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A Study of the Economic and Technical Analysis of Large scale Photovoltaic Plants in Ghana: A Model to Increase Foreign Direct Investments

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Abstract—To date, the primary energy issue facing developing economies is one of energy deficiency. Given continental Africa's geographic location and optimal access to the equator, terrestrial photovoltaics ('PVs') are the ultimate solution to Africa's quest of achieving an environmentally comparatively benign source of electrical energy.

The resulting energy deficiency highlights a scenario that is caused, in part, by a lack of investment in large scale commercialized renewable energy plants which is primarily due to the unwillingness of financiers to provide early stage resources in the developing world. This paper describes an optimal investment planning model for large-scale PVgeneration in an existing power grid. The objective of the model is to arrive at decisions that yield the most profitable outcomes for foreign direct investment ("FDI") opportunities, while taking into consideration the technical constraints as well as environmental impacts pertaining to Ghana.

Keywords—photovoltaics; levelised cost; foreign direct investment; system capacity factor ;

1.0 INTRODUCTION

To date the primary energy issue facing developing economies is energy deficiency. Terrestrial PVs are the ultimate solution to mankind's quest of achieving an environmentally comparatively benign source of electrical energy. PV technology has been under-utilized as a source of energy generation due to the perceived high cost relative to other sources such as fossil fuels in these emerging economies[1]. Recent advances in solar technology has led to increased efficiency, decreased cost of PV modules, and ultimately a significantdecrease in the cost of solar generated electricity[2]. Some authors predict large scale PV generated technology will achieve grid parity when appropriate carbon taxes are considered [2, 3, 4].

PV projects are generally recognized as embodying more elements of sustainable development than a conventional energy projects and sources. Among the noted benefits of PV projects are the reduction in greenhouse gas emissions from $CO_2$and NOx and an overall reduction in toxic gas particles (SO_2) [5,6]. In addition, PV plants can be placed in esthetically desirable places such as near natural parks, since these plants result in a reduction in electricity gridlines. However, these projects are not completely without environmental harm and as such FDIs need to consider Environmental Impact Assessments even for PV projects. Proper project design requires a complete contemplation of the potential environmental harms, which in the case with PV projects may include: noise pollution during construction, depletion of natural resources where the plant is situated, air pollution, and waste management arising from the disposal of batteries [7].

The economic feasibility of an energy generation project is usually evaluated by a number of measures such as ROI (Return on Investment), IRR (Internal Rate of Return) and LCOE (LevelisedCost of Electricity) [3]. LCOE is dominantly used in estimating the cost of producing electricity by a power producer. It is calculated by accounting for all of a system's expected lifetime costs (including construction, financing, fuel, maintenance, taxes, insurance and incentives), which are then divided by the system's lifetime expected power output (kWh). The LCOE can be expressed in units that are directly comparable to the rate paid for electricity from the local utility (e.g., cents /kWh), a simple way to assess the cost-effectiveness of a PV system is to compare its LCOE to the rate charged by the local utility [2,8,9].

Several authors have estimated the PV LCOE's for different countries [8]. Schmidt *et al.*[4]obtained LCOE's ranging from $0.20- $0.35/kWh for six developing countries – Brazil, Egypt, India, Kenya, Nicaragua and Thailand. Focusing only on Africa, it has been reported that estimated PV LCOEsrange from $0.20- $0.51/kWh [3]. On the other hand the PV LCOE for Canada ranges from $0.10 -$0.15/kWh [8], while that of the USA varies widely from $0.07-0.18/kWh for utility scale under various incentives [9].

Although several studies have been dedicated to economic and technical analysis in African countries, it remains challenging to project the study from one country to the other. Reasons include: the differences between regional markets, the complexity of the balance systems, transmission tariffs and labor rates. Secondly the LCOE varies based on geographic (including solar insolation), financing terms, as well as the grid connection capacity of the existing system. Finally the environmental aspect of large scale PV on developing nations and in particular Ghana has not been thoroughly studied. In the past two decades, Ghana's Foreign Direct Investment (FDI) has fluctuated initially dropping substantially from 1994 to 2004 by forty (40%), and later demonstrating a sharp increase between 2004 to 2012 of two thousand two hundred and sixty-five percent (2,265 %) (from 233,000,000 in 1994, reduced to 139,270,000 in 2004, and 3,294,520,000 in 2012) [10]. Despite this increase, there is still a level of consternation among multinational enterprises in investing in various sub-Saharan African countries, and particularly in high capital ventures such as PV plants. A number of scholars have explored the role of FDIs in contributing to development in Sub-Saharan Africa [12-14] however, few studies have focused on Ghana, and there is a clear absence in the literature on scholarly work dedicated to FDI and PV projects.

This paper focusses on using a suitable mathematical model to calculate the LCOE and in the process demonstrate to investors the viability of investment in Ghana, while examining the technical and environmental constraints. This model provides a framework and tools to help investors make good decisions in the complex LCOE calculations, thereby enhancing economic development through increased foreign direct investments (FDIs).

2.0ECONOMIC CONSIDERATION FOR PV PROJECTS IN GHANA

Ghana lies near the equator, this prime location leads to the country having optimal access to solar resource. It is also considered as a country with relatively stable economic growth and a suitable climate for industrial investment. However, there is a growing need for access to electricity. Subsequently, the emerging economy faces energy crisis because the electricity generation lags behind demand. The demand for energy has doubled within the past decade as displayed in Fig. 1. In addition to this, system losses have increased correspondingly. The annual growth rate for electricity demand in the country has exceeded 10% in the last three years. For instance, between the first quarter of 2011, and the same period this year, the system peak demand has grown by 101 MW (from 1609 MW to 1710 MW). Indeed peak demand has now risen to 1,726 MW, supply capacity, however, has not kept pace with this growth in demand thereby putting the power system under great stress in 2012 [15].

Transmission losses are also a major source of concern. As depicted in Fig. 1, the transmission network reported losses of about 2.8 % and that has steadily increased to about 4.7 % in 2013. To put the losses into perspective, in 2010, the transmission network transported about 10,232.1GWh of electricity with 3.7% losses. A loss of 3.7 % represents 378GWh [16]. This amount of significant transmission losses in the system impacts the incentive for foreign investment.

The Government of Ghana in a bid to encourage alternative sources of energy passed the renewable *Energy Act* 2011 [Act 832]. This act established Ghana's first comprehensive guaranteed pricing structure for renewable energy production applicable to large-scale PV generation.This policy is also referred to as a feed in tariff (FIT). In Ghana, the current FIT rate of $0.20 /kWhis much higher than the rate of conventional sources [16,17].

Some factors particularly favorable to FDI's include (i) political stability (ii) availability of solar resource, and substantial Government support. With all three indicators fairly met, it is aparadox that large scale PV generation has not yet began in Ghana with the exception of the Governments 2MW VRA test plant in the Northern region.The rest of the paper attempts to unravel this paradox by examining factors that are pivotal to attracting investors.

2.1A Model for Investment in PV in Ghana

Corporations involved with FDI are not only concerned with the LCOE, but also yielding a return on investment. Our LCOE was derived by analyzing the cost of generating electricity from PV, accounting for geographic location (including solar insolation), balance of system, inflation and discount rate.

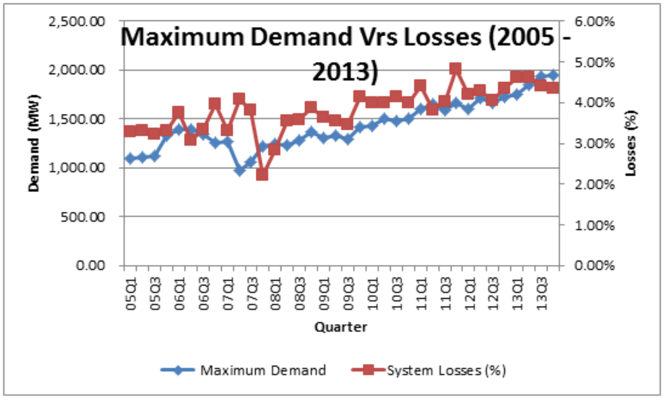

Figure1. Plot of energy demand and Loss between 2011 and 2013 (Source private communication with Gridco).

2.1.1Mathematical Model

The model proposedby Darling *et al*[2]is adopted with our additional constraints. Mathematically, the LCOE is represented as;

$$LCOE = \frac{PCI - \sum_{n=1}^{N} \frac{DEP+INT}{(1+DR)^n} TR + \sum_{n=1}^{N} \frac{LP}{(1+DR)^n} + \eta}{\sum_{n=1}^{N} \frac{Initial\ kWh \times (1-SDR)^n}{(1+DR)^n}} \qquad (1)$$

with $\eta = \sum_{n=1}^{N} \frac{AO}{(1+DR)^n}(1-TR) - \frac{RV}{(1+DR)^n}$

where PCI is the project cost minus any investment tax credit or grant, DEP is depreciation, INT is interest paid, LP is loan payment, and TR is the tax rate where AO is the annual operations cost, DR is the discount rate, RV is the residual value, SDR is the system degradation rate, and N is the number of years the system is in operation.

This work assumes a 10 MW grid connected PV system is to be developed at each of the ten regional capitals.The locations are Accra, Koforidua,Takoradi (Sekondi-Takoradi), Kumasi, Tamale, Wa, Ho and Sunyani. Because Ghana lies close to the equator, a single tracking axis system will provide optimum results. The rest of the assumptions are displayed in table 1.

Table 1

	PV Cost Assuptions		
I	**Capacity of Project**	MW	10
	Average Insolation in year	(> 2500 sunshine hours)	5.4
	Output per year per MW Installed Capacity	MWH	1971
	Increase in output with tilt	15%	2267
	System Efficiency to Grid		87.50%
	Degradation Factor for Panels		0.75%
	Project Cost per MW		
II	(including tilt)	$ mil / MW	1.75
	Total Direct Project Cost	$ mil	17.5
	Corporate, Consulting & Op Expense-Construct period	2 years	3.00
	Contingency as % of Project Cost	5%	0.88
	Total Project Cost	$ mil	21.38
	Working Capital	$ mil	**1.09**
	Total Capital Required	$ mil	**22.47**
III	**Financing**		
	Debt	**90.00%**	**20.22**
	Equity	**10.00%**	**2.25**
	Interest on Bank Borrowings		6.00%
	Loan Repayment		
	Grace Period for principle & Interest	Years	1
	(No accrued interest capitalization during construction)		
	Repayment from COD	Years	14
	Project Life	years	25

2.2 Major LCOE Inputs

Our model for FDI indicates that the total upfront cost of a solar PV power plant can be split into several major components [18]. These costs are dependent on a variety of parameters, as discussed next.

2.2.1Plant cost

There are a variety of ways to talk about plant cost. The first step is to determine the type of technology suitable for ones needs. The conventional flat PV modules are preferred in developing countries as opposed to the new technology Concentrated Photovoltaicsbecause of the reliable history flat PV'shave generated. In general, there are 3 types of flat panel PV modules on the market: monocrystalline, polycrystalline, and thin filmpanels. Polycrystalline has been found to be more suited for temperatures above 25°C [19].PV module costs represent 40-60% of total PV system costs, and installation costs account for the remaining costs [18]. Hence the PV module cost displayed in table 1 is reasonable [20].The equipment cost reflects the cost of modules, inverters and balance of system (BOS).The BOS refers to all the components that make up the grid-tied PV system except the PV panels and the inverter, it includes the wiring, protection devices, enclosures, disconnects, installation equipment and power metering devices.

2.2.2*Annual Costs*

In the LCOE calculation the present value of the annual system operating and maintenance costs is added to the total life cycle cost. These costs include inverter maintenance, panel cleaning, site monitoring, insurance, land leases, financial reporting, general overhead and field repairs, among other items.

2.2.3*System Residual Value*

The present value of the end of life asset value is deducted from the total life cycle cost in the LCOE calculation. Silicon solar panels carry performance warranties for 25 years and have a useful life that is significantly longer. Therefore if a project is financed for a 10- or 15-year term the project residual value can be significant [21].

2.2.4 *System Energy Production*

The value of the electricity produced over the total life cycle of the system is calculated by determining the annualproduction over the life of the production which is then discounted based on a derived discount rate.

3.0 PROJECT CONSTRAINTS

The project constrains considered included: (i)Thesolar insolation (geographic location) and ambient conditions which defines the most attractive design. (ii) The capacity factor is an index of the efficiency of the plant's output (iii) High capital cost (iv) Technical constraints.

3.1Solar Insolation

In other to determine the location of a PV plant, it is of prime importance to have an idea of the local weather and specifically the average annual daily solar radiation ($kWh/m^2/day$), as it is a good indicator of the long-term performance and economics of solar energy systems at that location [22].

To this effect data of the seasonal variation in horizontal solar radiation were obtained from NASA online database [22] and Avior Energy Inc. Technical reports [20]. A plot of the solar irradiance for each of the capital cities is displayed in Fig. 2. These provide a rough indication of the solar resource available in the area in units of$kWh/m^2/day$ of insolation. It means that on a sunny day with the sun high in the sky, the insolation at the earth's surface is roughly $1kW/m^2$ (1-sun). Therefore if, the average insolation is 5.4 kWh/m^2it is equivalent to 1 $kW/m^2$for 5.4 hours of full sun.

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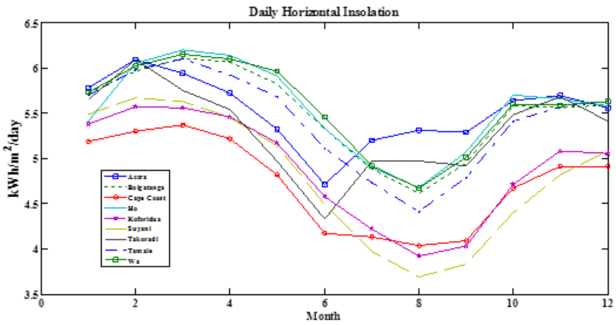

Figure 2: Average solar activity for Accra, Ghana [20, 22].

It can be seen from Fig. 2, that the average insolation of Ghana lies between 3.5 -6.4 kWh/m^2. The average solar insolation for the different cities (Fig. 2) displays a seasonal variation consistent with the rainfall pattern in Ghana. Generally the rainy season which occurs from the 5th – 8th month has more cloud cover and hence a lower insolation levels for all the cities. Clear days especially in the dry season with little overcast occurring in the 2nd- 4th month have higher insolation levels. Comparing the insolation at Wa with that of Cape Coast, we observed that the profile of Wa is about 15% higher than that of Cape Coast (Fig. 2). Hence in the average, aWalocation will give a PV output of 15% more output than an identical PV system situated in Cape Coast.

3.2System Capacity Factor

The capacity factor which is a key driver of a solar project's economics is dependent on the solar irradiation. With the majority of the expense of a PV powerplant being fixed, capital cost LCOE is strongly correlated to the power plant's utilization (capacity factor). In this work we extend the concept developed by Wajid*et al*[18] to evaluate the capacity. The capacity factor of a solar PV module is a function of the solar irradiance of the geographic location, and the performance of the PV panel among other factors.Mathematically the capacity factor is evaluated as follows,

$$CF_i^{PV} = \frac{\sum_m (Po_{i,m}^{PV} \eta_{d,m})}{P_r^{PV} \sum_m \eta_m} \qquad (2)$$

where,$\eta_{d,m}$ the energy produced is based on the number of daylight hours, $Po_{i,m}^{PV}$ is the PV output and P_r^{PV} is the rating of the PV module.

Using the above equation the capacity factor for the different regional capitals is calculated and displayedin Fig.3. It is worth mentioning that we were conservative in our calculations and we assumedthe worst case scenario for each case displayed in Fig. 3.

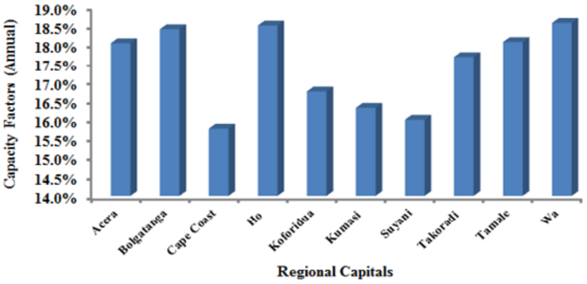

Figure 3: Solar capacity factors for the capitals in Ghana's ten regions.

The LCOE can be simplified to

$$LCOE\left(\frac{\$}{kwh}\right) = \frac{[Annual\ Fixed\ cost\ + Variable\ cost)(\frac{\$}{kW})}{24 * 365 * CF} \qquad (3)$$

To illustrate the impact of the CF, the LCOE is evaluatedassuming the same conditionsand panels except for a change in CF due to solar irradiance. The result is displayed in Fig 4.

TheWa site provides the most economically attractive returns, while Cape Coast provides the least returns. For the sake of brevity, all other factors were considered equal for all the regions with the exception of the CF.

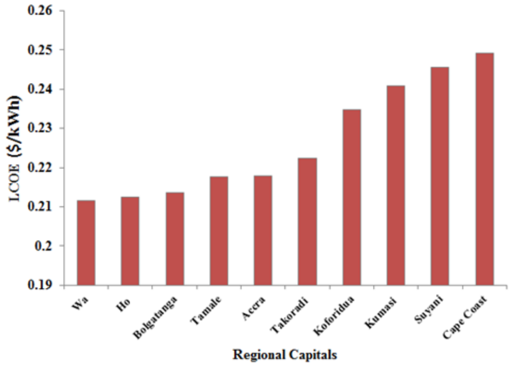

Figure 4: LCOE for the different regional capitals. The LCOE increases with decreasing CF.

3.1

3.3Capital Cost

There are various ways to optimize the capital cost.However because PV modules cost about 65% of the total capital cost hence an accurate forecast of the performance of the panels is crucial to project investors (Short *et al*, 1995). Hence for our analysis,the focus is on ways we can minimize PV panel cost.

First, capital cost can be reduced by minimizing the cost of the PV modules. PV modules are made up of interconnected PV cells and encapsulated to form modules. The PV module is protected further by covering the surface with tempered glass. The cost of shipping modules by sea is about $0.05–$0.06/W [9, 24] adding 5%–10% to module costs. As module costs decrease, shipping costs for some types of module manufacturing could become a more significant factor and may lead to disaggregated manufacturing models, with separate cell manufacturing and module assembly facilities, for example. Many PV components—including polysilicon, wafers, and cells—can be shipped cheaply due to their low weight and volume and high value. In fact, cells can often be shipped by air to module manufacturing facilities. The glass cover of c-Si modules adds the most to shipping costs, because glass is dense and tends to fill a shipping container based on weight rather than volume. Lower- efficiency modules have more glass per watt—and thus cost more to ship—per unit of power. The key to reducing these charges is to ship the cells separately into the country, fabricate the glass locally and assembly the unit locally.

Second, temperature plays an important role, PV modules are rated (power, voltage, and current) at a standard test condition (STC) temperature of 25°C (77°F). The effect of temperature on the PV module cannot be overstated, since crystalline silicon PV modules respond to the widely varying environmental conditions addressed above. From a performance perspective (needed to calculate the output of the PV system), the electrical output is directly proportional to the irradiance and has an inverse relationship with the module operating temperature. However, as themodule temperature increases above the 25°C level, the module power output will drop about 0.5 percent per degree C increase in temperature [26]. Hence meteorological records must be accessed to predict the temperature variation of the location.

Finally the PV modules cost about 65% of the total capital cost hence an accurate forecast of the performance of the panels is crucial to project investors. To be able to forecast accurately, the panel efficiency and an accurate quantification of power decline over time, also known as degradation rate is essential to all stakeholders. Financially, degradation of a PV module or system is equally important, because a higher degradation rate translates directly into less power produced and, therefore, reduces future cash flows [23]. Furthermore, inaccuracies in determined degradation rates lead directly to increased financial risk [23].PV systems are often financed based on an assumed of 0.5 to 1.0% per year degradation rate although 1% per year is used based on warranties [25].

3.4Interest Rates

Large scale PV projects require a considerable size of investment. Such finance can be provided by commercial bank loans or equipment finance from a global PV companies. For large scale utility projects involving PPA, the LCOE can be considered as revenue per unit of electricity generated that is required to recover costs, meet targets, cover debts and account for incentive payment. This required revenue can be considered as the LCOE [26].

Interest rate plays a substantial part which is the foremost in seeking finance for any project.In our calculation to verify the impact of interest rate on the LCOE, the following assumptions were made: (i) the life time of the solar farm was tied to the length of the PPA which is 20 years [16]. The discount rate in was assumed to be constant at 6% [2,27]. Fig. 5 shows how sensitive the LCOE is to interest rates. For each loan interest, at a debt fraction of 90% was assumed.

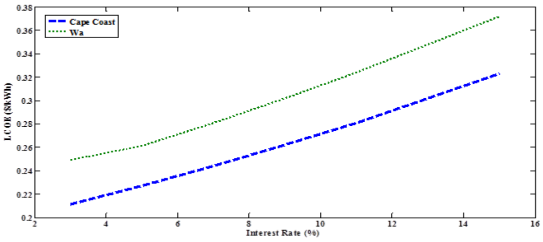

Figure 5: Interest Rate as a function of LCOE

The results are displayed in Fig 5 clearly shows that LCOE increases as interest rate increases andthat LCOE is heavily dependent on interest rate. Secondly Fig. 5 illustrates that the LCOE for different CF varies with interest, bycomparing the LCOE in $/kWh for identical PV systems installed in Cape Coast withidentical systems installed in Waas a function of the interest rate. To highlight the impact of interest component on LCOE, the models assumed that all other cost remain the same. Clearly the LCOE for the low CF (Cape Coast) is much higher than that of the relatively higher CF (Wa).

3.5Bankability

Bankability refers to whether the projects using the solar products are likely to be offered non-recourse debt financing by banks. Banks and independent ratingagencies use formal and informal ways to assess the credit risk of a project.Projects have to meet minimum criteria in order to bankable through commercialdebt; at least a BB or Ba grade is required to attract commercial debt [28]. Lower credit rating implies higher interest rates. Moody's Investors Service provides international financial research on bonds issued by commercial and government entities and, with Standard & Poor's and Fitch Group, is considered one of the Big Three credit rating agencies.

Unfortunately Moody’s has lowered Ghana’s B1 sovereign rating from stable to negative, the agency announced December 5, 2013 [29]. This implies that financing from a commercial bank for a solar project in Ghana will inquire higher interest rate, to obtain lower interest rates,equipment finance from large scale PV manufactures should be negotiated [20].

The bankability of a project is not only predicated on the pragmatics of systems capacity factors and technical constraints, but also on the viability of obtaining a bankable PPA.This includes negotiating payment currencies and frequencies, bank guarantees and comfort letters, price escalators and aterm duration sufficient enough to recoup the capital investment and earn a profit from the project. Consequently, PV projects require not just a solid financial plan and technical expertise, but also a legal team that is familiar with PPA clauses and negotiations. A small omission as not negotiating a price escalator that is greater than the rate of inflation could render the PPA un-bankable, and unable to attract FDIs.

3.6 Technical Constraints

These constraints deal with the actual construction and output of the PV farm. More often than not, a solar PV project can be made more economical by combining excellent components of various types of technologies and brands, for example, the PV panels are bought from a manufacturer other than the one supplying the inverter, checking the performance of the various types of technology can be extremely daunting. To maximize the output, there is a need for a universal algorithm that monitors performance of the entire site and can also detect a drop in performance of a specific unit of the site [30].

Other constraints include the degradation of the optical performance of the PV panels due to the accumulation of dirt on the PV panels especially in the dry season. Cleaning panels represents a considerable expense in manpower and water, usually a scarce resource in the dry season. Currently there is no record of any efficient automatic panel cleaning device. Developing of such a device will minimize the use of water and potentially decrease the expense of manpower.

Futhermore degradation also contributes to module mismatch over time which adversely impacts power plant performance.

3.7 Transmission Constraints

Illiceto*et al*reported that within the period of 1996- 1998 the 161 KV lines underwent an average of 2.1 outages per 100 Km per year due to lightening and transient faults [31]. Although GRIDco reports that the occurrence of power outages on the power lines is significantly lower, there are no existing records available to us to suggest otherwise. Besides there are no clear guidelines in the renewable energy Act as to who is responsible to pay for the power of renewable energy without storage in the case of such an outage. Furthermore there is no grid code for renewable energy. This lack of uniformity will be an impediment to integrating renewable energy on the grid.

Currently in Ghana there is an on-going project to replace all the 161kV lines with 330kV as the country's primary transmission backbone will be 330 kV, which will provide significant reinforcement and increased power transfer capability from generators to load centres. Although this is a step in the right direction, conventional power systems have addressed the uncertainty of load demand by controlling supply. With renewable energy sources, however, uncertainty and intermittency on the supply side must also be managed. The *smart grid*—an evolution of electricity networks toward greater reliance on communications, computation, and control—promises a solution.

4.0 DISCUSSIONS

As mentioned earlier, grid parity is considered pivotal for the cost effectiveness of solarPV, and entails reducing the cost of solar PV electricity to be competitive with conventionalgrid-supplied electricity. For parity, the total cost to consumers of PV electricity is compared toretail grid electricity prices. Although the LCOE is not the same as retail electrical prices, it isused as a proxy for the total price to be paid by consumers, adding in as many of the realisticcosts as possible. The LCOE methodology is then used to back calculate what the requiredsystem and finance costs need to be to attain grid parity.

In Ghana, electricity prices range from \$0.09/kWh - \$0.22/kWh in major cities for residential and commercial load[16] so using that as a proxy for grid parity, with the addition of incentives like carbon credit and government tax credits, the LCOE for solar in Ghana is attractive.

Any the positive aspects of PV far outweigh any negative potential, however, the potential destruction of farms, and forest land for PV's should be considered carefully.

5.0 CONCLUSIONS

A number of measures from the developing point of view was discussed that can reduce the LCOE. By the methodology adopted, site, CF and capital cost can reduce the LCOE, and make the project viable.

Ghana's' solar resource is vast, accessible, and can be synchronous with energy demand. While the resource differ from one region to the other, with proper planninga suitable site can be accessed. The main factor limiting utilization of the Ghana's solar resource at a large scale today is its cost and bankability of the PPA.

Secondly if the residents of the country pay less than the tariff as it used to be in the case(electricity bill was \$0.05/kWh,while solar tariffs were \$0.24/kWh [20]), it drives FDI's away because the process appears to be unsustainable. However with the recent increase in tariffs (domestic users are currently at ranging from \$0.09/kWh whilst heavy industrial users like the mines are at \$ 0.22/kWh) makes theprogram sustainable (albeit the FIT is now \$0.20/kWh).

The poor credit rating of the Government of Ghana (although ECG is the off taker) negatively impacts lending interest rates from commercial banks for developing solar PV's in Ghana, it is therefore suggested that project developers should seek equipment finance from venture and manufacturing companies to reduce interest rates. Finally, for brevity the cost of land was assumed to be the same for all regional capitals, which is not the case and that should be factored in any working model.

The final conclusion is that the frame work and technology that currently exist is sufficient and cost effective to attract FDI, when the right modalities are considered.

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