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Original article

Economic assessment of a-Si and CIS thin film solar PV technologies in Ghana

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ABSTRACT

Thin film solar photovoltaic technologies contribute significantly to PV installations annually. Although thin films have lost market share in recent years, they have nonetheless grown at a robust rate of 24% between 2004 and 2014. Advantages such as lower cost per watt, ease of manufacturing, lower materials consumption among others continue to interest installers and developers. In this paper, we use performance and financial data from two 4 kWp thin film technologies – Amorphous Silicon (a-Si) and Copper Indium disulfide (CIS) – installed at the Kwame Nkrumah University of Science and Technology Kumasi Ghana to conduct a comparative techno-economic analysis. The cost and performance of a-Si results in a LCOE of €0.28/kWh compared with €0.41/kWh obtained for CIS. At installed cost of €3601.95/kW and €3576.25/kW for a-Si and CIS respectively, both technologies, however, do not compare favourably with existing tariffs on grid-based electricity for the non-residential sector – which pays the highest tariffs. Investment support of 63% and 44% would be required for CIS and a-Si respectively to be competitive with grid for the commercial sector.

Introduction

Thin film photovoltaic (PV) cell technologies, though have generally lower solar-to-electric conversion efficiencies, have a number advantages compared to crystalline silicon counterparts. These advantages include: lower cost per watt, relatively low consumption of raw materials, high automation and production efficiency, ease of building integration, good performance at high ambient temperature, and reduced sensitivity to overheating [1]. Thin-film technologies have lost market share since 2009 [2,3] contrary to earlier projections [1,4]. In absolute terms, however, the volume of annual installations have increased from 1.19 GW in 2004 to 3.51 GW in 2014 as shown in Table 1 and will continue to play an important role in electricity generation as the technologies continue to evolve and improve. Although not as rapidly as the crystalline silicon technologies, thin films have seen a growth of about 195% compared to 2009 level and grown at 24% per annum on average.

Various researchers and organizations have reported cost of solar PV electricity over the years [3,5–9]. A popular metric for assessing the cost of Solar PV is the Levelized Cost of Electricity (LCOE), which represents the total lifecycle cost of producing a unit of electricity. LCOE has the benefit of enabling comparison of the cost of electricity among different technologies. The LCOE of Solar PV is sensitive to geographical location (which determines amount of solar radiation available), type of PV cell technology deployed (solar-to-electric conversion efficiency and response to environmental conditions such as temperature, humidity and dust), installation cost, discount rate, cost of operation and maintenance, economic life, financing structure (debt/equity), etc. The installation cost in particular, and allied parameters that are used in the determination of LCOE are also affected by the scale of projects under consideration. Megawatt scale projects are likely, as a result of economies of scale, to have lower specific cost ($/kW) than small roof-top installations.

The LCOEs and related parameters reported from some PV installations in Africa and elsewhere are presented in Table 2. As shown in this table, LCOEs of solar PV installations have been reported from various parts of the world but very few have been reported specifically on operational systems installed in Africa. Branker et al. [10] in 2011 conducted a review of LCOEs reported in the open literature and analyzed various influencing parameters. Several organizations provide on a continuing basis, information

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Table 1
Thin film market evolution.

Year	Total global installation, GW (capacity added)	Thin film installed, GW (capacity added)	Thin film share
2009	7	1.19	17%
2014	39	3.50	19%

Data: [2,9].

on the rapidly-evolving cost of renewable energy across the world [3,6–9]. Largely as a result of data availability limitations and the generally under-developed renewable energy market in Africa, information on the performance and cost of PV systems installed in Africa tend to be scant or sometimes classified under the label "RoW – Rest of World". Furthermore, several reported figures on LCOE are based on pre-installation (or feasibility) assessments and assumptions. However, actual performance in real-life installations of these projects during operation tends to vary significantly from the simulated ones.

In this paper we use actual technical performance based on field measurement data and cost data to compare the economic performance of two grid-tied thin film PV technologies. These thin film PV technologies are Copper Indium disulfide (CIS) and amorphous silicon (a-Si), which are installed at the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi Ghana. Kumasi has a hot-humid climate and is located at latitude 6.67° N, longitude 1.6° W and 287 m above sea level. The econometric indices used in this analysis are LCOE, Net Present Value (NPV) and Internal Rate of Return (IRR). Considering continuously falling prices of PV modules, with a learning rate of 20% [2,11], we examine the effect of declining cost of installation combined with improved technology on these financial indices. It is hoped that this paper will shed more light on the performance of CIS and a-Si technologies in the hot-humid climate of Kumasi and assist home owners and policy makers with concrete data when considering technology options for similar climate zones.

Method and calculations

Technical data

The PV systems under study were commissioned in March of 2012 as part of a larger experimental installation at the College of Engineering at KNUST. The thin film technologies comprise 40 units of 100 W_p amorphous silicon (a-Si) modules from Schott Solar and, 81 units of 50 W_p CIS modules from SulfurCell. The a-Si modules are configured in 4 parallel strings of 10 modules each (4×10) while the CIS modules are configured in 9 parallel strings of 9 modules each (9×9). The unshaded modules of each systems were mounted on an inclined building rooftop with tilt angle of 5° orientated toward the equator ('south'). The technical characteristics of the PV technologies are presented in Table 3. Fig. 1 shows a picture of the installations.

The a-Si and CIS are individually and separately connected to the grid via 4 kW SMA Sunny Boy SB3800 central inverters with specifications shown in Table 4. Data logging is accomplished with a Sunny Webbox and is programmed to log data every 5 min. Data recorded by the Webbox include: current and voltage (both AC and DC), average power within the 5-min period and energy (kWh) exported to grid and module temperature, as well as other environmental parameters. The analysis in this paper is based on year 2014 recorded data.

Power outage correction and degradation

The system is connected to the grid and automatically disconnects when there is power outage and therefore, no energy production occurs during such times. We account for gaps in energy production by assuming that energy generated during normal operation hours is proportional to the electricity that would have been generated during the period when the system was down. By virtue of its location around the equator, Kumasi experiences approximately 12 daylight hours all year round. Daily energy lost due to grid downtimes are therefore compared to a 12-h duration. Based on these assumptions, the system energy output during a given period (say a day) is then corrected as [28]:

$$E_{AC,est} = E_{AC,mea} * \left(\frac{T_{\max}}{T_{\max} - T_{mis\sin g}}\right) \quad (1)$$

where $E_{AC,est}$ is the corrected electricity output, $E_{AC,mea}$ is the measured electricity output, $T_{\max}$ is total available time (in minutes) and $T_{mis\sin g}$ is total missing time (in minutes) within the measurement period. The monthly proportion of grid outage time at site of these installations is presented in Table 5.

In addition to the downtime production losses, Solar PV modules experience decline in output with age of exposure. An extensive review by Jordan and Kurtz [12] of published degradation rates established a module-level median degradation rate of 0.87–0.96% for thin film technologies. In this paper we use 1%/year degradation rate for both a-Si and CIS for a 25 year life.

Table 2
Some reported LCOEs of PV projects in Africa and elsewhere.

Author/Reference	Specific cost per kW	Module technology	Location	Capacity (kW)	LCOE (xx/kWh)	Year installed
ECREEE [20]	$3990	Poly-Si	Ghana	2500	$0.2413	2012
Schmidt et al. [21]	–	–	Egypt	–	$0.199	2010
Schmidt et al. [21]	–	–	Kenya	–	$0.222	2010
EMIS 2015 [22]	$735–4310	–	South Africa	Various	$0.07–0.13	2011–2014
Meyer Burger Technology Ltd [23]	$2190	Mono-Si	Arabia, Central Africa	1000	$0.067	2014
Fuentealba et al. [17]	€2433.40	a-Si	Atacama desert, Chile	3.36	€0.1448	2012
Fuentealba et al. [17]	€2371.33	Poly-Si	Atacama desert, Chile	3.33	€0.1565	2012
Bianchini et al. [18]	€2000.00	a-Si	Forli, Italy	1.44	€ 0.133	2013
Bianchini et al. [18]	€2000.00	Poly-Si	Forli, Italy	2.16	€ 0.135	2013
Bianchini et al. [18]	€2700.00	CdTe	Forli, Italy	2.31	€ 0.174	2013
Fraunhofer ISE [6]	€1000–1800	Various	Germany	Various	€0.078–0.142	2013
IRENA 2012 [8]	$1300–5 400	Various	Global	Various	$0.08 – 0.4	2014
IEA 2015 [7]	$1867–3366	Various	Global	Various	$0.096–0.374	2014
REN21 [9]	$2150–7000	Various	Global	Various	$0.16–0.55	2014
Bloomberg 2014 [5]	–	Thin film	USA	–	$0.09–0.33	2014
World Energy Council [24]	–	Thin film	Various	–	$0.11–0.31	2013