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Barriers and Prospects of Smart Grid Adoption in Ghana

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Abstract

Distributed generation presents the potential solution to the power deficit problem faced in developing counties by encouraging local generation with renewable energy resources that are abundantly available in some part of the world, especially in Ghana. Distributed generations on the other hand are closely linked to Smart Grid (SG) that uses information technology to manage electricity networks. A plethora of problems relating to safety, reliability and affordability of Smart grid solutions remains challenging today. In Africa, especially in Ghana, the adoption of smart grid has been very slow, poorly managed, and almost inexistent in some countries despite the crucial need for electricity provision. This slow adoption can be attributed to many limiting factors that demand a thorough investigation. This paper aims at investigating the barriers to the adoption of smart grids in Africa and also develops and evaluates countermeasures to hasten the adoption process. A stratified sampling approach was used to collect comprehensive data in Ghana that were handled with SmartPLS software. The evaluation of factors was done through inferential statistics. The impact of the proposed measures was tested using a partial least structural equation model analysis. Findings revealed some factors that strongly influence the adoption of SG including cost, education, government policies; other factors like culture, Grid stability, had slight influence on the adoption process, nevertheless, societal perception had a low impact on the adoption process and therefore attracts less attention in fostering the SG acceptance in Ghana. Regarding SG prospects, the study identified several factors that can foster the prospect of smart grid adoption in Ghana namely education on smart grid technology, government policies and consumers behaviour. It is believed that, if careful attention is given to the factors listed above, the adoption of SG in Ghana will move at a faster speed.

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Keywords: Smart grid, distributed generation, energy policy, economic growth, Smart technologies

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1. Introduction

According to [1], [2] an electrical grid is defined as an interconnected network of electrical devices for the purpose of transmitting electricity from a generation point to utilisation points. The grid is usually divided in three main parts namely generation, transmission and distribution. Smart grid on the other hand are intelligent grids that integrate a variety of Distributed Energy Resources (DER), smart meters, smart appliances, energy efficient resources, advanced control of power distribution, voltage and frequency synchronizers with improved monitoring devices. According to Massoud Amin, known as the father of the Smart Grid [3], Smart Grid refers to the use of digital information and control technologies to improve reliability, security, and efficiency of the electric grid. Smart grids are growing at a steady rate in Asia, Europe and America with the advent of renewable energy sources like solar, wind, mini-hydro, battery and with their amazing storage capacities[4], [5]. DERs help to decentralise the energy provision and also to reduce the need of extending the National grid in every locality that become very costly. They have the benefit to increase coverage in terms of electricity provision and can also help reduce considerably the electricity cost. With the smart meters in place, a local generation in excess may be sold to the grid, thereby reducing the cost of electricity. According [6] to smart grid can significantly improve load factor and reduce system losses. The multiple benefits of smart grid technology are clearly elaborated in [5], [7]–[12].

Smart grids on the other hands, bring a number of technical issues relating to grid safety, energy storage and availability which are mainly addressed by standards or policies[13], [14]. Despite the multiple benefits of Smart Grids, their adoption in some part of the world especially Africa, has been slowed down owing to a number of factors. Some of the identified factors include economic, political, financial barriers, inefficient pricing of electricity and consumer education and engagement[6], [13]–[16]. In brief there is a lack of commitment from both the government and the acceptance of the smart grid technologies by potentia consumers. In other countries, the problems are mainly related to non-existing adequate policies or guidelines to encourage the importation and use of renewable energy resources. Cybersecurity is also another impeding factor to the success of smart grid adoption as data access and ownership is critical for the privacy of consumers meanwhile the data is transmitted through internet and therefore subject to all possible cyberattacks. In the US, issues relating to the adoption of smart grids have been categorised as regulatory policies, legislation, culture and communication as well as technical challenges[17], [18].

Solutions proposed by previous studies including [13], [14], [17]–[19],to the slow adoption or integration of smart grids in national distribution network relate essentially to education and policies. In terms of Education, it is necessary that all stakeholders, essentially the energy service providers and the consumers understand the vision, align themselves with critical milestones having an idea of the end in mind. Education can eradicate cultural barriers, reduce poor and negative perception while preparing people to accept the adoption of the new technology. Finally, the unavailability of funding for Research and Development in the smart grid can also be addressed with more commitment from government and other stakeholders through education.

Regulatory policies can incentivize investment in Smart grid. Consumers active participation in smart grid issues can be gingered through the establishment of good policies. Similarly, policy may address favorable depreciation rules so as to ease assets management which it also an area of great concern in the smart grid. Policy must encourage the smart grid adoption from a business perspective. Investors should clearly foresee positive return through the availability of policies that encourage smart grid. Policies in the smart grid market must also ensure an improved system operation and reliability, availability of information on usage, and dynamic pricing. Some existing policies in US, supporting grid integration include Energy Policy Act (EPACT) in 2005, Energy Independence and Security Act (EISA) in 2007 and many others[17].

Technical issues relating to smart grid cover a wide range of problem including standardization relating to grid interconnection, operability and also the existing distribution or transmission system.[6], [14] explained that the variability of DER for power generation; namely: wind, solar hydro, batteries poses a technical challenge to electric grid operation. Depending on the distributed energy resources which may be Direct Current (DC) type, the distribution system may be modified, special safety devices meeting necessary specification will be needed at the points of interconnection with the grid. Local storage of energy can lead to increasing domestic fire or accident and therefore need to be handled properly.

Even though there were several attempts to identify and address the barriers of smart grid integration in Africa[6], [13]–[16], [18], [20]–[24], the problem of slow adoption persists and it is even aggravating. There is no foreseen prospect for smart grid adoption especially in some African countries. The barriers to this adoption vary based on financial, cultural, and governance factors which dynamically change anytime there is a new government in place. For instance, elections are run every four years in Ghana and the governance system varies according to the party in power which indirectly affects most factors related to the adoption. This situation calls for an update or re-analysis of the exiting barriers and also the possibility of forecasting prospects based on countermeasures proposed. The most recent study on these barriers in Ghana is dated 2013 [14]. Another limitation is the fact that most studies analyse some barriers but failed to evaluate with relevant research tools, their impact on the prospect and consequently, the reality with smart grid integration remains unchanged. Finally, cultural diversity has a strong influence on education and many other factors and for this reason, developing countries deserve greater attention since there is no available literature showing any significant volume of studies concerning the adoption of smart grid in West Africa.

This paper proposes a systematic investigation of the barrier to smart grid adoption in Africa with a particular focus on Ghana. The author further elaborates guidelines or recommends countermeasures to solve the slow adoption and evaluate their possible impacts on the prospects of smart grid adoption based on a self-developed model.

The rest of the paper is structured as follow: Section two deals with the review, section three deals with the methodology, section four presents the results and interpretation, section five covers the discussion and section six, the conclusion.

2. Review of Smart Grid Technologies in Ghana

Regarding the smart technologies used in Ghana, the Electricity Company of Ghana (ECG), has deployed since 1995, single phase and three phase smart prepayment metering systems. In Ghana, the Smart Prepaid Meters in addition to their basic function of Energy Measurement have two key features which are Communication and Control. ECG has extensively deployed two out of the three internationally recognized approaches to prepayment metering: Traditional Thick Metering and Thin Smart Metering.

In the traditional approach, a dedicated prepayment metering system is used to provide the functionality needed for a prepayment service. In addition to measuring consumption per interval, the meters incorporate firmware that allows them to rate the customer's usage against tariffs defined in the meter and then calculate a real-time balance. The meter activates an automatic disconnection when a customer's credit runs out. The customer can then upload the credit purchased directly onto their meter, using a physical token or swipe card or by entering a digital vending code via the meter's keypad. With keypad meter systems, utilities can extend the range of payment channels by enabling customers to obtain digital vending codes via methods such as short message service (SMS) or online sservice. This reduces the reliance on the physical vending networks and provides greater convenience to customers.

In the thin smart meter-based approach, centralized back-office systems rather than the meter are responsible for managing the prepayment service. Tariffs are defined in the prepaid account management system, which rates the customer's consumption based on usage of data obtained from the smart meter over the Advanced Metering Infrastructure (AMI) network and then calculates the user's balance. Utilities can push the centrally held customer usage data and balance information to a variety of end-user devices, including In-Home Displays (IHDs), web portals, mobile phones or tablets. Customers are typically updated about their account status on a daily basis.

ECG approach to deployment of SMART Prepayment for the future is a composite of the traditional and thin smart metering that will have the following features: Like the traditional prepayment, it shall keep most calculations on the meter and disconnect the supply when credit runs out; Purchases can be uploaded automatically to the meter over a wide area communications network; Should there be a failure in communications, the customer can fall back to entering a vending code manually; The smart meter shall have facilities to enable the supplier to switch meter modes between prepayment and post-payment billing; tariffs can be updated from the back office as well; utilities can also apply policies on load management easily.

ECG smart metering project is backed by a number of International Electrotechnical Commission's (IEC) standards that specify the ICT requirements for the energy meters, their criteria for acceptance test and inspection. Figure 1 provides an illustration of typical smart meters deployed in Ghana.

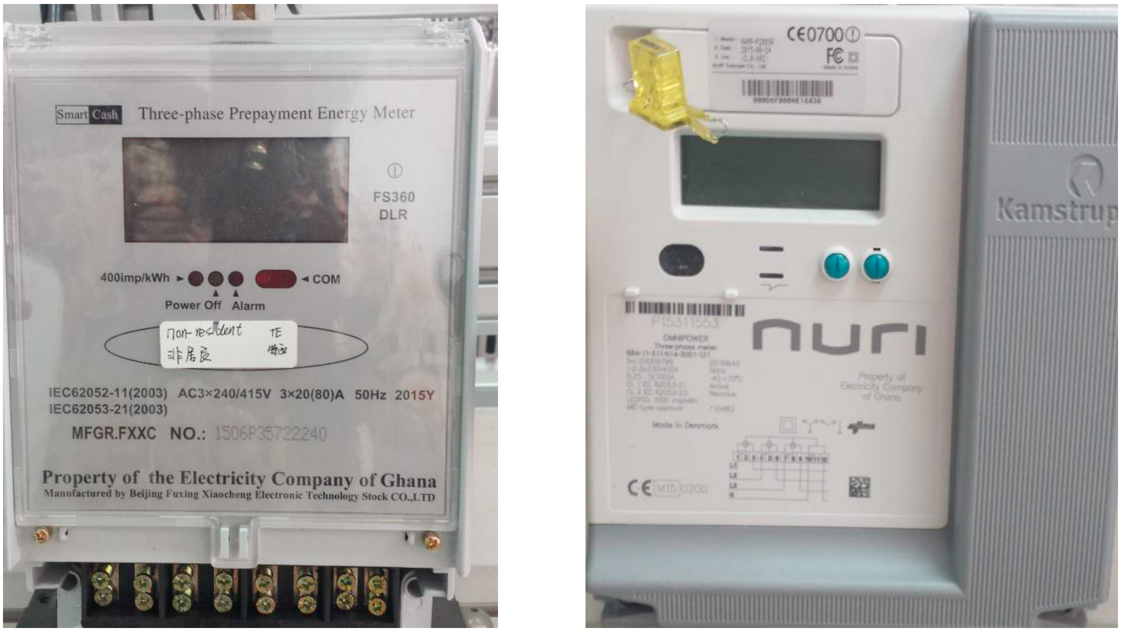


Fig. 1. Sample Smart Meter Deployed in Ghana by ECG

3. Methodology

This section presents the tools and methods used to analyse both the barriers and prospects of smart grid adoption in Ghana. The method used in this study is derived from the unabated search for a better solution for the adoption of smart grid in African countries, especially Ghana. A literature survey on existing standards was first conducted to highlight the technical challenges followed by some inferential analysis with PLSEM to evaluate the influence of identified factors on the challenges and prospect of smart grid adoption in Ghana.

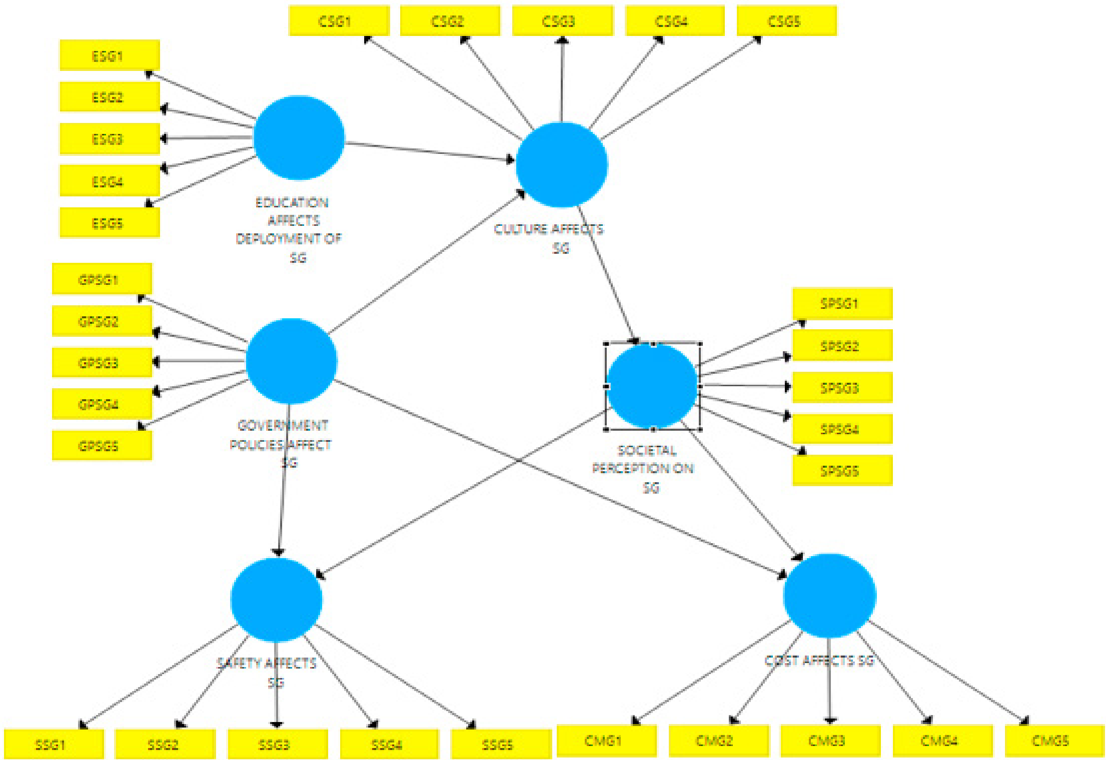
Factors affecting the adoption of smart grid are analysed by applying the SmartPLS (software with graphical user interface for variance-based structural equation modeling (SEM) using the partial least squares (PLS) path modeling) tools for both the factor and path analyses of the drivers of the integration of smart grid in Africa. This method is employed based on its ability to test the relation and effects between latent variables on the slow adoption of SG.

The Roasoft software tool was used to calculate for the sampling size based on a random sampling approach. The population of Ghana in 2018 is estimated to be approximately 29.47 million according to [25]. Out of the 29.47 million the corresponding sampling size of 361 was obtained, at a confidence level of 95%, 5% margin of error with a response distribution being 50%.

Well-structured closed ended questionnaires were developed to collect primary data that were used to measure the effect of the indicators on the independent and dependent variables. Most questions were targeting the prospects of smart grid adoption and barriers to the adoption of smart grid by considering the effects of education, government policies, culture, societal perception, safety and cost.

4. Data Manipulation, Results and Interpretations

This section deals with the measurements of the constructs of interest and total interpretation of the structural model. Specifically, the model will lead to the estimate of effects, stability and validity of the variables on each other and an overall factor analysis. Figure 2 presents the original conceptual model for this study.



Legend

- ESG1, ESG2, ESG3, ESG4, ESG5: Effect of Education on Smart Grid, Variable 1, 2, 3, 4 and 5 respectively
- GPSG1, GPSG2, ESG3, GPSG4, GPSG5: Effect of government policies on Smart Grid, Variable 1, 2, 3, 4 and 5
- CSG1, CSG2, ESG3, CSG4, CSG5: Effect of culture on Smart Grid, Variable 1, 2, 3, 4 and 5 respectively
- SPSG1, SPSG2, ESG3, SPSG4, SPSG5: Effect of societal perception on Smart Grid, Variable 1, 2, 3, 4 and 5 respectively
- CMSG1, CMSG2, ESG3, CMSG4, CMSG5: Effect of cost on Smart Grid, Variable 1, 2, 3, 4 and 5 respectively
- SSG1, SSG2, ESG3, SSG4, SSG5: Effect of safety on Smart Grid, Variable 1, 2, 3, 4 and 5 respectively

Fig. 2. Original Model Construct

Some of the selected factors were extracted from literature while others were anticipated by the author to have an influence on SG adoption. The tested factors include government policy, culture, cost, degree of safety, societal perception, economic, political and financial barriers, inefficient pricing of electricity, consumer education and engagement [6], [13]–[16]. The inclusion of societal perception and level of education were innovaive addition brought in by the authors.

The first examination of the result is concerned with the assessment of reliability and validity of the proposed model. The rule of thumb is that the composite reliability should be greater than 0.6 which is the threshold of acceptance. Table 1 confirms that all the composite reliabilities were effectively above the threshold of 0.6 proving therefore the reliability of the proposed model.

Table 1: Construct Reliability and Validity Result

	Cronbach's Alpha	Rho_A	Composite Reliability	Average Variance Extracted (AVE)
Cost affects SG	0.816	0.822	0.871	0.575
Culture affects SG	0.761	0.821	0.842	0.536
Education affects deployment	0.833	0.862	0.883	0.607

of SG				
Government policies affects SG	0.729	0.740	0.818	0.478
Safety affects SG	0.722	0.803	0.802	0.485
Societal Perception on SG	0.350	0.343	0.216	0.250

Apart from the composite reliability, an assessment of the structural estimate stability is needed to further represent the stability of the model construct by considering the indicator loadings, for which the value should preferably be 0.7. Table 1 shows that all variables at the exception of societal perception have a construct reliability above 0.7.

Furthermore, the values obtained for the Average Variance Extracted (AVE) were also good as they meet the threshold value of 0.5 with the exception of the last variable (societal perception on SG). Finally, the Discriminant Validity test is considered positive when the preferred values obtained for each latent variable construct are higher than other latent variables construct [26]. The discriminant validity was measured by using the Fornell–Larcker criterion and the results demonstrated a positive validity.

Additionally, confirmatory analysis had been conducted considering values of Fornell–Larcker criterion, cross loadings and the Heterotrait- MonotraitRatio (HTMT) as illustrated in Table 2 and 3 respectively.

Table 2. Fornell–Larcker criterion test

Variables	Cost affects SG	Culture affects SG	Education affects deployment of SG	Government policies affects SG	Safety affects SG	Societal Perception on SG
Cost affects SG	**0.758**					
Culture affects SG	0.608	**0.732**				
Education affects deployment of SG	0.555	0.599	**0.779**			
Government policies affects SG	0.417	0.588	0.756	**0.691**		
Safety affects SG	0.564	0.685	0.608	0.558	**0.666**	
Societal Perception on SG	-0.226	-0.312	-0.229	-0.177	-0.510	

Table 3. Heterotrait- Monotrait Ratio

Variables	Cost affects SG	Culture affects SG	Education vs SG	Govt. policies affects SG	Safety affects SG	Societal Perception on SG
Cost affects SG	0.861					
Culture affects SG	0.778					
Education affects deployment of SG	0.646	0.726				
Government policies affects SG	0.492	0.766	0.949			
Safety affects SG	0.719	0.843	0.723	0.693		

Societal Perception on SG	0.408	0.485	0.443	0.576	0.667	

Results for the cross loading and HTMT in Table 2, are in agreement with the preferred values. Figure 3 shows the graph for the HTMT for the model construct.

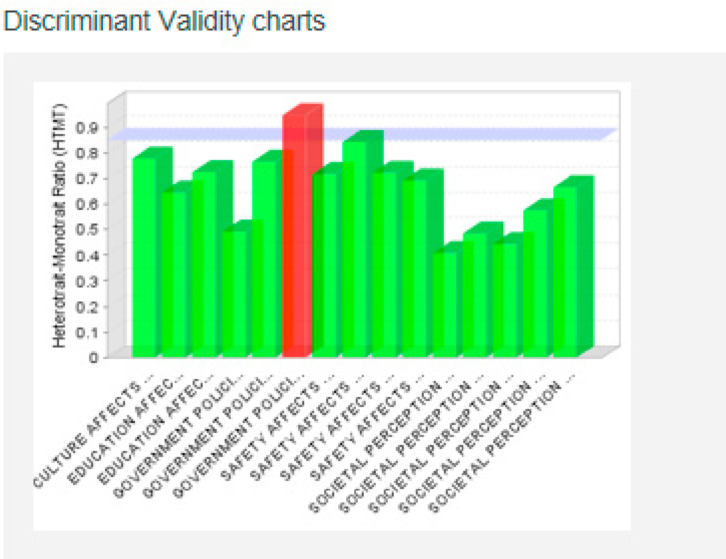


Fig. 3. Graph of The HTMT for the Adoption of Smart Grid

The values of HTMT listed in Table 3 showed that education and government policies significantly influence the adoption of smart grid, whilst safety, culture and cost effects slightly hinder the easy adoption with societal perception not really influencing the adoption process.

Furthermore, the outer loading for the reflective constructs for both the exogenous and endogenous variables are tested by bootstrapping. Subsequently, the quality test, the r-square and r-square adjusted values are indicated in Table 4 and the values displayed are excellent.

Table 4. R- Square and R-Adjusted Values

	R Square	R Square Adjusted
Cost affects SG	0.198	0.179
Culture affects SG	0.406	0.392
Safety affects SG	0.406	0.474
Societal Perception on SG	0.097	0.067

On the other hand, results for the prospects of smart grid in Africa revealed very interesting facts by producing strong correlation and covariance results for the selected factors being tested. Based on the model construct in Fig.2, a factor analysis was run for some selected variables including effects of government policies, definition of SG in Ghana, consumer behaviour, technology, as well as grid stability and resilience. Results demonstrated a significant influence of all the above listed variablees on the prospects of SG leading to the finally improved model of Figure 4.

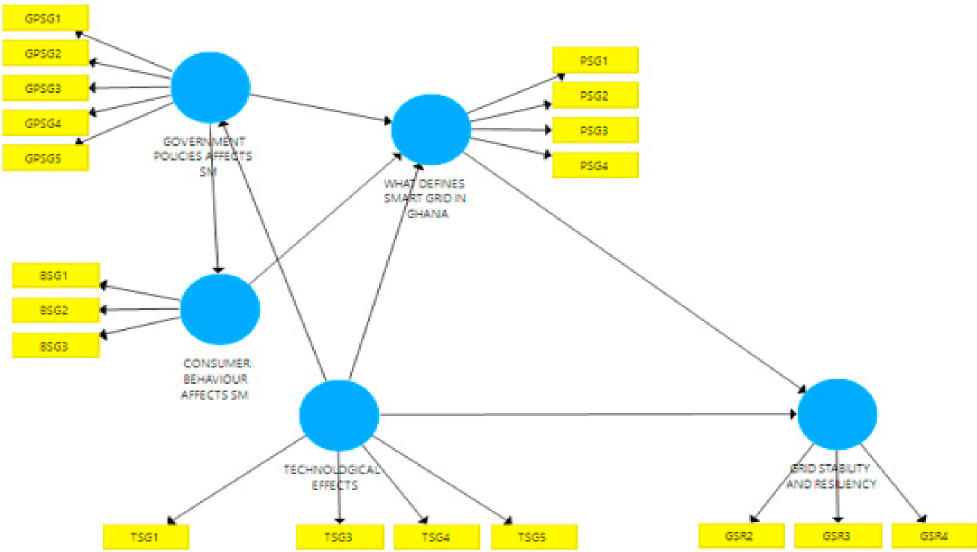


Fig. 4. Model Construct for Prospects of SG in Africa

5. Discussions

This section presents two major findings and discusses them.

Finding 1

The study found out that variables such cost, education, government policies can be considered as strong challenges influencing the adoption of smart grid in Africa while other variables including culture, Grid stability, have slight influence; Finally, per the results obtained, societal perception has little or no influence on the smart grid adoption in Ghana.

These results corroborate a number of previous studies dealing with challenges of smart grid adoption including [27]–[32]. Furthermore, previous efforts in Ghana also concur with the findings, especially [33] whose study qualifies Ghana to be at the level 1 of the Smart Grid Maturity Model (SGMM).

Finding 2

The study also found that factors such as education on smart grid technology, government policies and consumers behaviour constitute the main factors that will propel the smart grid adoption in Ghana. With regard to the IEA definition of smart grid that links it to a digitized network with sophisticated monitoring system to satisfy the end user, education on the SG technology is paramount and undoubted. Additionally, government policies can drive the change towards the acceptance of the technology and revert the wrong perception. [34] and [35] found similar prospects of smart grid adoption with the advancement of technology in communications and policy drives.

6. Recommendations

The introduction of Smart Grid Concepts in educational program is strongly recommended. The advancement of smart grid relates to many technical factors that have been left out by the aquake curricula of most polytechnic and Technical Universities in Africa. The new area of knowledge includes, advanced hardware programming, advanced metering system handling and power electronics leading to the design of special converters, inverters, frequency and phase synchronizers. Less attention has been given to these areas of knowledge that have become fundamental in smart grid systems. Newly designed curricula addressing these gaps will add up to the speedy penetration of the smart grids in Africa.

Awareness and sensitization campaign. This will educate the society at large and raise the image and perception of smart grids.

Regulation on interconnection, Net metering implementation. The need of regulation or legislative instrument on the calculation of electricity tariff and also net metering in some countries including Ghana is paramount to the penetration and acceptance of smart grid technology.

7. Conclusion

In summary, this study investigated the barriers to the adoption of smart grids in Ghana and also developed and evaluated countermeasures to hasten the adoption process. The study reveals interesting results on both the factors that greatly influence the adoption of smart grid and prospects of smart grid in Ghana. From the results obtained, some of the factors that strongly influence the adoption of SG were cost, education, government policies; other factors like culture, grid stability had slight influence on the adoption process, nevertheless, societal perception had an insignificant impact on the adoption process and therefore attracts less attention in fostering the SG acceptance in Ghana. From the point of view of prospect, the study also pointed a number of factors that can foster the prospect of smart grid adoption in Ghana namely education on smart grid technology, government policies and consumers behaviour. Even though there were evidence that Ghana is still at the starting point of integrating SG, it was found that a careful attention to the factors listed above can propel the transformation at a faster rate. In this regard, the study also made some recommendations among the introduction of smart grid in education.

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