DECREASING PV COSTS IN AFRICA

Opportunities for Rural Electrification using Solar PV in Sub-Saharan Africa

Even though Solar PV has had a significant effect on rural electrification in general in developing countries, the current status of solar home systems in Sub-Saharan Africa is not very well-known. Magda Moner-Girona, Rebecca Ghanadan, Arne Jacobson and Daniel M. Kammen, University of California provide an overview of the status of solar home system installation in Africa and highlight the opportunities for cost reductions via local manufacturing.

As of 2004 there were approximately 720 million people in Sub-Saharan Africa (WDI database, 2005). Precise estimates are unavailable, but outside of South Africa, fewer than 25% of all households are connected to the electrical grid. Most of these unelectrified households in Africa are in rural and peri-urban areas, where the overall level of electrification is less than 15% (Acker and Kammen, 1996). In many African countries, however, rural electrification rates are far less than 15%. For the majority of African countries, levels of 1-2% are more common.

Investments in electricity services, particularly in rural areas, are critical to improve conditions in rural households, farms, businesses, health clinics, schools, and community centres. Current activities in these areas represent only a small fraction of the total need. Greater investments are needed in this area if social services as well as household services are to improve with growing private solar markets (Table 1).

The bulk of energy consumed in rural areas of Sub-Saharan Africa is used in households for cooking, lighting, and space heating. Cooking accounts for 90% to 100% of energy consumption (Karekezi and Kithyoma 2002). Electricity from solar is primarily used for lighting, radio, and television (Jacobson 2004, Nieuwenhout, van Dijk et al. 2001). Electric lighting represents a dramatic improvement over kerosene in terms of light quality, air quality, and safety. Television, radio, and increasingly cell phones provide important communication, information, and entertainment services.

Solar PV-based rural electrification

At present, the international market for photovoltaic electricity systems is in the middle of a period of dramatic growth (A. Jaeger-Waldau 2005). With the exception of South Africa, grid electricity in rural Sub-Saharan Africa is currently almost non-existent. Solar markets are growing to meet this latent rural demand, but they still only reach a small percentage of the total potential market. In the last decade, solar home systems (SHS) have received significant attention as a strategy for expanding rural electricity services in developing countries using a private market model, when grid extension is considered to be too costly or an unlikely option in the near term. It is estimated that 1.3 million solar home systems had been installed in developing countries by early 2000, at that moment one out of every 100 households that gains access to electricity uses solar power (Nieuwenhout, van Dijk et al. 2001). As of 2002, 50-125 MWp of off-grid PV had been installed in Africa. According to Duke and Kammen (Duke and Kammen, 1999, 2003) there is a potential solar home system market of 63 million households in Sub-Saharan Africa. This is out of a global total of approximately 330 million unelectrified homes (Table 2). SHS account for roughly one third of the off-grid PV capacity installed in Africa. The remainder of the capacity is used in telecommunications and other various government and donor projects in health, education, and water supply.

Rural families are reporting high value associated with TV or radio, evening lights, and charging cell phones. Solar electricity is "connective power" for rural people; its use is playing an important role in increasing interconnections between rural Africans and people, institutions, and ideas in national and international urban centres. At present these interconnections are made primarily through solar powered television, radios, and cellular telephones (Jacobson 2004). All of these play an important role

Author information
Magda Moner-Girona, Rebecca Ghanadan and Arne Jacobson are based at the Energy and Resources Group, University of California, 310 Barrows Hall , Berkeley, CA 94720-3050, USA. Daniel M. Kammen is based at the above institution as well as Goldman School of Public Policy, University of California, Berkeley, USA. For further information, contact: Magda Moner-Girona; Tel: +1 510 643 2243; magdam@berkeley.edu

Table 1: Status of Rural Grid-Based Electrification

Country	GNIa (US$) /capita 2001	Population 2001	% Rural 2001	% Rural electrification (grid-based)	Rural Population without Grid-based Electricity	Number of Un-Electrified Rural Household
Sub-Saharan Africa	461	719.0 million	65.2%	<15%	>350 million	63 million
Kenya	460	32.4 million	65.7%	2%	19.8 million	5.5 million
Uganda	270	25.9 million	85.5%	0.7%	19.3 million	2.5 million
Tanzania	330	36.6 million	66.8%	1%	22.8 million	2.2 million
Ethiopia	110	70.0 million	84.1%	0.2%	54.8 million	6 million
Eritrea	180	4.4 million	80.9%	2%	3.3 million	0.6 million
Somalia	296	9.9 million	62.7%	0%	5.7 million	>1 million
Sudan	530	34.4 million	63.0%	<15%	17.0 million	4.5 million
Malawi	170	11.2 million	84.9%	0.3%	8.9 million	
Mozambique	250	19.1 million	66.8%	0.7%	12.0 million	
Zambia	450	10.5 million	60.2%	2%	6.1 million	
Botswana	4,340	1.7 million	50.6%	2%	0.8 million	
Zimbabwe	387	17.2 million	64.0%	18%	6.7 million	

Sources: (Karekezi and Kithyoma 2002; ESD 2003; WDI database 2005; Duke and Kammen 1999; Duke et al 2002)
Note: (a) Atlas method , GNI (Gross National Income)

Table 2: Status of Solar PV in Selected Countries, Total Installation

Country	No. installed SHSs, 2000	Estimated total SHS capacity installed, kWp	Estimated total PV , capacity installed* kWp
Kenya	150,000	2,900	3,900
Uganda	20,000	400	1,050
Tanzania	10,000	450	1,200
Ethiopia	5,000	200	2,200
Eritrea	5,000	15	500
Somalia	<100	3	100
Sudan	<1,000	Negligible	400
Zimbabwe	85,000	1.700	1,689
South Africa	150,000	3,000	11,000
Botswana	5,700	110	286
Zambia	5,000	100	400
TOTAL	**437,000**	**9,000**	**22,600**

Sources: (Nieuwenhout, van Dijk et al. 2001; ESD 2003).
Note: (*) PV Capacity Installed includes SHS, water pumping, health/vaccine refrigeration, institutional/government, and telecommunications

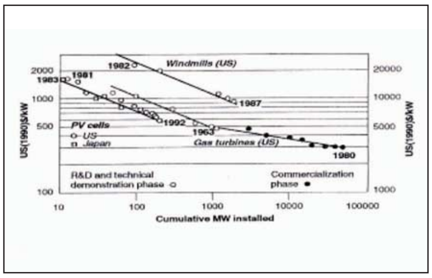


Figure 1: Industry-wide experience curve relationship for PV (right scale), wind generators (left scale), and gas turbines (left scale)

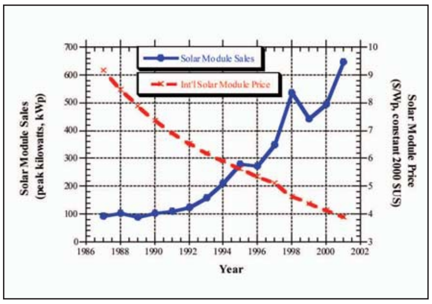


Figure 2: Solar Module Sales and per Watt Price in Kenya from 1987 to 2001

in the social, economic, and political development of rural Africa, and cellular telephones in particular are emerging to play a key role in facilitating rural economic growth.

In addition, clinics, schools, and community centres also provide valuable services to rural and peri-urban areas that would benefit from solar PV electrification. Particularly important services are refrigeration of vaccinations, lighting for classrooms and examinations (particularly child-birth), and telephone and internet communications services for rural and peri-urban communities. These community services are important areas that are largely left out of the current development of solar markets. Table 3 draws on a review of East African countries and shows that there is a large solar market potential in each of these different potential applications of solar (ESD 2003).

Current conditions

Decreasing costs of PV

Solar system costs have dropped significantly over the past few decades due to technical advances, manufacturing innovations, and economies of scale in production. Figure 1 shows the international experience curves for PV, windmills, and gas turbines demonstrating decreasing prices with increasing production. Historical data for growth of international PV manufacturing shows a 20% drop in price for every doubling of cumulative MW installed. These patterns reinforce the importance of decreasing prices with technological innovation for development of solar markets in Africa, particularly as all modules are effectively imported from an international market at this time.

Decreasing costs for Africa

The solar market in Sub-Saharan Africa has benefited from steadily decreasing international prices for PV equipment over the last few decades. The price of equipment is perhaps the single most important factor in the growth of solar markets in Africa. Data on solar sales growth and price trends in Kenya shown in Figure 2 is an example of a vibrant and growing solar market with decreasing solar module prices in Africa. However, despite growing interest in solar, most PV markets in Sub-Saharan Africa are still small.

Table 3: Solar Market Potential in Selected African Countries

Type of system	PV (Wp) system capacity	Size of potential market kWp Kenya	Uganda	Tanzania	Somalia	Sudan	Ethiopia	Eritrea
Off-grid households								
One light and radio	10Wp	7,700	3,840	6,954	436	7,410	5,988	705
2 light and radio	20Wp	6,600	4,480	3,974	523	2,280	7,186	376
4 light	50Wp	5,500	1,600	2,484	436	-	8,982	235
≥6 light	>80Wp	5,500	3,200	4,967	872	-	5,988	470
TOTAL		25,300	13,120	18,379	2,268	9,690	28,145	1,786
Off-grid schools								
Classroom lighting	100Wp	189	40	210	20	20	50	45
Classroom and dormitory lighting	200Wp	75	20	168	4	4	12	9
Lighting and ICT (Information Communication Technologies)	500Wp	50	25	21	-	5	20	16
TOTAL		314	84	399	24	29	82	70
Off-grid health facilities								
Lighting system	200Wp	14	16	312	8	20	132	6
Lighting and refrigeration	500Wp	5	6	78	3	8	30	10
TOTAL		19	21	390	11	28	162	16
Off-grid community centers, churches, mosques, and missions								
Lighting system	100Wp	-	-	-	10	300	-	-
Lighting and public address/ICT	200Wp	-	-	-	100	60	-	-
Lighting, entertainment, ICT and communication	500Wp	-	-	-	250	75	-	-
TOTAL		-	-	-	360	435	-	-

Source: (ESD 2003)

Table 4: Costs of Solar Home Systems in Selected Countries

Country	No. Installed SHSs 2000	Prices for SHS (US$/Wp)	Estimated SHS Cost (50 Wp) US$	GNI (US$)/capita 2001
Kenya	150,000	9.5	550	350
Uganda	20,000	11	730	260
Tanzania	10,000	14	850	270
Ethiopia	5,000	13	750	100
Eritrea	5,000	13	650	160
Somalia	<100		>800	296
Sudan	<1,000	12	650	340
Zimbabwe	85,000	17	800	387
South Africa	150,000	10		1,221
Ghana		14		290
Namibia		22		823
Swaziland		17		1,300
Botswana	5,700	16		3,100
Zambia	5,000		1200	320
Lesotho			1000	530

Sources: (Nieuwenhout, van Dijk et al. 2001; Karekezi and Kithyoma 2002; ESD 2003; World Bank 2003)
Note: Solar PV system cost includes solar panel, battery, 4 lights, charge controller, installation materials, and installation

Table 5: PV and Balance Of System (BOS): Retail Price Comparisons (US$)

Item	Kenya	Uganda	Ethiopia	Tanzania	Indonesia (2000)	China (1998)
12Wp a-Si	50	97	70	87	N/A	39
50Wp x-Si	280	340	390	467	225	262
Charge controller 8-10A	60	73	63	106	15	25
DC light fluorescent	10	16	13	13	6	5
100Ah battery	56	58	56	93	47	45

Source: (ESD 2003)

Developing the supply markets is an important part of growing these markets. But perhaps more importantly, PV equipment is still beyond the reach of most rural Africans. Price decreases will be important for these markets to provide services to a larger portion of the population. Table 4 shows that typical 50 Wp solar home system costs are more than the average gross national income per capita in most African countries. For this reason, the benefits of solar home systems currently in place are primarily limited to private rural middle class homeowners (such as rural teachers, professionals, business owners, and some cash crop farmers).

In addition, decreasing PV costs alone will not provide the organizational and financing solutions needed to bring electricity and water pumping services to rural communities, clinics, and schools. Thus, there is an important place for international support and financing to catalyze the growth of these markets beyond the rural middle class and provide immediate benefits to peri-urban and rural communities. Extending these benefits to the rural and peri-urban poor and to community services will require continued cost reductions and innovative service approaches in order to reach its full potential.

Comparisons internationally

In general, PV system prices are higher in Africa than in other parts of the world. For example, a Ugandan may pay two times what an Asian customer pays for an equivalent PV system. High African prices are largely due to taxes and transaction costs in the process of delivering the system.

One exception to this trend is the Kenyan solar market, where intense competition and import tariff reductions have played an important role in bringing prices down. However, most African countries still have a long way to go to bring down system prices (Table 5).

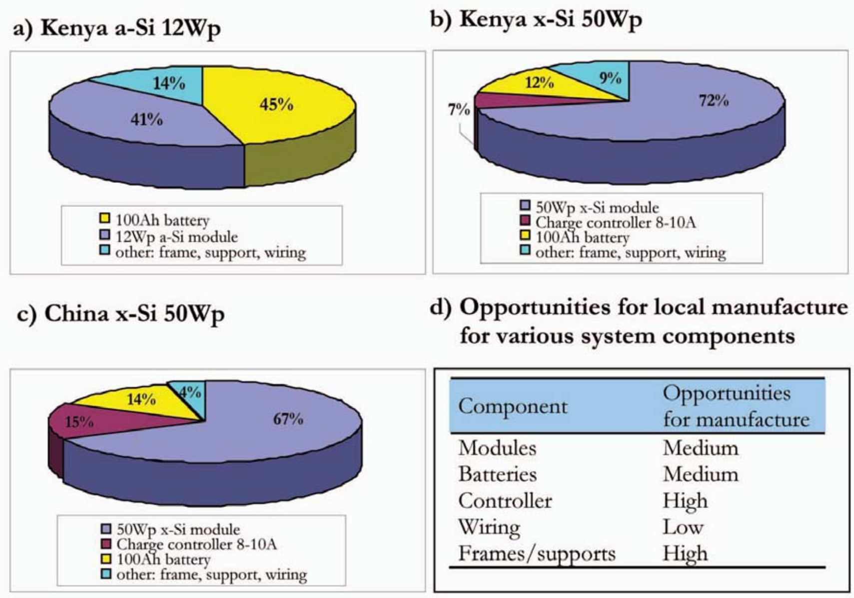
Decreasing costs via local manufacture

The local production of photovoltaic modules and systems can have a significant effect on the sustainability of the local market. At present the solar modules used in Sub-Saharan Africa are mainly imported. Most developing nations rely on imports for most of their energy supply so every locally produced and installed PV system component results in a net saving of foreign currency. Moreover, 95% of the world's wafer and solar cell production capacity is located in industrialized nations. The existence of a local module assembly business also has the tendency to create new markets for photovoltaic systems (e.g. currently, 20% of the world's module assembly capacity is located in developing nations) (Figure 3).

Local manufacturing has the potential to expand existing markets as well as to create jobs, service, training and financing, to reduce solar module costs, economically manufacture special order modules in low volumes; be well positioned to offer parts, and create opportunities to tailor solar technology to specific in-country African requirements. In this regard, locally manufactured PV modules can be considered an indigenous energy source. Products that are developed specifically for African markets can play a particularly important role in stimulating growth.

The local manufacturer has several competitive advantages, including the manufacturing of products that are precisely matched to local market requirements. For example, the development of small and inexpensive amorphous silicon (a-Si) modules over the last 15 years for developing country markets by US and European manufacturers has played a crucial role in the growth of solar markets in Kenya, Morocco, and other African countries.

These low cost modules are particularly appropriate for the small system applications (e.g. 10 to 40 Wp) where high-energy conversion efficiency is not required. Local (African) manufacturing of a-Si technology could lead to further price reductions, and emerging thin film photovoltaic technologies show even greater promise. The local manufacturer would have the competitive advantage of manufacturing with locally available module materials where appropriate. Of the various cell cost reductions, perhaps the most difficult will be materials cost reductions, then it is important to acquire information



Component	Opportunities for manufacture
Modules	Medium
Batteries	Medium
Controller	High
Wiring	Low
Frames/supports	High

Rural solar home systems are usually DC (no inverter) and typically cost less than $1,000 initially.
Source: (IEA PVPS, 2003)

Figure 3: Relative costs of PV system components and opportunities for local manufacture

Table 6: In-country manufacture of components in Africa

Ethiopia	Yes	No	Emerging market. No system components manufactured (except 1 battery manufacturer).12 major importer/module distributors, <10 retailers. University of Addis Ababa involved in PV technology and applications research.
Ghana	Yes	No	Estimated 13 companies working with PV. University of Science and Technology manufacturers BOS components.
Kenya	Yes	No	Mature market. Estimated 150,000 SHS installed on a commercial basis. As many as 8 major importer/module distributors,>700 retailers and a further 20 companies involved in BOS component manufacture, 3 as battery manufacturer.
Morocco	Yes	Yes	As many as 30 organizations involved in manufacture, systems design and installation. 6 modules distributors and one local module manufacturer using cells purchased on international market.
Namibia	Yes	No	Most BOS components manufactured locally or imported from South Africa. Modules sourced from South Africa or direct from manufacturer.
Senegal	Yes	No	Most PV components imported, although automotive batteries manufactured locally.
South Africa	Yes	Yes	All components manufactured in country. Most major international module manufacturers have dealerships in South Africa.
Tanzania	Yes	No	Emerging market. 9 firms involved in system installation. All components imported (excepted 1 battery manufacturer) and systems are purchased privately. Estimated nine companies involved in PV installation, 5 major importer/distribution, and >60 retailers.
Uganda	Yes	No	Emerging market. System components imported and assem bled locally. Estimated 9 companies involved in PV installation, 6 major importer/distribution, and >20 retailers.

Source: (IEA PVPS, 2003)

about the raw material market and to achieve adequate designs to each application.

In order to assess the impact of local manufacture on cost, the typical solar home system must be examined taking in to account that the main cost elements for the manufacture of photovoltaic are locally manufactured such as modules, battery control units, inverters, and storage batteries.

It can be seen from Table 6 that cost reduction should not be the overriding reason to introduce local manufacturing. Other reasons should be taken into account, such as the need to transfer technology, improve manufacturing, and strengthen the country's human resources in research and development.

All of this suggests that local manufacture of PV systems would not solve things alone, but would go a long way to make PV a source of economic strength, and not a net drain on the economies of African nations.

Acknowledgements

The main purpose of this document has been to synthesize and pull together existing information on PV in Sub-Saharan Africa, particularly combining market, SHS use, and manufacturing elements. To this end, we acknowledge the extensive work of the wider solar research community represented in this document; in particular we acknowledge ESD, IEA PVPS and Nieuwenhout, van Dijk et al.

References

Acker, D.A. and D.M. Kammen (1996) "The Quiet (Energy) Revolution: The Diffusion of Photovoltaic Power Systems in Kenya," Energy Policy, 24, 81-111.

Duke, R. D. and D. M. Kammen (2003). Energy for Development: Solar Home Systems in Africa and Global Carbon Emissions. Climate Change for Africa: Science, Technology, Policy and Capacity Building. Pak Sum Low, Kluwer Academic Publishers: 250-266.

Duke, R.D., A. Jacobson and D.M. Kammen (2002) "Photovoltaic Module Quality in the Kenyan Solar Home Systems Market," Energy Policy, 30, 477-499

Duke, R.D. and D.M. Kammen (1999) "The Economics of Energy Market Transformation Initiatives," The Energy Journal, 20 (4), 15-64.

ESD (2003). World Bank Study on PV Market Chains in East Africa, Energy for Sustainable Development.

IEA PVPS Task III (2003). Stand-alone PV Systems in Developing Countries.

Jaeger-Waldau, A. (2005) "PV status report 2005", Office for Official Publication of the European Communities.

Jacobson, A. (2004) "Connective Power: Solar Electrification and Social Change in Kenya", Ph.D. Dissertation, Energy and Resources Group, University of California, Berkeley.

Karekezi, S. and W. Kithyoma (2002) "Renewable energy strategies for rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa?" Energy Policy 30, 1071-1086.

Nieuwenhout, F. D. J., A. van Dijk, et al. (2001) "Experience with Solar Home Systems in Developing Countries: A Review." Progress in Photovoltaics: Research and Applications 9, 455-474.

World Development Indicators database. African Development Indicators 2005. Washington, DC.