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Technical and socio-economic assessment for a Si-based low-cost solar cells factory in West Africa

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ABSTRACT

As the cost of silicon-based solar cells has been decreasing sharply in recent years, photovoltaic (PV) systems have dramatically increased their attractiveness in many countries and in mall power systems. This increase of attractiveness can be objectively described in terms of grid parity reached in many areas around the world and a substantial improvement for accessing to electricity without subsidies in places where the power supply is intermittent or, simply, is not offered. One of such places around the world where power supply is limited is West Africa. On the other hand, as the PV industry is maturing and the production capacity is increasing, it is expected that PV companies will place new factories close to markets in highly solar irradiated developing countries, where the demand will grow in the near future. In this work a technical and socio-economic assessment of silicon-based low-cost solar cells produced in a manufacturing factory located in West Africa is exposed. The cost of the solar cells, in terms of USD/W_p is obtained for different West African countries and compared to the production costs of a similar factory operating in China but exporting the cells to West Africa. A sensitive analysis of the final cost of the solar cells varying the cost of key input parameters (mainly labor, electricity, silicon contract price, investment and logistic costs) into a defined range is also exposed. The cost of the solar cells produced is integrated with other sensitive parameters for business competitiveness in a synthetic indicator which offers a ranking of the ten more favorable countries for the location of this PV factory.

1. Introduction

Over the past decade, the photovoltaic (PV) market has experienced a 55.7% global average annual growth rate, from 331 MW in 2001 to 27.7 GW in 2011, and a 67.4 GW cumulative installed production capacity worldwide in 2011 [1,2]. On the other hand, grid parity may have been reached in certain countries [3,4], as the average price of installed PV grid-connected systems in 2010 declined to USD 3700/kW_p [3,5]. Along 2011 the reduction of the PV systems price has continued, and further fallings are observed in 2012 [5,6]. The electricity price for households of OECD countries oscillated between USD 0.0886 and 0.409/kWh in 2011 [7]. Considering the average PV system prices exposed above, the PV electricity generation cost can be considered at about USD 0.129–0.386/kWh for 2400–800 kWh annual solar irradiation, respectively [4]. Consequently, grid parity may have been reached in many OECD countries. Moreover, PV electricity can be already competitive without subsidies during peak power demands in countries where grid parity is close to be reached, as these peaks are typically produced at midday, when maxima solar irradiation is obtained and intra-day electricity costs in this period are high [7].

On the other hand, the PV market is mainly based on crystalline silicon (c-Si), and this scenario is likely to continue in the medium-term as c-Si has a huge potential for further cost reductions, and technology innovations continue to be implemented [8]. Accordingly, estimates show a 30–32 GW global Si module production capacity and a 3.5 GW thin film module production capacity in 2010 [7].

The introduction of silicon-based PV systems in many developing countries is favored by intermittencies and lack of quality for

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electricity supply in urban areas, along with the absence of power grids in rural areas. Alternatively, production of electricity via isolated diesel generation has an average cost of USD 0.299/kWh (considering USD 0.754/l and 0.397 l/kWh) [9], higher than the cost of electricity from the PV systems in medium and highly solar irradiated areas.

In addition, as the PV technology is maturing and PV system costs are decreasing, the demand of these systems in developing countries is growing. Consequently, as a significant percentage of the investment cost needed to set up a PV plant is made in these countries (typically grid connection, engineering, mounting and financing), the advantages for producing PV cells and modules close to these countries are growing.

In this work we consider different locations in West Africa to install a Si-based low-cost solar cells manufacturing factory and discuss the viability in terms of technical and socio-economic factors. West Africa combines very high global irradiation areas in the range of 1500–2400 kWh/m^2 [10] (USD 0.207–0.129/kWh in terms of PV electricity costs exposed above), highly populated urban areas where usual power intermittencies are detected and also a lack of power grids in many rural areas. Consequently, this study can be very helpful to define a methodology for PV manufacturing companies to manage their expansion in this region. Furthermore, the increase in GDP at current prices in USD [11] shown by the countries situated in this area (11.7% annual average in 2003–2010) and the expected increase in GDP in the future (9.0% annual average in 2010–2016), above the world forecasts (7.7% annual average in 2010–2016), can enable a strong and maintained growth for PV systems demand in this area.

2. Methodology

The estimated cost of a standard PV system can be decomposed into a sum of three parts: production of the PV module (57.5%), acquisition of the power electronics (7.3%) and the costs related to the emplacement of these systems in the final location (35.2%) (Table 1) [12]. Values given are for large projects and can be approximated as applicable for both developed and developing countries, as in a globalized market same prices can be searched and obtained by means of information technologies. On the other hand, local low labor costs can be balanced by other high local costs. For small projects, these values can vary substantially as they are highly dependent on the distributor original prices and margins. In general, we can determine that the most labor intensive processes for producing PV modules are the solar cell manufacturing and the module stringing and framing. There is not actual need for specialized work-force for the jobs related to these activities, being the training given by the machine supplier enough in most of the cases to maintain the manufacturing line on production. Additionally, the costs associated to the connection, engineering, mounting and O & M are mainly produced in the final location of the PV systems.

The current trend in the PV industry is to vertically integrate in a single location all steps associated to the production of a PV module value chain, offering a slight manufacturing cost reduction and improving supply security compared to the combined processing in different locations [1]. However, other factors as labor costs, investment, basic infrastructure, supplies, access to market, and environmental impact, could counterbalance the advantages of the production integration in a defined location. Furthermore, the production sites close to distribution centers allow to customize products with lower costs, an aspect needed in most of the building integrated PV.

In order to show the ranking of the countries where the factory is best placed, we have selected the essential cost-parameters for manufacturing PV cells (mainly labor, electricity, silicon, investment and logistic costs) and considered a range of values for each cost-parameter in accordance with international trading markets and local conditions. Also, we include in our analysis the alternative of producing solar cells in China and shipping them to West Africa.

Consequently, the main parameters and ranges for our sensitive analysis have been:

i) silicon contract prices, considering the evolution in the past (Fig. 1) and the forecasts exposed in different works and forums (forecasts influenced by current overcapacity and narrowing of benefit margins in this maturing sector) [6,13–16]: USD 20–80/kg Si;
ii) amount of silicon used per solar cell and the average efficiency associated to it [17]: 3.9 g/W$_p$ and 18% eff. to 6.5 g/W$_p$ and 15.5% eff.;
iii) total average labor costs per worker for the different countries analyzed [18,19]: USD 220–3265/month;
iv) electricity price range, defined by the minimum and maximum prices for the industrial sector in the OECD countries in 2011 [7]: USD 0.0695 (USA)–0.2793/kWh (Italy);
v) shipping costs evolution, considering a 70% maximum percentage increase in diesel fuel cost in nominal terms in the

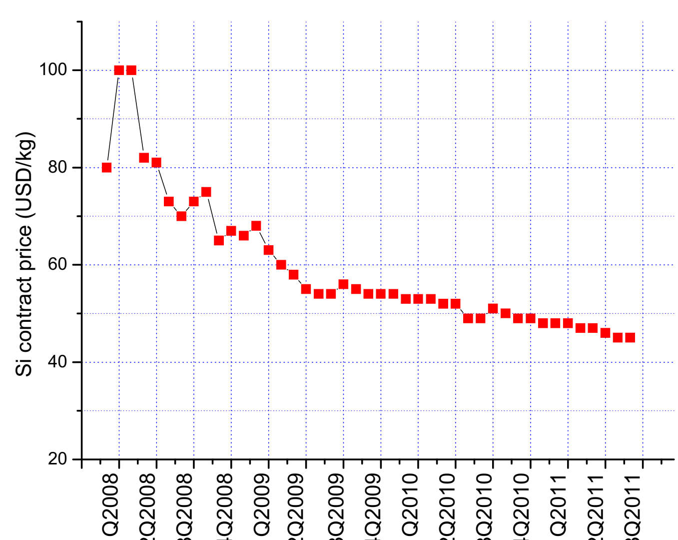

Fig. 1. Evolution of the Si contract price from February 2008 to August 2011 in terms of USD/kg Si [10].

Table 1
Decomposed cost of a standard PV system considering the different steps related to production, power electronics and location.

		Costs (%)
PV module	Silicon	12.7
	Wafering	9.8
	Cell manufacturing	13.3
	Module lamination	12.7
	Framing and sorting	9.0
Power electronics	Inverter	7.3
Emplacement	Connections	7.3
	Engineering, mounting and financing	20.6
	O & M	7.3
Total		100.0