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Concentrated Solar Power (CSP) and Photovoltaic (PV): Has time come for solar energy in Africa?

Jennifer Mbabazi Moyo | Ralf Krüger | Driss Belamine | Anna von Wachenfelt

Jennifer Mbabazi Moyo, International Monetary Fund
Corresponding author : **jmoyo@imf.org**

Ralf Krüger, International Training Centre of the International Labour Organization, Italy

Driss Belamine, African Development Bank, Côte d'Ivoire

Anna von Wachenfelt, African Development Bank, Côte d'Ivoire

Abstract

As Africa's energy supply needs to be stepped up urgently to satisfy the continents' growing energy needs and avoid some of the serious economic and social costs of the deficiency, renewable energy technologies have emerged as additional alternatives to build the relevant energy infrastructure while aligning Africa's growth with the Sustainable Development Goals (SDGs). They currently carry a substantial economic cost, and technological choices in the sector are long-term and have important implications. The share of modern renewables (i.e. solar, wind and geothermal) in Africa's energy mix currently stands at only 0.4% but is increasing. Solar technologies have some very positive characteristics, but are not yet competitive in all circumstances.

…/…

Keywords: Solar power; PV; CSP; Renewable energy; Africa

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…/… Nevertheless, financing for these technologies is increasingly available and production costs are coming down. Depending on a specific country's situation, PV and CSP are valuable contributions to the energy mix, with CSP recommendable for more economically advanced countries given its considerably higher cost. African countries should consider well whether to engage in such expensive technology at this point in time given the expected cost-reductions in the medium to long term. PV, on the other hand is already cost-competitive and holds much promise for Africa. While the importance of off-grid PV systems is well-recognized, the discussion in this paper focuses on grid-connected systems that have experienced the greatest expansion. It will be imperative for African countries to develop a conducive environment so as to support the growth of the appropriate kind of solar energy in Africa.

1. Introduction

Africa's energy sector has much room for improvement. It was estimated that only 42% of Africans had access to reliable energy in 2013, up from 38% in 2005, and with over 620 million people living without an electricity connection. In fact in rural areas electrification rates can be as low as 10%. Average electricity consumption is also lagging far behind other developing regions, standing at 690 kWh/year often due to insufficient production capacities, but also inefficiencies and waste in the distribution and transmission networks (AfDB, 2015).

The economic and social costs of this energy deficit are enormous, deterring private sector investment and harming human health and the environment. The opportunity cost of outage and load shedding, leading to expensive emergency energy generation (using diesel generators), is estimated at 2% of GDP on average in Africa, while 70% of businesses cite unreliable power as a major constraint for African business (AfDB, 2015). The use of traditional fuels also carries high health and environmental costs.

The continent, however, boasts of significant renewable energy potential which could be further harnessed. Africa's significant share of the world's renewable energy potential presents an opportunity to leapfrog over carbon-intensive technologies in response to the pressures of climate change and the need for sustainability. It is estimated that Africa's renewable potential (comprising hydropower, bio-energy, geothermal, solar and wind) could, if well-harnessed, be expected to account for 40% of total energy generation in Africa within 20 years (AfDB, 2015). This paper will examine the practical feasibility of such an assertion, especially regarding solar energy, as it assess the cost-effectiveness of solar energy, an area in which not much work has been done owing to its only recent popularity.

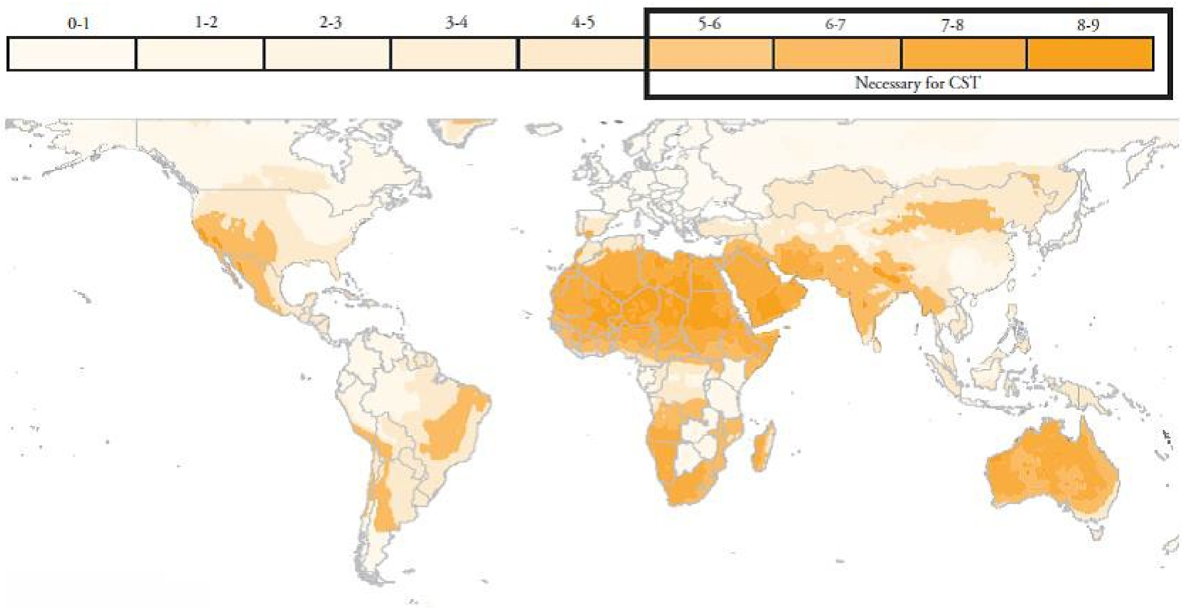
2. Problem identification and basic principle

Today, Africa remains dependent on fossil fuels, primarily oil, coal and natural gas for the majority of its energy needs with a limited but growing share of modern renewables. Modern renewables (solar, wind and thermal energy) account for only 0.4% of total African primary energy which is considerably below the estimated 12 % of global energy consumption generated from green sources. Within Africa as a whole, by 2040, Africa's energy production from renewable sources is projected to increase to 40% (Africa Report, 2015).

Nonetheless there has been growth in renewable energy consumption in Africa, albeit from a very low base. The growth in renewables in Africa has been largely driven by the growth in wind energy consumption, solar energy consumption was mainly flat from 2000-2008 and has since then seen a slow take-off, largely driven by the growth in consumption in Algeria accounting for 50% of total consumption (BP Statistical Review, 2014).

Significant efforts have been dedicated to tackle the energy deficit in Africa and these have featured prominently at international level and also within the priorities of the African Development Bank (AfDB). The AfDB has more recently been processing an increasing number of renewable energy projects, from one project per year in 2009 and 2010 to nine projects per year in 2013 and 2014 thereby capitalizing on Africa's radiation potential. Africa's huge solar energy potential is shown in figure 1 below. Indeed, it is estimated that many African countries receive an average of 325 days of sunlight per year (Africa Report, 2015).

Fig. 1: Africa has a clear advantage in solar based on its irradiation potential (Global Direct Normal Solar Radiation (kW/m²/day))



Source: Childs Staley, B., J. Goodward, C. Rigdon, and A. MacBride. 2009.

The Bank has mainly considered PV projects but in the very recent past, concentrated solar power (CSP) options have also become available and considered. The assessment of one such project led to the production of this paper as a contribution to the debate about which renewable energy solutions may be most appropriate for the continent at this time. In particular the question on whether a technology like CSP, which is considered to be an "expensive" one, is an appropriate answer to the energy challenge in African countries.

3. Solar PV and CSP: What are we talking about?

a. Solar Photovoltaic (PV)

PV systems come in different forms but generally consist of two main components. First, a solar module which converts sunlight to electricity and accounts for the largest share of the PV system cost (about 35-55% of total system cost) and second, the balance of system (BoS), such as wiring, inverters, mounting structures, battery (for off-grid systems) and metering (for grid-connected applications) (Ernest & Young, 2011; Parsons Brinckerhoff, 2012). There are two major types of PV modules: crystalline silicon representing approximately 85% of capacity and thin film representing 15% (Business Wire, 2011).

A major distinction of solar PV systems is whether they are off-grid or grid-connected. Off-grid systems operate independently from the grid network but still play a role in global PV markets particularly in developing countries, while grid-connected PV accounts for the major market share and explains the considerable expansion over the last decade (Candelise, 2012). While there is a recognition that off-grid applications could become more important in Africa in the future, it is an area for further research and the discussion in this paper remains focused on grid-connected systems that have experienced the greatest expansion.

Returning to on-grid solutions, Solar PV has enjoyed rapid cost declines over the past five years mainly driven by significant declines in prices of modules, largely on account of increased research and development and more market entrants. In the last few years, Chinese firms entering the market have rapidly acquired market share, and in doing so have led to over-supply, leading to negative operating margins for almost all major suppliers (NREL, 2012), thereby shifting the market to a more supply driven market (Solarbuzz, 2015).

PV is on its way to become a mainstream technology. In fact the cost of rooftop solar is approaching that of coal-fired power and over the next 20 years it is projected that over 100 million new customers worldwide will deploy solar (Africa Report, 2015). By 2050, the International Energy Agency (IEA) expects it to be a mainstream technology, producing 11% of the world's electricity in both on- and off-grid applications. It is projected that by 2020 module efficiencies will reach 20-24% for crystalline modules and 15% for thin- film.

Demand for Solar PV is growing in Africa. In 2014, South Africa became the first country on the continent to install close to 1 GW of PV (IEA, 2014). A number of large solar PV projects were commissioned during the year: the 75 MW Letsatsi solar project, and the 96 MW Jasper with capacity to supply power to up to 80,000 households (SolarReserve, 2015). Recently, it was acknowledged that the firm SunEdison won five solar projects in South Africa, to provide a combined capacity of 371 MW (Kenning, 2015). However, the interest for solar PV is not only confined to South Africa. The world's fourth largest solar facility, the 155 MW Nzema solar project is currently under construction in Ghana. With 630,000 solar PV modules, it will add 6% to Ghana's overall power generation. (Africa Progress Report 2015).

However storing PV-generated energy remains a challenge. This challenge to-date is a major drawback for PV, as with wind energy. Nonetheless, given the vast increase in capacity for these generation technologies, new storage types are increasingly under development. Although very much in the research and development phase, battery storage techniques are being investigated in Japan and gravity storage techniques similar to pumped storage are being developed in the United States.

b. Concentrated Solar Power (CSP)

Solar Thermal or Concentrated Solar Power (CSP) lags PV in terms of global installed solar power. As at the end-2014, CSP represented only 4.4% of installed solar capacity (REN21, 2015), but with an upward trend with a further 3 GW already financed and under construction (Stadelmann et al., 2014a). CSP plants use mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which typically boils water to drive a conventional steam turbine that produces electricity. Global CSP capacity increased by 60% in 2012 and 36% in 2013 with an average annual rate approaching 50% during the five-year period from the end of 2008 to the end of 2013.

There are three major types of CSP, namely parabolic trough, solar tower and linear fresnal with a fourth (solar dish) in development and only suited for smaller scale projects. A major advantage CSP (with storage) has over solar PV and wind is its thermal storage capacity using several CSP storage techniques including molten salt, concrete and ceramics. The inclusion of thermal energy storage with a CSP plant removes, to a great extent, interruptions to its production that result from the intermittency of the solar resource. Storage also enables its power to be shifted to periods of highest demand and aids system flexibility which is becoming increasingly important for grid operation. The storage capability enables it to produce power on cloudy days and at night, thereby bringing its capacity factor up to 75% for the most advanced plants, whereas CSP plants without storage operate in the 20- 40% range, which is still above solar PV efficiency. It is noted that molten salt is the most commonly used in Africa although this still faces considerable technology risk which may limit its applicability.

The cost of CSP has fallen as more capacity is installed. Firms from China have just begun to enter the market as the country itself shows interest in the technology, which could bring further cost reductions as was the case when Chinese firms entered the solar PV market. Despite these positive developments in the industry, it remains a long way behind solar PV, and continues to rely on government support as it is estimated that over 98% of the total investment in CSP to date needed some form of public support (Stadelmann et al., 2014a). As REN21's Global Status Report notes: "some experts have expressed concern that the window of opportunity for CSP is closing as solar PV prices continue to fall and utilities become more familiar with PV." There does however remain room for cost reductions given the technology's infancy. Indeed CSP could become competitive in countries such as Morocco and South Africa, if international finance institutions (IFIs) and governments together deployed 5-15 GW of CSP, which would reduce electricity production costs by around 14-44% (Climate Policy Initiative). Furthermore, a harmonized approach by multiple IFIs can speed up deployment when lending to large projects (Stadelmann et al., 2014b).

Going forward, further significant cost reductions can be expected for CSP. It is estimated that in the region of 28% to 40% of overall CSP investment costs could be reduced by 2020 on account of economies of scale resulting from increased plant capacities and improvement in manufacturing (GIZ, 2013).

Overall, the outlook for CSP is mixed with three major concerns and three advantages. First, and most important is the consideration that PV is already too far ahead in its development and cost reduction thus making it difficult for CSP to catch up and become cost-effective. Second, CSP requires large water usage if dry cooling systems are not installed, which increase the cost and may present a challenge in the context of water scarcity in Africa. The fact that it has been done in Morocco, does not diminish the challenges that water scarcity presents in the context of the CSP technology application in Africa. Third, the cost of transmission lines from remote desert regions may significantly increase the final electricity cost. To its advantage, CSP can find applications where other renewables cannot, thanks to its ability to store energy and its complementarity to conventional power production technologies. In addition, CSP's ability to generate and transfer heat makes it more efficient for desalination – an expensive and energy-intensive process – than many other sources of renewable energy (Childs Staley et al., 2009). Indeed CSP's ability to store energy remains its greatest advantage and a decisive factor in the choice between PV and CSP systems as this enhances its predictability in dispatch and allows it to support peak periods when power is most needed on the grid system (GIZ, 2013).

c. PV and CSP as hybrid technologies

Developments are underway for the addition of solar energy to conventional sources of energy. CSP's ability to generate and transfer heat makes it complementary to technologies using steam turbines such as coal and gas. Taking advantage of its relatively low costs, PV is more and more combined with the costliest power generation sources such as heavy fuel oil (HFO) and diesel plants. These costly sources of energy are in certain circumstances the only ones relevant and available, when base load power is crucially needed with no other alternatives available in a short-term period for instance. The association with PV solar power facilitates significant cost reduction by decreasing fuel consumption when solar energy is available during the day. Also, it reduces the exposure to highly variable operating costs due to fuel prices while at the same time it helps reduce the negative environmental effect of such power plants. In fact in early January 2012, Namibia's largest solar-diesel hybrid system was inaugurated in the north east of the country (Konrad-Adenauer-Stiftung, 2012).

4. Benefits of solar technology

Several factors play a key role in choosing renewable energy technology in general and solar energy in particular. This section discusses the benefits of renewable energy in general and solar technologies in particular before delving further into the production costs in the next section.[1]

Renewable energy gives little to no global warming emissions and has limited impact on the environment. This holds true for solar energy as both types of solar technology (PV and CSP) have little environmental impact with almost no greenhouse gas emissions in operation. Compared with natural gas, which emits between 0.6 and 2 pounds of carbon dioxide equivalent per kilowatt-hour (CO2E/kWh) and coal, which emits between 1.4 and 3.6 pounds of CO2E/kWh, solar emits between 0.07 to 0.2 pounds of CO2E/kWh therefore having a low emissions footprint.

Renewable energy, including solar power, provides a vast and an inexhaustible energy supply. For countries such as Namibia, where sun is an abundant commodity, solar power allows long-term price stability and independence of foreign exchange fluctuations and international markets (Konrad- Adenauer-Stiftung, 2012).

Renewable energy, particularly solar energy, can contribute to the diversification of countries' electricity generation mix. For example, the Moroccan government plans to have renewables account for 42% of its electricity generation mix by 2020 with solar, wind and hydro each representing 14%. South Africa is heavily reliant on coal power and is targeting 18,000 MW of renewable power generation capacity by 2030 and has in fact attracted the largest clean-energy investments for the first quarter of 2015, with planned investments estimated at USD 3.1 billion. (Frankfurt School-UNEP Centre, 2015).

CSP and PV can be viewed as complementary to each other. The storage capacity of CSP allows greater flexibility for utility companies, since they can meet varying peak demands and respond rapidly to demand increases. Instead of seeing CSP as a competitor to solar PV, the two technologies can work together to reinforce each other's strengths since CSP can act as a complement to solar PV power when the sun has set. By diversifying the energy mix with PV and CSP, one can reduce importation of fossil fuel and the need for foreign exchange as well as the exposure to oil price volatility (CSP Today, 2013). Furthermore, in contrast to fossil fuels, renewable energy prices are stable over time. As most costs are related to investments, solar plants tend to

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[1] This section also draws from http://www.ucsusa.org/clean_energy/our- energy-choices/renewable-energy/public-benefits-of-renewable.html#.Va- zlHli-Ul.

operate at a low cost and offer a more stable alternative to the fluctuating fossil fuel prices.

Solar systems are less prone to large-scale failure when exposed to external shocks such as extreme weather conditions as the systems are modular and spread over a large geographical area making it less likely that the entire region will be affected. Indeed in Africa, the resilience of the solar energy system could help withstand and provide a buffer against the continent's changing weather conditions.

Renewable energy industry provides a greater amount of jobs. In contrast to fossil fuel technologies which are typically mechanized and capital-intensive, renewable energy industry can be more labour-intensive. The potential for job creation largely depends on a committed projects pipeline. For example, in South Africa, it is estimated that the first three CSP projects totalling 200 MW under the Renewables Energy Independent Power Procurement program (REIPP) could result in 1,800 construction (temporary jobs) and 120 jobs during operations (GIZ, 2013). In fact, solar technology generates industrial linkages through local content requirements with CSP technology engendering more local linkages than PV.

One of the key benefits of solar technology is the ease of its set-up. Both types of solar technology are quicker to set up than conventional technologies. For example, the construction of a solar CSP or PV plant takes on average 24 months compared to at best four or five years for a conventional coal- fired plant.

5. Production costs of renewable energy

Based on the levelised cost of electricity (LCOE), in developed countries, renewable energy technologies like geothermal, onshore wind and PV have already reached cost competitiveness with conventional sources of electricity while CSP technology remains significantly more expensive.

Table 1. Some renewable energy technologies have reached cost competitiveness in developed countries (LCOE in developed countries by technology, USD/kWh).

	EIA (2014)			Lazard (2014)		
	Min	Average	Max	Min	Average	Max
Conventional Coal	0.09	**0.10**	0.11	0.07	**0.11**	0.15
Conventional Gas (CCGT)	0.06	**0.07**	0.08	0.06	**0.07**	0.09
Nuclear	0.09	**0.10**	0.10	0.09	**0.11**	0.13
Geothermal	0.05	**0.05**	0.05	0.09	**0.12**	0.14
Wind Onshore	0.07	**0.08**	0.09	0.04	**0.06**	0.08
Wind Offshore	0.17	**0.20**	0.27		**0.16**	
PV	0.10	**0.13**	0.20			
PV - thin film				0.06	**0.07**	0.09
PV - crystalline silicon				0.06	**0.07**	0.09
Solar Thermal (CSP)	0.18	**0.24**	0.39	0.12	**0.12**	0.13

Sources: EIA (2014); Lazard (2014).

In a recent EIA study (EIA, 2014; Table 1 below), no conventional source is cheaper on average than geothermal (USD 0.05 per kWh). PV (with costs at USD 0.13 per kWh) is close to the cost of nuclear and coal (both at USD 0.10 per kWh). The exceptions seem to be CSP (at USD 0.24 per kWh on average) and offshore wind (USD 0.20 per kWh), which are significantly more expensive.

This picture is repeated across Africa where again solar technologies are still at a significant cost disadvantage. Considering existing and planned renewable electricity generation projects across Africa, estimates indicated in Table 3 below show that the bandwidth of costs for geothermal (USD 0.04-0.07 per kWh) and onshore wind (USD 0.05-0.16 per kWh) do not even overlap with those of PV (USD 0.18-0.39 per kWh) and solar thermal/CSP (USD 0.17-0.37 per kWh). The LCOE for a given technology is not only driven by the availability of natural resources but also by the cost of capital and the availability of equipment locally. This may explain some specificities for Africa, where low-cost capital can be challenging to source and where tariff and non-tariff barriers are significant thereby resulting in higher costs in Africa.

For CSP, as plants become larger, there are greater economies of scale as increased plant capacities and improved production technology result in cheaper components. Overall, relative to a 50 MW plant, 100 MW and 200 MW parabolic trough plants are likely to be 12% and 20% cheaper respectively (Kistner, 2009). Cost reductions would be proportional to deployment over the coming years and these are expected to be significant possibly resulting in a 50% decrease in LCOE by 2020. However, in Africa the CSP technology is much more in its infancy and cost remain high and corresponding price reductions have not yet materialized. Prices have been seen to be sticky downwards as evident from the bidding prices between the second and third bidding window of the Renewables Energy Independent Power Procurement program (REIPP) in South Africa.

Although it can be argued to partly be on account of the two tier tariff introduced in the third bidding window, it is also evidence that the expected price reductions have not yet materialized.

For PV technology, the biggest potential for cost reductions lies in components that are a result of manufacturing activities such as modules**.** Reductions in manufacturing costs are determined by two factors namely, economies of scale and technological innovation. Specific opportunities for reducing costs are through (i) increasing the efficiency and throughput of cell production processes, (ii) less costly methods for packaging and integrating modules, (iii) standardizing manufacturing equipment, and (iv) increasing annual production capacity of manufacturing plants (GIZ, 2013).

6. Conclusions

Solar technologies have some very positive characteristics, but are not yet competitive in all circumstances. In particular CSP technology seems to be an overly expensive source of energy even within the renewables category. Dynamic considerations make CSP like a "big bet" that could offer an alternative to conventional sources of energy. One can then wonder if Africa is best placed to make this bet, knowing the important and urgent needs of energy and the limited funding sources of the continent. Seen from this perspective, it appears logical that the only African countries that have invested in the CSP technology are the most advanced ones (South Africa and the North African countries). For other African countries it can be argued that currently, the high costs of CSP substantially outweigh the benefits until such a time when expected cost reductions materialize.

Currently PV holds much promise for Africa due to its natural potential and provides a compelling case for support even though the technology does not offer the same ability to dispatch as CSP. Also, PV has in some cases reached grid- parity which makes it a compelling case. PV offers the possibility to contribute to the reduction of the carbon footprint of the continent, but can also help to reduce the overall cost of energy production. This can be at the grid level by injecting into the system the PV Solar energy whenever it comes as an addition to the baseload production, but also at the plant level, by considering innovative mixed technologies (such as Heavy Fuel Oil – HFO/PV) which give the possibility to balance costly and polluting fossil fuel plants however needed in some contexts, with a renewable source of energy. These hybrid technologies under development, for both PV and CSP, seem to offer a balanced and timely solution to the Africa energy challenge: to meet its urgent needs of power with the global efforts to minimize greenhouse gas emissions align Africa's growth with the sustainable development goals (SDGs).

To maximize the gains from harnessing the solar energy potential in Africa, providing an enabling environment will be critical. It will require policy measures that indicate government support for the development of solar energy or renewable energy in general while eliminating or reviewing fossil fuel subsidies. Careful thought will also need to be given to having a conducive regulatory environment including issues related to "feed-in-tariffs" to reduce the policy reversals that have undermined its recent development elsewhere, including in Europe. The development of local value chains to support the growth of the solar industry will also be beneficial and ensure shared gains to the country promoting solar energy.

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+33 (0)4 73 17 75 30