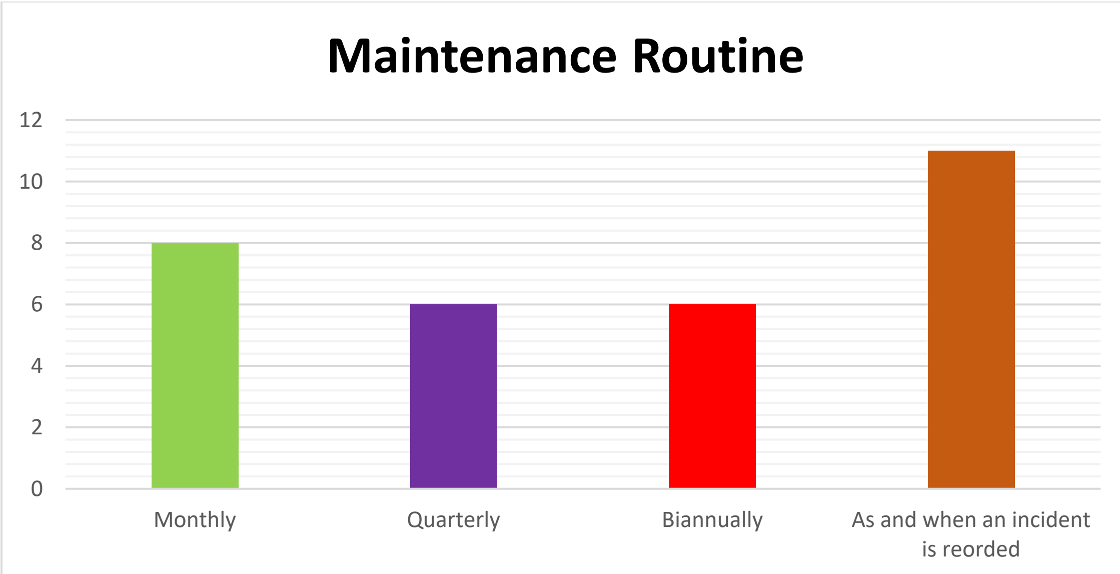


Figure 7. Response to the Frequency with Which the Company Does Maintenance

Furthermore, the shutdown procedure is an emergency step that is followed to turn off the SPV project in case of an emergency. This is also important in two ways.

1. To protect lives in case of a life-threatening emergency.
2. To protect all or some of the components of the SPV from damage in case of an emergency like a fire outbreak.

On the above procedures, results show that, 77% of solar PV projects in Ghana don't have a displayed emergency shutdown procedure on site. It is very indicative most industry workers place less or no value on the shutdown procedure which is very important in case of an emergency. More often than not, the technician or engineer will not be on site when there is an emergency. The shutdown procedure serves as a guide for anyone present on-site to quickly shut down the system. Congruently, interview reports indicate that, out of 10 personnel, 4 affirmed to the fact that their company follows a set O&M protocol. They clarified that the O&M contract and installation location define the frequency of maintenance activities, and that remote monitoring assists in identifying defects and determining the appropriate course of action for correction. The rest of the 6 indicated that the non-existence of O&M protocols for usage.

As stated earlier, a review was done on some of the limited existing local project-specific checklists. This was done to determine the limitations of those checklists. These checklists do not consider all the various components in the SPV system. Some of the balances of systems are left out of the maintenance schedule which makes it incomplete for SPV projects across the country. Checklist 1 does not categorize the activities according to their duration or time of maintenance. Since it is not possible to do all maintenance at the same time, this checklist is hugely limited in duration unless technicians guess when to do particular maintenance. As shown in fig. 4.5, 2 out of 4 companies wait for the failure of the system before carrying out a maintenance activity. Since MTBF is the indicator of the reliability of the parts of the system, an increase in MTBF is a good thing. But since about 50% of companies respond to breakdown maintenance, MTBF in these companies will be long, leading to unscheduled downtime and a huge loss of income. The Table 7 below summarizes and gives an idea of how local companies relate to these KPIs. Most SPV projects fall short of KPIs 1, 2, and 5.

Table 7. Comparing selected SPV project Checklist with KPIs

KPIs	Checklist 1	Checklist 2	Checklist 3
1. Unscheduled Downtime	x	x	x
2. Reactive Maintenance Work Hours	x	x	x
3. Maintenance Costs	✓	✓	✓
4. Mean Time Between Failure (MTBF)	✓	✓	✓
5. Work Order Cycle Time (WOCT)	x	x	x

4.1 Graphical Results

MS Word was used to create the hard copy of the SPVOMP. SPVOMP as shown in Figure 8 is designed to suit both new and existing users. New users will fill in some general information about a particular project. A new user will be able to register a project with its location. E.g., for a 30kW project at Kumasi Airport, The user will be able to describe the project by stating important information like the PV size, PV capacity and quantity, Inverter capacity and quantity, etc. Figure 9. is showing some portion of the general information on the hardcopy of OMP.

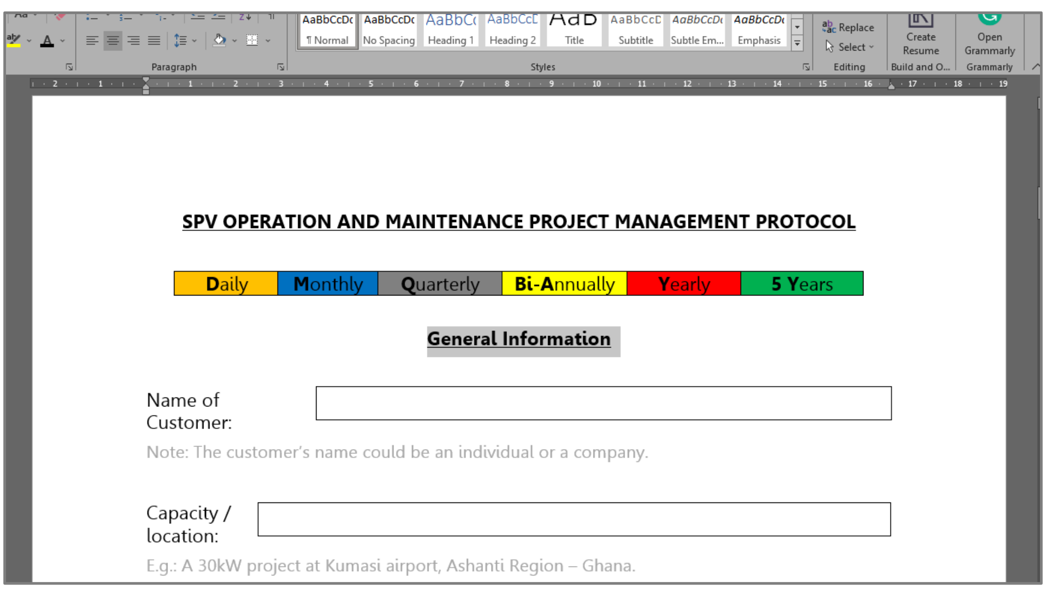
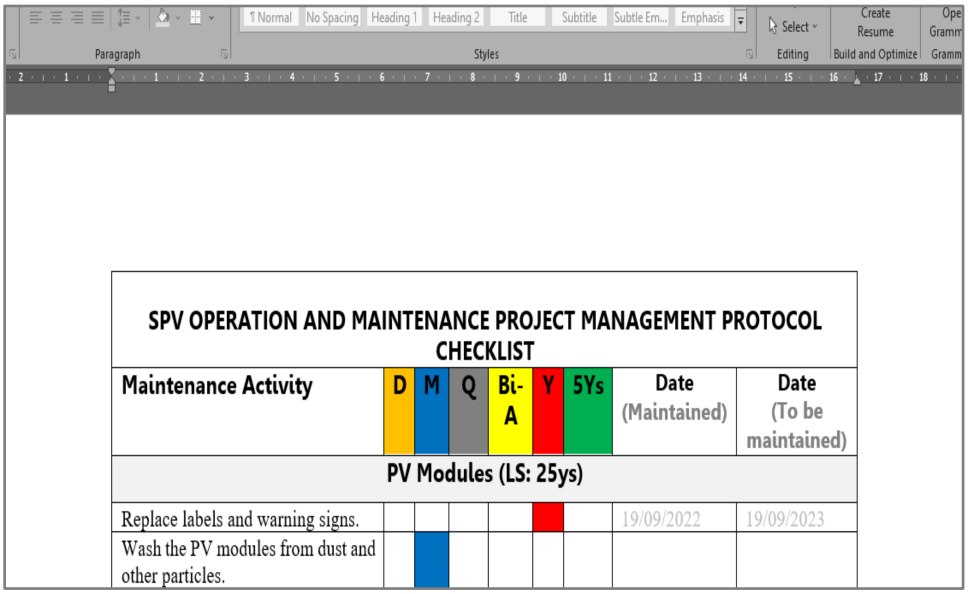


Figure 8. SPVOMP Checklist General Information

Existing specific project users will maintain their projects by strict adherence to the modules. There are seven modules which are PV Modules, DC & AC Side of the System, Inverters, Isolation Transformer and System Test, Earthing and Lightning Protection System, Instrument and system monitoring, and Battery System (for off-grid & hybrid systems). The OMP has three columns consisting of maintenance activity, the timing of activity (e.g., Monthly), and specific date (for maintain and next maintenance). This is shown in Figure 9.



SPV OPERATION AND MAINTENANCE PROJECT MANAGEMENT PROTOCOL CHECKLIST								
Maintenance Activity	D	M	Q	Bi-A	Y	5Ys	Date (Maintained)	Date (To be maintained)
PV Modules (LS: 25ys)								
Replace labels and warning signs.							19/09/2022	19/09/2023
Wash the PV modules from dust and other particles.								

Figure 9. SPVOMP's Three Major Columns Consist of Maintenance Activity, the Timing of Activity, and the Specific Date.

Work Order Cycle Time (WOCT) considers the time of the project installation including (in this case) the lifespan of individual components. This SPVOMP checklist satisfied this KPI by considering the lifespan of all components of the project. Secondly, an Increase in MTBF is a loss of money. But SPVOMP ensures that less downtime of the system is achieved. This is a result of the SPVOMP checklist and app telling and predicting the proper maintenance time for all components of the system. Thirdly, this checklist makes it very easy for users to even predict both current and future maintenance costs as shown in Figure 8. This is easily achieved because the checklist provides a time for both current and future maintenance for all components of the system.

Table 8. Comparing SPVOMP Checklist with KPIs

KPIs	SPVOMP Checklist
1. Unscheduled Downtime	✓
2. Reactive Maintenance Work Hours	✓
3. Maintenance Costs	✓
4. Mean Time Between Failure (MTBF)	✓
5. Work Order Cycle Time (WOCT)	✓

Reactive maintenance often referred to as breakdown maintenance, means that equipment repairs are performed after the equipment failure. It is a metric for maintenance work that interrupts the daily or weekly maintenance schedule. The SPVOMP checklist, if followed ensures virtually less or no breakdown of the system. The checklist ensures that all components of the project receive up-to-date maintenance. With this improved checklist, Unscheduled maintenance will be reduced, and MTBF will also reduce. It is possible because not only does the checklist and mobile app keeps track of the performance of the project but also stores every information of a project, making it easy for technicians to perform all necessary maintenance practices. In short, this work satisfies all the KPIs, which implies that not only will solar PV projects meet their proposed operational lifetime, it will also be more time-saving, man power saving and most importantly cost saving as illustrated in Table 8.

4.1.1 How to use the MS Word OMP Checklist.

The MS Word SPVOMP can be used in both the Hardcopy format and Softcopy format

4.1.2 Usage Procedure for the Hardcopy Format

1. For a new project, users will fill in the general information.
2. Check all the colour codes under the "timing of activity." E.g., All blue colour code corresponds to **M**onthly maintenance practice.
3. Write the "date" of maintenance and the date for the next maintenance.
4. Snap a photo of the OMP and upload it to the virtual app.

4.1.3 Usage Procedure for the Softcopy Format Procedure

1. For a new project, users will fill in the general information by clicking and typing in the boxes provided.
2. Check "*" for all the colour codes under the "timing of activity." E.g., All blue colour code corresponds to **M**onthly maintenance practice.
3. Type the "date" of maintenance and the date for the next maintenance.
4. Save and upload the OMP file to the virtual app.

4.2 JavaScript programme

The JavaScript programme (JSP) was used to develop the OMP software application.

4.2.1 How to use the JSP OMP software application.

After installing the OMP mobile app, new users will create an account by "signing on" with their details like name, email, password, and most importantly the Certified Electrical Wiring Professional (CEWP) number. The number requirement will ensure that only certified technicians and engineers can sign in.

On the home page, you see "Project Summary" and "Upcoming activities." The project summary shows the 'new', 'ongoing', and 'completed' projects. A completed project will always have a commissioning date. The upcoming activities show the project name and date and the days left to affect the activity.

This means that, aside from the notification that is received as emails, upcoming activities tied to specific projects will pop up as the time draws closer.

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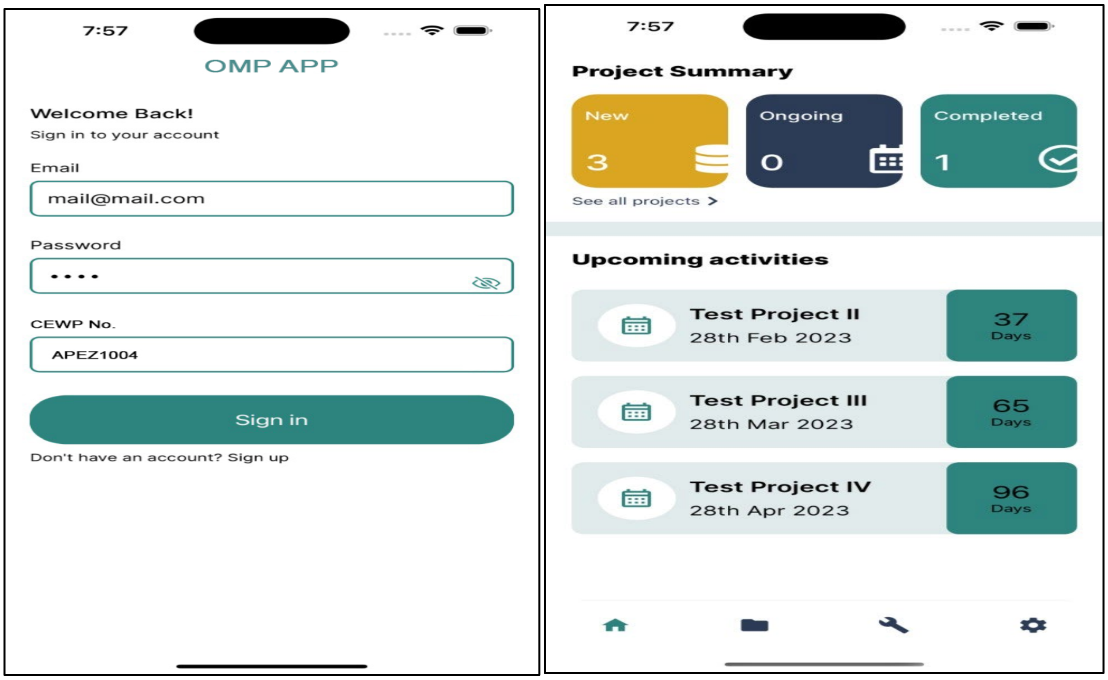

Figure 10. Project is registered.

The next thing to do is to register/add a project and save it (Figure 10 and Figure 11). The 'Add project' page is next to the right of the home page. Here, users will provide the project name and describe the project by indicating vital things like the number and size of panels and inverters. A typical example is shown in 10a, 10b, 10c, and 10d. The 'Choose a date' is the commissioning date of the project. 'Add photo' allows users to add specific technical drawings and pictures in picture and pdf formats. Moreover, users will be able to add/register as many projects as possible.

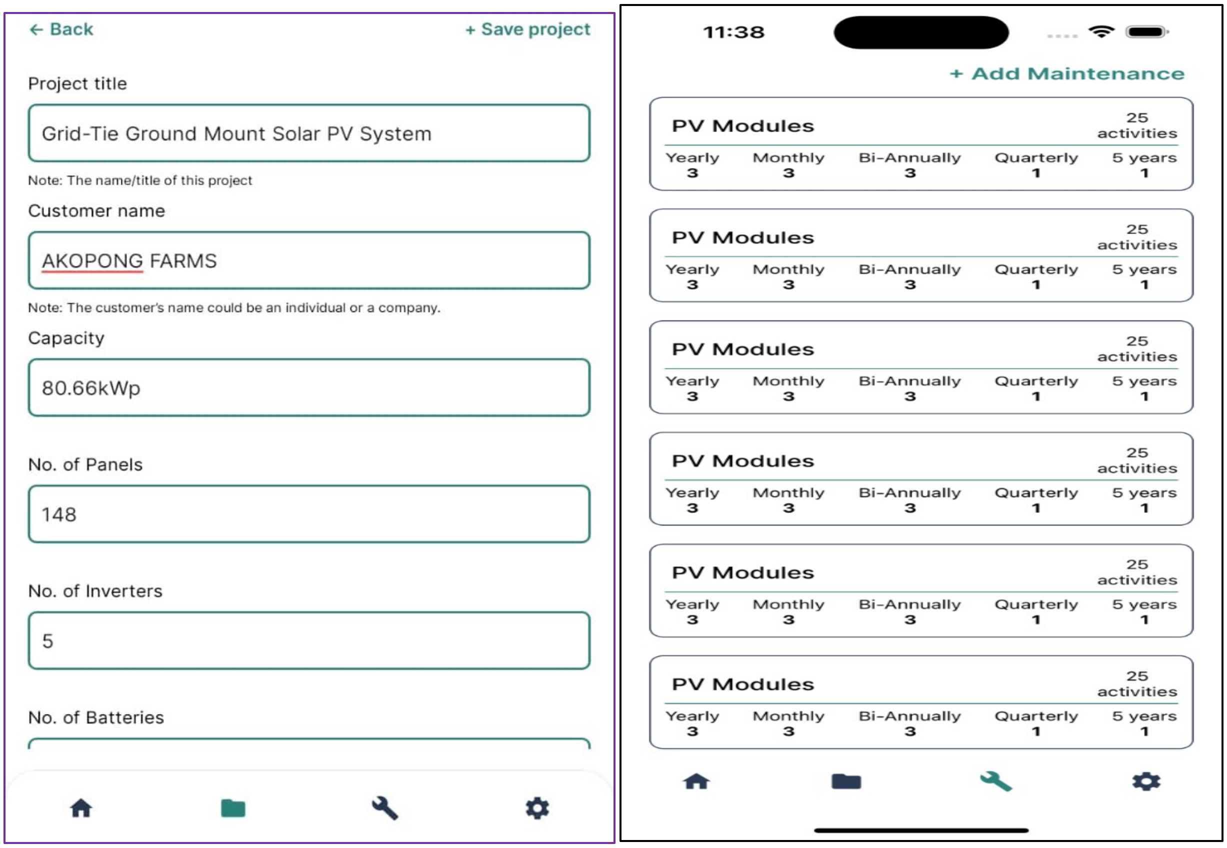

Figure 11. A project is registered.

The next thing to do is to "add maintenance." The "add maintenance" is linked to the added/registered project. The maintenance name could be Monthly or Yearly maintenance. For example, when you have monthly maintenance for a particular project, all monthly maintenance will pop up to allow you to schedule a date for that particular maintenance.

So, a particular project reminder will be handy on the App for daily through to 5 years of maintenance schedules. As the days get closer, if 'check hotspot using an infrared camera' is annual maintenance, reminders will pop up on the home page under upcoming activities.

In conclusion, The SPVOMP protocols (hardcopy checklist and mobile app) can be used separately or together. The mobile app will only permit certified technicians and engineers to create an account since it will require a unique CEWPs number to sign in. The hardcopy can be used by all technicians and engineers. This will enable all solar PV systems (residential and commercial) to be properly maintained to ensure solar PV systems work efficiently and the expected project lifespan is attained and even beyond. Also, with the SPVOMP the warranties for all the major components can be very much accessed because both routine corrective and preventive maintenance are requirements when there is an incident and a client wants a warranty claim.

Using both protocols i.e., hardcopy and mobile app gives the technician and engineer the flexibility of performing and recording maintenance activities with the help of the hardcopy in a situation of lack of connectivity. The information could later be transferred onto the mobile app. The mobile app ensures there is no data loss. It also ensures a smooth transition for any engineer or technician who hands over to another within a company to continue maintenance activities without any data loss. A summary of the major features of the OMP mobile app is described below.

A major feature of the mobile app is creating or adding an SPV project whether new or old. In adding a project, the registered CEWP user is required to add a title, customer name, system capacity, number of panels, inverters, and batteries. Also, the registered user is allowed to add further information deemed necessary in a sector called project description. Technical drawings as well as site photos can be uploaded while adding a project.

Lastly, the project commissioning date can also be added. This makes it easier for project documentation and for reference as and when the need arises.

The OMP mobile app has the core function of organizing and keeping track of all maintenance activities for all projects. For every project added, various maintenance activities can be added with a set date. These activities (SPVOMP) are impeded in the app for the registered to select and assign to a project with a date. For example; a user may assign monthly maintenance activities which are already contained in the app to the project.

Finally, the OMP mobile app sends notifications when a specific maintenance activity is due. When assigning maintenance activities to a project, dates are set for the various activities. Due to this, the app sends notifications to remind the user of impending maintenance activity.

The SPVPOMP is the solution to the above observations from the data collected. The protocol will address these challenges and ensure all projects are installed, operated, and maintained appropriately. This would ensure efficiency, avoid periodic breakdown, and adequate generation and value for money.

5. Proposed Improvements

A major challenge faced was the lack of enough literature on the subject matter. There were few cases or materials to review. Most of the available materials were developed for specific projects and also to suit operations and environmental conditions for other continents but not Africa. This makes it difficult to just lift it and implement it in the West Africa region.

6. Conclusion

The case study reviewed the existing procedure for the operation and maintenance project protocol for SPVs in Ghana and assessed the performance of SPVs in Ghana based on its operations and maintenance culture with questionnaires and brief interviews with engineers and technicians. An improved protocol or checklist for the operation and maintenance of SPV projects in Ghana was developed on the back of the review and assessment.

A review was done on some of the limited existing local project-specific checklists. This was done to determine the limitations of those checklists. Work Order Cycle Time (WOCT) considers the time of the project installation including the lifespan of individual components. This SPVOMP checklist satisfied this KPI by considering the lifespan of all components of the project. Secondly, an Increase in MTBF is a loss of money. But SPVOMP ensures that less downtime of the system is achieved. This is a result of the SPVOMP checklist and app telling and predicting the proper maintenance time for all components of the system. Thirdly, this checklist makes it very easy for users to even predict both current and future maintenance costs. This is easily achieved because the checklist provides a time for both current and future maintenance for all components of the system.

The results of a technical survey to assess the performance of SPVs indicate that out of over 31 technicians and engineers (either operating or maintaining solar photovoltaic projects), only a little over 19% of SPV projects have single contractors on site to provide routine maintenance, 70% do not have a standard operating procedure for each step of the maintenance process to follow and about 2 out of 4 companies across the country will wait for an incident to occur at the site of the project before responding.

The operation and maintenance protocol together with the mobile app is an invaluable tool for optimizing energy efficiency and at least a value for money for all stakeholders. The checklist will ensure consistency in both corrective and preventive maintenance of SPV projects across Ghana. Also, customers and financial institutions will get value for money for investments made. The rate of pollution will drastically decrease as we gradually make conscious efforts to generate more power through renewable energy sources and as a result mitigate climate change.

6.1 Recommendation

The operation and maintenance protocol developed by this academic exercise could be adapted by other institutions within the sub-Saharan Africa region to serve as a guide for any SPV project. In effect, the response justifies the need for an OMP checklist and mobile App. The designs will accommodate both CEWP and Non-CEWP. Non-CEWPs can only use the checklist. The OMP mobile App will be a valuable asset for all stakeholders in the solar power industry who wish to maximise SPV power output and meet value for money.

Also, education and training on the need for a good maintenance culture should be encouraged. Most (renewable power) projects carried out in Ghana do not get to their expected lifespan. The most common are solar streetlights. This is a result of poor operation and maintenance culture. A well-structured education and training on good maintenance practices should be championed by the government, civil society organizations, and non-governmental organizations. This will help create awareness and improve the maintenance culture in Ghana.

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