EXECUTIVE SUMMARY

Africa has abundant renewable energy resources. Traditionally reliant on hydropower, the continent is increasingly turning to solar photovoltaics (PV) to bolster energy security and support rapid economic growth in a sustainable manner. Solar PV module prices have fallen by 80% since the end of 2009, and PV increasingly offers an economic solution for new electricity generation and for meeting energy service demands, both on- and off-grid.

Africa is endowed with significant renewable resources of all forms. Hydropower has traditionally been the largest renewable power generation source, contributing 97 terawatt-hours (TWh) of hydropower generation in 2013 (15% of total generation). However, with recent cost reductions for solar PV, concentrating solar power (CSP) and wind power, this could change rapidly. Solar PV module prices have fallen rapidly since the end of 2009, to between USD 0.52 and USD 0.72/watt (W) in 2015.[1] At the same time, balance of system costs also have declined. As a result, the global weighted average cost of utility-scale solar PV fell by 62% between 2009 and 2015 and could decline by 57% from 2015 levels by 2025.

Globally, new capacity additions of solar PV have increased six-fold from around 8 gigawatts (GW) in 2009 to around 47 GW in 2015. This growth has largely bypassed Africa, despite solar irradiation in African countries being 52% to 117% higher than in Germany. However, technology improvements and lower costs have spurred local and social entrepreneurs in the solar home system (SHS) market[2] and in stand-alone mini-grid markets, while in the utility-scale sector – systems larger than 1 megawatt (MW) – support policies are beginning to bear fruit. New capacity additions of solar PV in Africa in 2014 exceeded 800 MW, more than doubling the continent's cumulative installed PV capacity. This was followed by additions of 750 MW in 2015. By 2030, in IRENA's REmap analysis of a doubling of the share of renewable energy globally, Africa could be home to more than 70 GW of solar PV capacity.

With recent cost reductions, solar PV now offers a rapid, cost-effective pathway to providing modern energy services to the approximately 600 million Africans who lack access to electricity and utility-scale electricity for the grid.

Solar PV is a highly modular solution, both on-grid and off-grid. It can provide lighting and electricity to a single home off-grid, can be incorporated into mini-grids that can scale from several kilowatts (kW) to many MW, and at utility-scale can achieve higher economies of scale. Facilitated by and pulled by the growth of "mobile money"[3], small 20-100 W SHS can be purchased on pay-as-you-go schemes, and provide modern energy services for lighting, mobile phone charging and other small appliances that are higher quality than the equivalent (*e.g.,* kerosene lanterns), at a similar, or lower, monthly cost. At the same time, auctions and tenders for utility-scale solar PV in North Africa and South Africa have shown that solar PV can be a cost-effective large-scale source of new capacity. There also is increasing interest in the use of solar PV in mini-grids, both isolated and grid-connected, which can be an attractive option to reduce diesel costs or to go 100% diesel free.

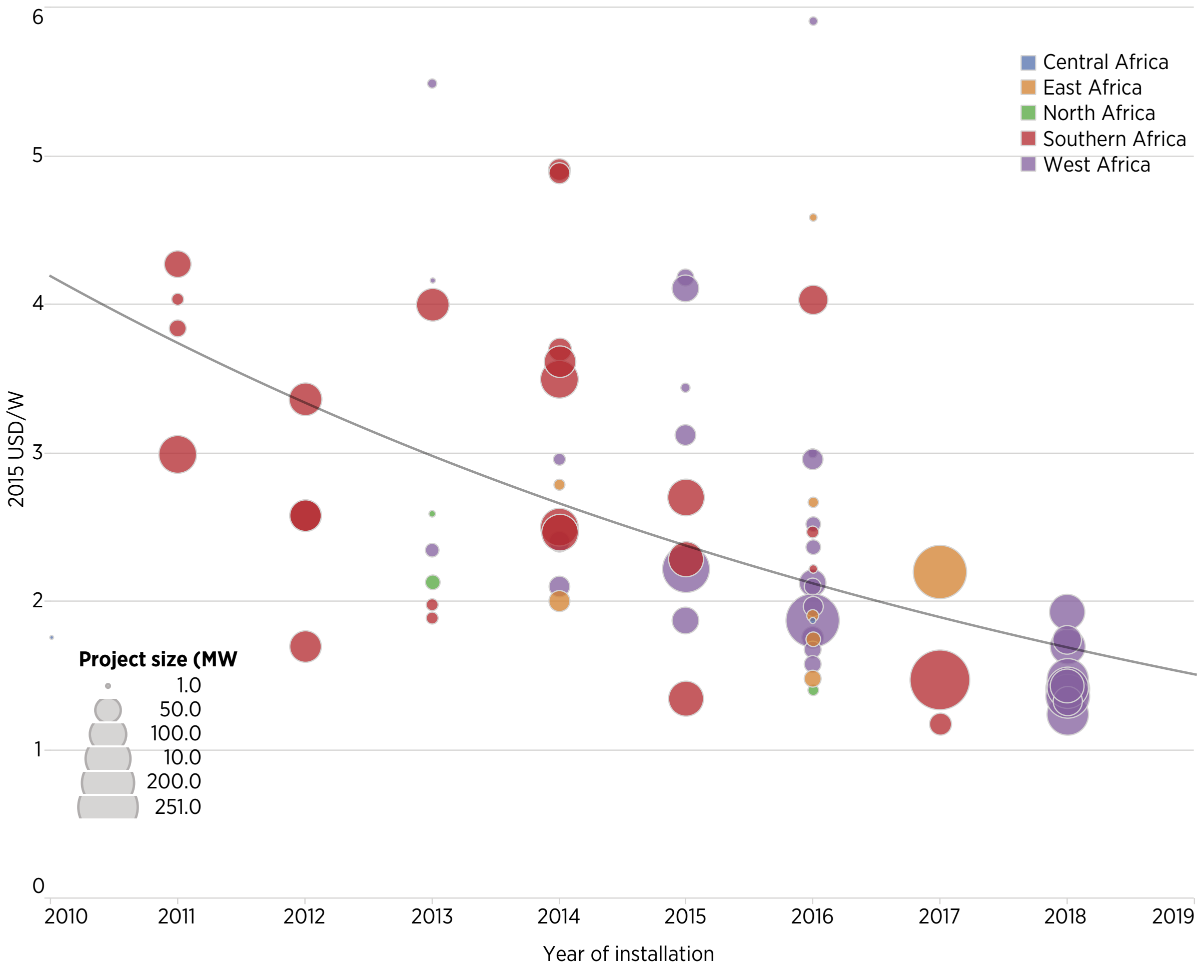
Solar PV has another advantage. Project lead times are among the shortest of any power generation technology and can be deployed much more rapidly than many other generation options. Given the pressing need across Africa to address the low rates of access to electricity and poor-quality electricity supply (*e.g.*, frequent blackouts and brownouts), the ability to rapidly scale up solar PV is a significant benefit.

1 All financial values in this report are expressed in real 2015 USD values, that is, taking into account inflation.

2 This report does not cover the so-called solar pico lighting solutions of rechargeable solar lanterns with integrated or connectable very small solar cells.

3 Banking services provided via mobile phones.

Figure ES 1: Operating and proposed utility-scale solar PV project installed costs in Africa, 2011-2018



Note: Each circle represents an individual project. The centre of the cricle represents the value on the Y axis and the diameter of the cricle the size of the project.

Many of the latest proposed utility-scale solar PV projects are targeting competitive installed cost levels that are comparable to today's lowest-cost projects.[4] This is a very positive signal, given the nascent market for solar PV in Africa and the challenging business environment for infrastructure projects in many African countries.

On-grid commissioned and planned utility-scale solar PV projects between 2014 and 2018 in Africa range from around USD 1.2 to USD 4.9/W (USD 1 200 to 4 900/kW). Although Africa is currently home to a very small set of utility-scale solar PV projects, costs have been declining over time. The cost range was between USD 3.4 and USD 6.9/W in 2012, declining to USD 2.4 to USD 5.5/W in 2013 and to USD 2 to USD 4.9/W in 2014 (Figure ES 1). For 2015 to 2016, the cost range is anticipated to be between USD 1.3/W and USD 4.1/W. If the projects targeting USD 1.3/W in installed costs can be built to budget, this would represent a very competitive level for Africa, given the estimated worldwide weighted average for utility-scale projects of USD 1.8/W in 2015.

South Africa, with its strong civil engineering sector and large renewable independent power producer (IPP) programme (which provides investor certainty), has the lowest installed cost for an operating solar PV plant (around USD 1.4/W for the best project) on the continent for the data available. Other countries

4 In this report, the term "cost structures" refers to the individual cost components that contribute to the total installed costs of a solar PV system (*e.g.*, modules, inverters, racking and mounting, cabling, installation costs, permitting fees, system design costs, etc.). See the full report for a detailed description of the cost categories analysed.

are targeting cost structures in the range of USD 1.5 to USD 2.5/W in 2016. Given the challenges of doing business in some parts of Africa – and the fact that these will be either the first solar PV plant in a country, or one of just a handful – this cost range is reasonably competitive. Project announcements in 2016 that are targeting commissioning dates in 2018 (with perhaps some projects online in late 2017) are targeting a competitive total installed cost range of USD 1.2 to USD 1.9/W.

Off-grid utility-scale projects (> 1 MW) are relatively uncommon, with little data available for Africa. In many cases these represent the bundling of a number of smaller solar PV plants into a single strategic project. For instance, data for one project of rural electrification of schools and hospitals suggests costs of USD 6.8/W for 1.9 MW in total. Another project targets costs of USD 4.6/W for 4 MW of electrification projects. However, without specifying the total number of systems involved, it is not possible to analyse the relative economies of scale that these projects should expect. As a result, it is difficult to come to any conclusion about the competiveness of the installed cost structure for these projects. However, there are off-grid projects in the 1 to 5 MW range that are targeting costs below USD 2/W for 2016 and beyond, which is relatively competitive for this scale in the African context.

Mini-grids utilising solar PV are potentially an attractive electrification option. The installed costs of solar PV for mini-grids span a wide range, but recent and planned projects show examples of competitive cost structures.

Isolated mini-grids offer the potential to electrify entire communities in a single project, as well as providing flexibility to scale and interconnect with the grid at a later date. Existing, grid-connected mini-grids (in government, education or hospital complexes, mining or business activities) also represent an opportunity for solar PV to reduce operating costs and lock in prices.[5] Their scale is typically modest and can range from as low as 8 kW to 10 MW in Africa, although large cornerstone customers like mining operations offer the opportunity to have even larger solar PV systems (*e.g.*, the planned 40 MW solar PV plant at the Deep South Mine in South Africa).

With the fall in solar PV costs, solar PV mini-grids offer important economic opportunities today as either the sole source of generation or in hybrid configuration with other generation sources. Stand-alone solar PV mini-grids or solar PV-hybrid mini-grids have installed costs in Africa ranging from USD 1.9 to USD 5.9/W for systems greater than 200 kW. Solar PV mini-grids that came online in 2012 or earlier have higher costs.

The rapid growth in the market for solar home systems is being driven by lower system costs and innovative new business models. Yet Africa's systems, typically under 100 W, are tiny compared to their counterparts in developed countries and require batteries and charge controllers to ensure stable output. As a result they have higher costs per kilowatt.[6]

The average residential solar PV system in OECD countries has a capacity of 3 to 5 kW. SHS in Africa can be 60 to 250 times smaller, with a typical capacity of 20 to 100 W. In addition to having higher costs per watt due to their small size, these systems need to incorporate batteries and charge controllers. They also may include lights and appliances (*e.g.*, radios, phone charging ports) which raise costs further. These small SHS, with their integrated lighting and appliances, and "plug-and-play" nature, more closely resemble consumer electronic products than residential solar PV systems in the OECD.

5 Mini-grids can rely solely on a single source for generation, such as solar PV, and utilise batteries to ensure that demand is met whenever needed, or during desired periods outside peak solar irradiation, depending on the economics of storage for the site and the users' needs. Alternatively, the mini-grid can rely on multiple generation sources, the so-called hybrid system, which could include mini-hydro, wind and/or diesel, etc.

6 Assuming a 1 to 10 kW system in developed countries.

Typical costs for sub-1 kW SHS systems, which represent the vast majority of SHS sold in Africa, range from USD 4 to USD 16/W, with most systems between USD 4 and USD 11.3/W. There is a wide range of costs for the battery and charge controllers for sub-1 kW systems, from USD 2.5 to USD 6.8/W. The system cost, excluding the battery and charge controller, ranges from a low of USD 1.8/W to a high of USD 13.9/W. These systems in the dataset are based on direct current (DC) and avoid the need for an inverter. Alternating current (AC) systems in this small-size segment have higher average costs.

For larger SHS systems with capacities greater than 1 kW, more recent projects have seen costs within the range of USD 2.5 to USD 7/W, although a number of projects or programmes exhibit higher cost structures, in the range of USD 8.3 to USD 17/W. The battery and charge controller account for between USD 0.5 and USD 6.3/W and on average account for 31% of total installed costs. The lights, fittings and associated materials for these larger SHS are more systematically reported than for the sub-1 kW systems; they account for between 10% and 40% of the total installed costs and average one-fifth of total installed costs. Importantly, falling costs in highly efficient LED (light-emitting diode) bulbs have led to their widespread use in SHS, thereby reducing PV system size and battery requirements for the same lighting service.

Solar home systems in Africa are providing better-quality energy services at the same or lower cost as poor-quality lighting from kerosene lanterns in off-grid situations. Their use, as well as that of solar lanterns, is growing rapidly.

The falling prices of solar PV modules have made SHS an economic alternative for the 600 million Africans without a grid connection, for lighting and basic electrical services. For example, Kenya has seen rapid, market-based growth in SHS, with the number of households using SHS doubling or tripling between 2010 and 2014. In Africa, competitive business models exist that provide better-quality energy services to those using traditional energy sources, even when their monthly expenditure is as low as USD 2 per month for lighting (IFC, 2012). The data for sub-1 kW SHS collected for this report translate into annual costs of USD 56 to USD 214/year, assuming a 5% real cost of capital, a six-year life and one battery replacement.[7] Given estimated annual expenditures today for off-grid lighting and mobile phone charging of between USD 84 per year in Ethiopia and USD 270 per year in Mauritania, SHS can represent a very economical solution (Figure ES 2).

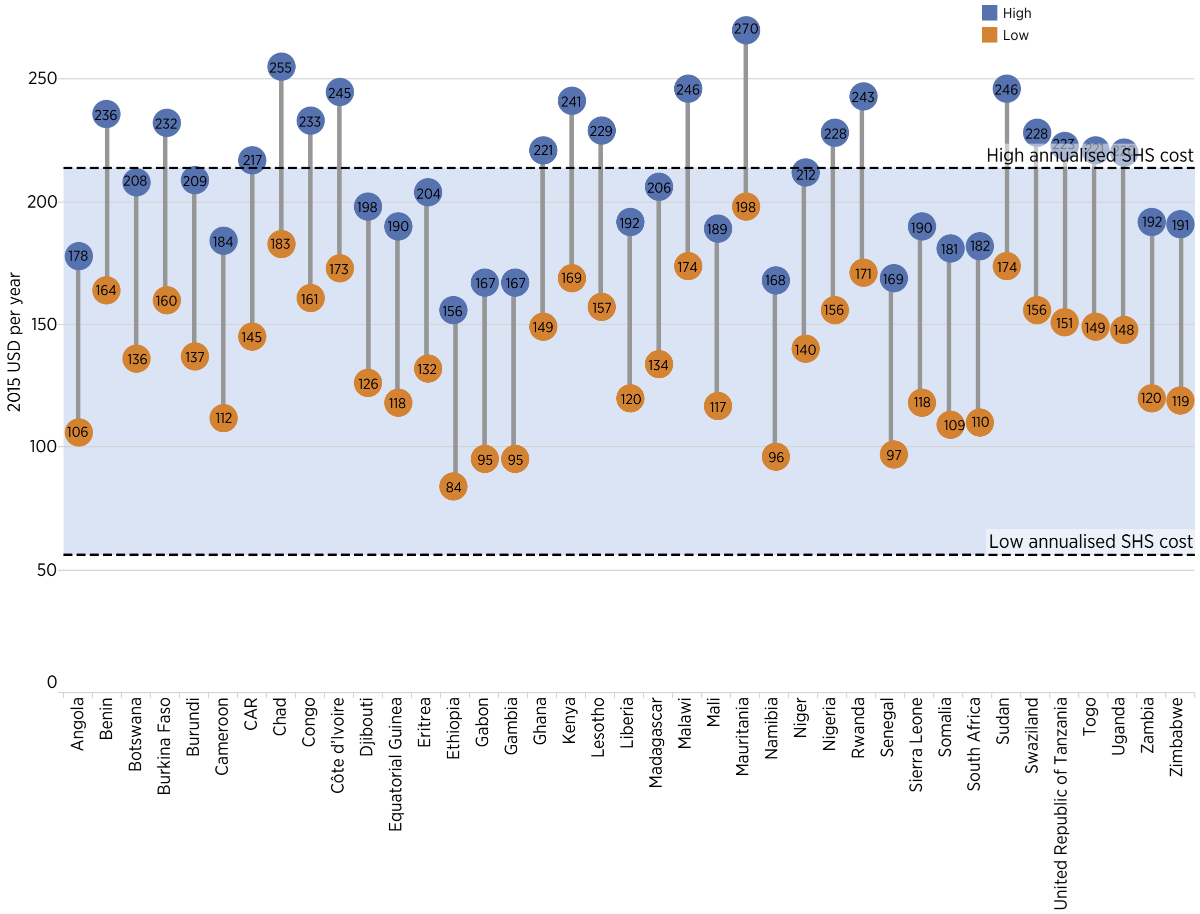
This is before taking into account any reduced transportation costs for trips dedicated to mobile phone charging, which can amount to USD 25 per month in some cases. It also does not take into account the improvement in the quality of energy services provided by SHS using LED lights. For instance, a 2 W LED light will produce around 380-400 lumens of light compared to 8-40 lumens for a kerosene wick lamp. The price per unit of useful light provided by SHS can be one-third to one-hundredth that of the equivalent light from a kerosene wick lamp.

Current solar home systems rely mostly on deep-cycle lead-acid batteries to keep costs down, although lithium-ion batteries are beginning to appear on the market. Battery and charge controller costs currently account for around one-third of total solar home system costs in Africa.

Deep-cycle lead-acid batteries are a proven, relatively cheap electricity storage solution. For the data available for sub-1 kW SHS in Africa, average costs are around USD 2/Amp-hour (Ah) for battery storage capacities of 20 Ah to 220 Ah. This translates into costs of USD 2.1 and USD 6.8/W for the battery and charge controllers, depending on the battery and SHS size combination.

7 For the main components, excluding the battery, this is a conservative assumption but reflects the "consumer electronics" nature of these small SHS products.

Figure ES 2: Annual off-grid household expenditure on lighting and mobile phone charging compared to SHS (< 1 kW) annualised costs, by country in 2015



Note: The blue band represents the range of annualised SHS costs, while the circles represent the high and low annual expenditures of off-grid households for lighting (e.g., kerosene, batteries, candles, etc.) and mobile phone charging.

A drawback of deep-cycle lead-acid batteries is that even if they are carefully managed, they have expected lifetimes of as little as three years, much shorter than that of the other PV system components. Well-managed lead-acid batteries (*e.g.*, limiting their depth of discharge to 20%) may last five years, but the low depth of discharge means that more storage is needed for the same usable electricity. Lithium-ion batteries provide much improved performance (number of cycles) and can support a depth of discharge of 80%. The challenge they face is that they have much higher costs today than lead-acid batteries. However, because of the higher depth of discharge – which reduces the total storage needs compared to lead-acid batteries – and the larger number of cycles possible, depending on the specifics of the PV system and user requirements they already may make economic sense in some cases. Their higher initial costs are a real barrier in the African market, however, and their penetration is currently low. This is expected to change as Lithium-ion battery costs continue to fall rapidly, while lead-acid batteries are a mature technology with little further cost reduction potential.

Cost reduction opportunities for solar home systems exist for the core hardware components of modules and batteries, but also for the balance of system, including all non-hardware, costs. For mini-grids, the challenges are more varied given the multi-stakeholder engagement required, and project development costs dominate the total cost reduction opportunities.

For SHS with a capacity of 1 kW or more, most of the cost reduction opportunities arise from the hardware. Solar PV module cost reduction opportunities account for 14.5% to 17% of the cost reduction potential, batteries from 11% to 21%, the charge controllers from 11% to 22%, other hardware and lamps from 29% to 36%, and soft costs and all other costs from 18% to 21% of the total cost reduction potential for existing systems.

In contrast, for stand-alone mini-grids, soft costs account for 38% of the cost reduction potential, compared to the average in Africa in the IRENA database. Batteries account for 27%, the solar PV module for 20%, the inverter for 7%, wiring and cabling for 5% and mounting and racking for 4% of the total cost reduction potential, relative to best practice costs of USD 2.4/W in Africa.

Solar PV cost data in Africa are not systematically collected or made available to policy makers, resulting in difficulties in setting realistic policy support levels that are efficient and effective.

The collection of representative real-world project costs in Africa is extremely challenging due to the small scale and fragmented nature of the industry in Africa, as well as confidentiality issues. IRENA's dataset is the largest and most comprehensive available to the best of our knowledge. However, data quality and coverage are highly variable, and collecting data on cost breakdowns is extremely difficult. This makes data analysis time-consuming and sometimes limits the conclusions that can be drawn. Systematic cost data collection and comparison is not the norm in Africa meaning that there is often a lack of information on costs and their evolution over time.

A co-ordinated effort to collect the installed costs of solar PV in Africa, across all market segments, is required to improve policy making and to share experiences among countries and regions. This will improve the efficiency of policy support and accelerate deployment, by targeting efficient cost structures in new markets.

This effort to collect better cost data shoud ideally:

- Include a standardised cost data collection categorisation that is agreed upon and implemented by stakeholders, to facilitate the comparison of costs within programmes and between programmes and countries.

- Include governments, international development organisations, regulatory authorities, development banks and multilateral lending institutions and others that provide public financing or other financial assistance to renewable energy projects – including solar PV, but also other energy technologies. These stakeholders will need to systematically collect, on a standardised basis, cost and performance data on the technologies they are supporting.

- Identify a neutral third party to collate and pool the data and make it publicly available (safeguarding unit record confidentiality where necessary), to ensure market efficiency (transparency on costs) and to allow for the evaluation of cost trends and differentials among countries.

- Encourage greater co-ordination in the provision of support to renewables projects in Africa, including information sharing on costs and trends. There is a clear role for donors and organisations that are active in energy sector assistance (*e.g.*, the World Bank, GIZ, African Development Bank (AfDB), etc.) in initiating and driving forward this process through a dedicated multi-year project.

IRENA is ready to help its member states in Africa, and stakeholders providing assistance (*e.g.*, the World Bank, GIZ, AfDB, etc.), to develop a standardised methodology for the collection and dissemination of renewable project cost data and performance, as well as being the neutral, third-party repository for these data.

The IRENA Renewable Costing Alliance could be one vehicle to co-ordinate this activity. It would provide a platform for stakeholders to exchange data and lessons learned, and to identify opportunities for collaboration to reduce duplication of effort. It would be most efficient if this activity was integrated into an existing partnership programme in Africa, with established contacts with stakeholders and an ongoing programme specific to the energy sector (*e.g.*, Africa-EU Energy Partnership, Power Africa, etc.).

The drivers of the current, wide variation in costs for different market segments in Africa are not well understood. Further work needs to be done to identify why cost differentials exist in different market segments and countries. A sub-regional analysis for Africa – which brings together all stakeholders, from government, business, communities, project developers, financing and development partners – could help identify the reasons for cost differentials, map out strategies to reduce them, and identify roles and responsibilities.

More work needs to be done to understand why today's cost differentials in Africa exist, how new markets can shift rapidly to efficient installed cost levels, and how best to share these practical experiences to accelerate the deployment of solar PV in Africa.

It could be useful to explore co-ordination at a sub-regional level, where countries could discuss together with solar PV project developers, SHS businesses, policy makers and regulators how to exchange experiences of what has contributed to low-cost projects. This should look at present cost structure components (*e.g.*, module, inverters, other electrical, other hardware, permitting, installation, customer acquisition, etc.) and how these are affected by national circumstances (as opposed to outlining current cost levels). Sharing these experiences will help other countries to apply these lessons to their unique national and institutional circumstances.

A detailed assessment of the barriers and opportunities to replicating efficient cost structures in new markets will be needed to inform this approach. This will require an in-depth engagement on the ground with stakeholders (*e.g.*, project developers/business, policy makers, regulators, etc.) to identify these barriers and opportunities, as well as their applicability in different national circumstances. Regional dialogue (*e.g.*, through joint projects/workshops) can complement this analysis by helping to share different perspectives and identify the specific roles of each stakeholder in contributing to the successful implementation of cost reduction pathways.

For SHS, issues of economies of scale and profit margins are paramount in arriving at efficient cost structures. African regions could consider the bundling of SHS deployment programmes (whether implemented by regulatory bodies, industry or social businesses) in order to achieve purchasing power benefits, and make financing more attractive and less costly. They also should aim for a measure of standardisation for products to help with training, installation and maintenance costs, and quality. Co-ordination could take the form of joint tendering, or be more hands-off, as in agreeing on standardised processes and specifications for national programmes.