European Union Tropical Forestry Paper No. 2. Brussels: European Commission, 1999.

Dewees, Peter. "The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity." *World Development* 17, no. 8 (1989): 1159–1172.

Food and Agriculture Organization of the United Nations. *State of the World's Forests, 2005.* Rome: Food and Agriculture Organization of the United Nations, 2005.

Girard, Philippe. "Charcoal Production and Use in Africa: What Future?" *Unasylva* 53, no. 211 (2002): 30–34.

Ribot, Jesse. *African Decentralization.* Program on Democracy, Governance and Human Rights, Paper No. 8. Geneva: United Nations Research Institute for Social Development, 2002.

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ELECTRIFICATION

Sub-Saharan Africa, the region with the highest levels and the most rapidly rising percentages of the population in poverty, also has the least access to modern energy. Since late 1980s, the absolute number of the poor in sub-Saharan Africa (SSA) has grown five times more than in Latin America and twice that in South Asia. Since the mid-1990s, not only has SSA lagged behind globally in gross domestic product (GDP) per capita, but also in the mid-1990s, electricity consumption (see Figure 1). The levels of electricity consumption are strikingly low at 126kWh/capita (kilowatt hours per capita) or 150 times that in industrialized countries. Further, in the 1990s, the average per capita consumption of modern energy in Africa was less than 300 kilograms of oil equivalent (kgoe), or approximately 50 percent of the global average.

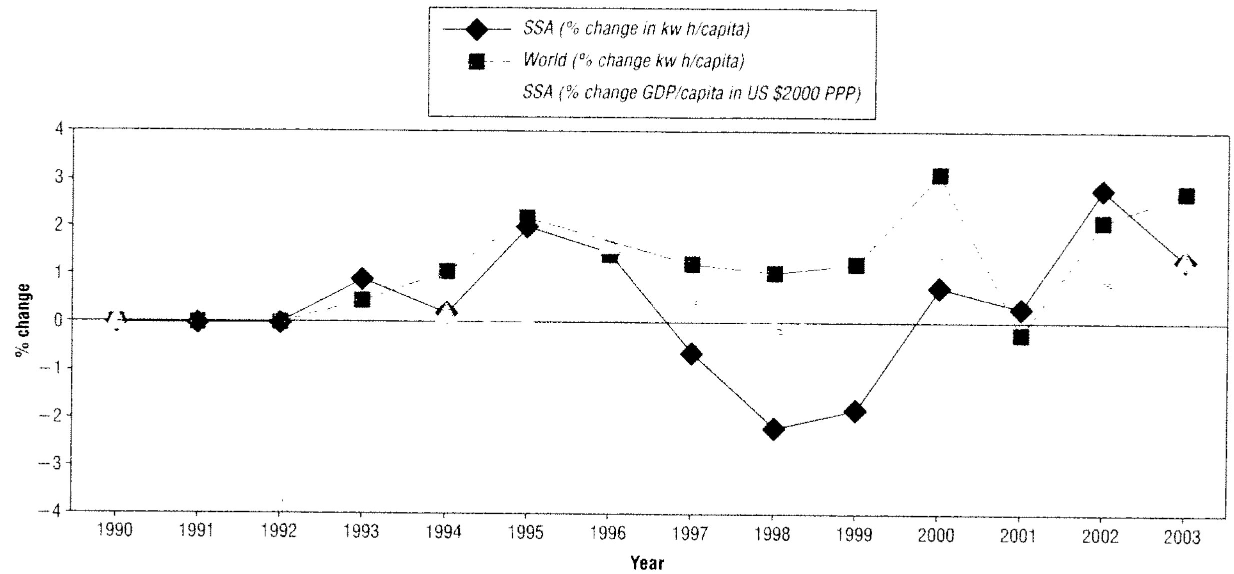
After five decades of rural electrification, less than 5 percent of the rural population has access to the central grid in SSA and new connections barely keep pace with population growth (see Table 1). The patterns of regional energy production and consumption are far from uniform, however. North Africa is heavily dependent on oil and gas, the Republic of South Africa on coal and nuclear energy while in the rest of SSA biomass (charcoal, fuelwood, dung, and crop residues) supplies 70 to 90 percent of energy demand. The Republic of South Africa accounts for 50 percent of installed electricity generation in the continent. Moreover, energy use and energy investments in SSA are clearly mismatched. Despite serving a minority, large-scale conventional energy sectors (electricity and petroleum) receive the bulk of energy investments. This is at the expense of the abundant, mature and cost-effective small-scale renewable energy technologies (RETs) such as micro-hydro, solar energy, and improved biomass cookstoves. Many studies in SSA and elsewhere demonstrate strong empirical linkages between RETs and a wide range of the United Nations (UN) Millennium Development Goals (MDGs), including reduced child and maternal mortality, poverty alleviation, improved education and health services.

INNOVATIVE REGULATORY TOOLS FOR EXTENDING RURAL ELECTRIFICATION IN AFRICA

Sub-Saharan Africa, like many other least-developed countries (LCDs), has spent over a decade implementing a standard reform package aimed at creating competitive markets in the power sector. Implementation of these reforms raised many hopes, not the least of which was increased access to rural electrification. After nearly two decades of implementation, the results are disappointing, however. Improvements in electricity access, quality, reliability, and affordability have not materialized as expected. A number of international and national factors and processes underlie the failed promise of reforms in sub-Saharan Africa. First, while reforms in Organization for Economic Cooperation and Development (OECD) countries were limited to the power sector and supported by strong and functional economic and political systems, reforms in non-OECD countries, SSA inclusive, were economy-wide; overlaid on weak and dysfunctional economic and political institutions. This led to mismatched expectations and capabilities in the latter.

Additionally, while reforms improved financial and technical performance in certain utilities (e.g., Tanzania), researchers have contested the international indicators (e.g., customer-employee and electricity sales-employee ratios) used to measure such success. Given the monopolistic power supply conditions in developing countries, employee performance has limited effect on customer's choice. Moreover, using consumption average to rate utility performance created negative incentives toward

Percentage changes in GDP per capita, and electricity consumption in sub-Saharan Africa and electricity consumption in the world



SOURCE: http://devdata.worldbank.org/dataonline/ (accessed 11/10/06).

Figure 1.

Electrification rates in selected sub-Saharan African countries

Country	% of total population below the poverty line(1)	Electricity use per capita (kWh)	Electrification level (%)			Traditional energy as % total energy consumption
			Rural	Urban	National	
Malawi	54		<1	46	6	82
Ethiopia	76	24	<1	12	3	93
Eritrea		44	2		18	66
Mozambique	78	48	1	18	9	93
Sudan		49			31	
Benin		54			25	90
Tanzania	51	62	1	26	9	95
Congo		70			20	75
Nigeria		89			45	
D.R. Congo		90			8	
Angola		92			5	
Botswana	33		8		26	
Zimbabwe	41		19	80	41	60
Namibia			15			
Zambia	86		2	25	18	78
Uganda	55		1	20	4	92
Kenya	47	104	4	46	15	78
South Africa		3800	50	84	67	

(1) Defined by national poverty references using PPP of $1/day

SOURCES: World Bank. *African Poverty at the M[illegible]nnium – Causes, Complexities and Challenges.* Washington, DC: World Bank, 2001; AFREPREN/FWD. *AFREPREN/FWD Energy database.* AFREPREN/FWD, Nairobi, 2002; Ministry of Energy Kenya. "Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments." Final Report by Kamfor Ltd. Nairobi, 2002. Entries with no data reflect either the lack of reported information, or cases where published estimates differ significantly.

Table 1.

rural areas where demand is generally low and dispersed. The reforms also justified massive retrenchment and a steep rise in tariffs, by as much as 300 percent in Ghana, for example; triggering social and political unrests. By narrowly focusing on cost-recovery and finance, the standardized reform menu lacked the appropriate breadth and sequence required to address important social and public goals such as electrifying the poor-both urban and rural. Further, instead of lowering the cost of electricity supply, thus increasing demand, breaking up of public monopolies, and liberalizing generation and distribution has had the opposite effect.

In the post-reform period, rural energy service suppliers in Africa will be very different from the large national utilities with which most governments are traditionally familiar. Given the right incentives and institutional framework, individual entrepreneurs, small companies and industries, nongovernmental organizations and local communities are likely to catalyze and dominate the liberalized rural electricity markets in the future These players may be inexperienced with electricity, and constrained by capital and technical skills. Yet, the profit motive and ability to manage costs are likely to compensate for any deficiency in technical knowledge and finances. The Urambo Electric Consumer's Cooperative in Tanzania is a promising example; it performs better than the national utility, Tanganyika Electricity Company (TANESCO), in terms of lower operation and maintenance costs, setting and enforcing cost-reflective tariffs and improved customer service.

In Latin America, South Asia, and SSA, the emerging rural electricity suppliers can be grouped in three broad models: concessions, cooperatives, and dealers. In the concession model, the entity or concessionaire is granted a franchise to supply power for a profit. Supply can take different forms: distribution or generation or generation and distribution. Also, concession can either be exclusive or nonexclusive. The former is time bound, with the concessionaire enjoying exclusive right to supply to a predetermined geographic territory. Producing and/or distributing goods and services for its members, a cooperative is a commercial enterprise created to serve the interests of its members. Electric cooperatives pioneered rural electrification in the United States in the 1930s. Dealers sell (and often) maintain energy equipment such as solar photovoltaic (PV) and related components to rural customers. Dealers face many challenges including stiff competition, limited cash flow, limited access to credit and low purchasing power of rural customers. Successful models in Kenya and Sri Lanka have penetrated and grown through existing dealer networks, retail businesses, and personal relationships. These networks help in lowering the per-unit costs because many costs are spread over a wide range of retail products. Through cash sales and check-off system, the rural middle-class, notably tea and coffee farmers and salaried government employees such as teachers, have provided a critical market for solar PV in Kenya.

Africa stands to gain the most by drawing from vast experience and lessons gained in South Asia and Latin America on how to seed and grow rural electricity markets while protecting private investments. A number of innovative regulatory tools have demonstrated success in these regions. Examples include licensing; standards and guidelines; metering; tariffs and out-put based contracting. Licensing is a standard regulatory tool for restricting access to an industry. Licensing can vary from a lengthy and costly bureaucratic nightmare to a simple one-stop process. Generation and distribution in rural India is license-free; rural generation and distribution below 1MW and 0.5MW (megawatts) is license-exempt in Nepal and Uganda, respectively.

Despite power sector reforms, conventional technical standards inherited or adopted from Europe and the United States are still enforced for rural electrification in most African countries. Reducing the size of poles and increasing the distance between poles (long span) can dramatically cut costs. In El Salvador, for example, the long span is 295 feet as opposed to 442 feet in many other countries. Given the low loads in rural areas, switching transmission from three-phase to single phase can be economical. Many rural towns in the United States, with much higher loads than many urban areas in Africa, continue to be served cost-effectively by single-phase power. Further, the Single Wire Earth Return (SWER) systems are the cutting edge technology for rural electrification in many countries such as Australia, Canada, New Zealand, Brazil, India, Tunisia, Botswana, South Africa and Namibia.

Conventional metering is inappropriate for rural Africa for, at least, two reasons. The transaction and administration costs of installing and reading meters and bills preparation by far exceeds the corresponding revenue generated because of low demand, subsidized tariffs and scattered rural population. Additionally, unlike the large-scale utilities, distributed generation systems operated by rural electricity suppliers are likely to be too capacity-constrained to meet temporary peak demands. This problem can be easily solved by metering on the basis of instantaneous power consumed (kW) rather than cumulative consumption (kWh). Customers are then charged for a preset maximum power per month and circuit breakers, which are much cheaper than normal meters, are used to enforce load limits.

Getting tariffs right is essential if rural electricity markets are to emerge and grow in Africa. Common claims that rural people cannot afford the true cost of electricity can be misleading. Through wide use of batteries to power lights, TV and radio, a sizeable proportion of rural people have demonstrated willingness and ability to pay for improved energy services in the order of three to ten dollars per kWh. In setting tariffs, the regulator must therefore ensure that private rural electricity suppliers receive a reasonable return on investment. This is not an argument against subsidies, however. If directed at capital investments rather than operating costs, combined with cost-reflective tariffs, technology-neutral subsidies could make a positive difference in rural electrification.

Linking subsidies to concrete outputs is another institutional innovation suitable for the energy sector in Africa. Introducing supply competition through output-based contracting for rural electrification has increased electricity access while lowering costs in Cape Verde, Chile, and South Asia. Under this system, private companies bid to supply rural electricity services to selected areas at least cost. Payment of subsidies and/or renewal of contracts (by government or donors) are conditional on meeting pre-determined targets (e.g., number, rate and cost of connections). Active participation of the beneficiary community through financial or labor contributions, local management and in the contract renewal processes can lower costs further, enhance monitoring of targets and improve service delivery.

Wheeling-and-dealing and net-metering are additional transmission constraints facing rural electricity suppliers. Despite two decades of reforms, transmission and pricing mechanisms and rules are heavily skewed in favor of utilities with steady and predictable flow of power. This presents a serious setback to rural suppliers operating and/or considering investing in highly variable renewable sources such as solar, wind, micro-hydro and co-generation. Moreover, metering systems have not been adjusted to measure two-way flow. Consequently, rural industries (e.g., tea and sugar factories operating micro-hydro and co-generation DGs, respectively) are unable to sell electricity to the national grid when they have surplus generation while buying back during low generation seasons. Another major disadvantage is the pricing of transmission services. Utilities charge a flat transmission fee irrespective distance wheeled, congestion and line losses incurred. Uniform transmission pricing fails to reward rural suppliers located closer to their demand centers for lowering line losses and cost of power supply vis-à-vis state owned utilities.

THE UNMET PROMISE OF RENEWABLE ENERGY IN AFRICA

In 1981 Africa hosted the first international conference on New and Renewable Sources of Energy in Nairobi. As the world faced unprecedented high petroleum energy prices, Africa, as elsewhere in the world, embraced the strong optimism and vision for transition to renewable energy sources. While important initiatives have since been taken, notably in biomass and solar energy, the promise of renewable energy in Africa remains largely unmet.

Biomass Energy and Co-generation. The renewable energy conference played a key role in launching programs for research, design, and dissemination of improved household woodstoves in the region. Designed to improve both combustion and heat transfer efficiencies, about three million improved household woodstoves have been disseminated in over ten African countries (see Table 2). Most of the improved stoves have been adopted in urban households and therefore dissemination to rural areas needs to be aggressively pursued.

In 2001, 400,000 premature deaths, especially for women and children, in SSA or 25 percent of such deaths globally, were attributable to indoor

Dissemination of improved household woodstoves in sub-Saharan Africa

Country	Improved household stoves disseminated
Botswana	1,500
Malawi	3,700
Zimbabwe	20,880
Sudan	28,000
Ethiopia	45,000
Eritrea	50,000
Uganda	52,000
Tanzania	54,000
South Africa	1,250,000
Kenya	1,450,000
Total	2,955,080

SOURCE: AFREPREN/FWD. *AFREPREN/FWD Energy database*. AFREPREN/FWD. Nairobi, 2002.

Table 2.

air pollution from biomass use. This mortality trend is projected to reach 10 million by 2030. Rapid transitions to sustainable charcoal production and use have the potential to prevent three million deaths, however. Moreover, biomass fuels, particularly the charcoal trade, are a vital source of livelihoods and employment to millions of people in Africa. In Kenya, for example, charcoal trade provides direct employment to about 200,000 people, supports roughly 2.5 million livelihoods, with women playing a significant role in production, distribution, and selling.

In SSA, cogeneration provides substantial opportunities for producing electricity and/or process heat, cost-effectively and in environmentally friendly manner. Various forms of biomass, notably sugar cane waste (bagasse) could be used. Sugar is a major agricultural export crop in many countries such as Ethiopia, Madagascar, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe. Mauritius already meets 20 percent of its total electricity demand from bagasse-based cogeneration; estimates show that 16 other SSA countries could meet significant proportions of their current electricity demand through this process

Solar Energy. For lighting, rural households in Africa spend an overwhelming amount on kerosene, a fuel that delivers poor and very costly lighting services. The cost per useful lighting energy services ($/lumen-hour of light) for kerosene lighting is 3,000 times higher than for compact-fluorescent light. This makes solar PV an increasingly important alternative for cleaner and cheaper lighting services. In addition to lighting services, demand for "connective power" by the rural middle class—i.e., electricity to power television, radios, cellular telephones phones—are the key socioeconomic uses driving the solar PV in rural Africa. In Kenya, solar electrification has outpaced grid connection with cumulative sales of solar home systems in excess of 200,000 units and growing at 18 percent annually.

Debates about solar PV in SSA revolve around cost, equitable access and potential for productive uses to generate income and contribute to poverty reduction. Of primary concern is the high cost of the technology. The cost of a typical household PV system (40-50W_p) can be as high as 200 percent of the GNP per capita of most SSA counties (see Table 3). The PV cost estimates could even be higher considering that rural incomes are much lower than the national average GNP per capita in SSA. Through better-quality lighting, solar PV has enabled important but modest income-generation activities in Africa. However, the amount of power delivered by typical solar home systems is insufficient for mechanical applications such as agro-processing, irrigation, welding, and carpentry. These productive uses account for over 50 percent of off-farm income and employment in rural Africa.

The high costs combined with the market-driven dissemination approach have decidedly kept solar PV beyond the reach of the majority rural poor. The richest 10 percent own 50 percent of all solar PV systems in rural Africa. Another important observation is that the small size PV systems affordable to rural middle-class households deliver less than one-tenth of the electricity (about 30kWh/year) used by an average grid-connected rural household.

Fuel-based lighting is another major concern in Africa. Apart from delivering low quality lighting at high cost, extensive fuel-based lighting is also a major source of greenhouse gases (GHGs). Used four hours a day, a typical kerosene lantern emits over 100 kilograms of GHGs into the atmosphere each year. But rapid penetration of cost-competitive cleaner alternatives such as solar PV and solid-state white light-emitting diode (WLED) is constrained

GNP per capita and cost of household solar PV system

Country	GNP per capita	Estimated cost of solar PV system (40-50W$_p$) US$	% of estimated cost of solar PV system per GNP per capita
Zambia	330	1200	364
Uganda	310	1037	335
Eritrea	200	600	300
Kenya	350	620	177
Lesotho	570	1000	175
Zimbabwe	610	800	131

SOURCE: Karekezi, S., and W. Kithyoma. "Renewable Energy Strategy for Rural Africa: Is a PV-led Renewable Strategy the Right Approach for Providing Modern Energy to the Rural Poor of Sub-Saharan Africa?" *Energy Policy* 30 (2002): 1071-1086; Jacobson, A., and D. M. Kammen. "Engineering, Institutions, and the Public Interest: Evaluating Product Quality in the Kenyan Solar Photovoltaics Industry." *Energy Policy* (2006).

Table 3.

by substantial subsidies extended to kerosene and propane fuels by African governments. In addition to creating price distortions, encouraging fuel diversion and adulteration into the transport sector, fuel subsidies divert scarce public resources from critical pro-poor social services such education and health.

Heating Energy Services. Electrification commands the largest share of rural energy projects and funding in Africa as in other developing countries. While electricity is important for rural development, studies have shown that heating energy—which is too costly to provide with electricity—is crucial particularly for cooking and income generation. In many parts of SSA, women travel for 6–8 hours each day collecting sparsely distributed fuelwood for their cooking needs. Heating energy is also crucial for many rural industries and micro-enterprises such as beer brewing, brick-making, food processing. These enterprises are the primary sources of rural and urban livelihoods, particularly for women in Africa And in many parts of SSA, charcoal and fuelwood dominate the available heating energy mix.

Emphasis on heating fuels has the advantage of opening food micro-enterprises as a significant market niche for improved energy services. Greater attention to heating energy and switching to more efficient heating fuels like LPG would have twofold impact: first, enhance the profitability and employment in the heat-intensive micro-enterprises and industries; second, substantially reduce the aggregate woodfuel consumption in urban areas, thus lowering losses in forest cover in ecologically fragile savanna lands where charcoal is commonly produced in Africa.

See also **Children and Childhood: Infancy and Early Development; Production Strategies; Women: Women and Urbanism.**

BIBLIOGRAPHY

Bailis, R.; M. Ezzati; and D. K. Kammen. "Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa." *Science* 308 (2005): 98–103.

Cabraal, A.; D. F. Barnes; et al. "Productive Uses of Energy for Rural Development." *Ann Rev Environ Resources* 30 (2005): 117–144.

CORE International. *Zambia: Regulating Rural Electrification Experiences and Lessons; Learned Report Prepared for the United States Agency for International Development.* CORE International, Inc., 2005.

Jacobson, A. "Connective Power: Solar Electrification and Social Change in Kenya " *World Development* 35, no. 1 (2007): 144–162.

Karekezi, S. "Poverty and Energy in Africa—A Brief Review." *Energy Policy* 30, nos. 11–12 (2002): 915–919.

Wamukonya, N. "Power Sector Reform in Developing Countries: Mismatched Agendas." *Energy Policy* 31 (2003): 1273–1289.

Williams, J. H., and R. Ghanadan. "Electricity Reform in Developing and Transition Countries: A Reappraisal " *Energy* 31 (2006): 815–844.

World Bank. *Reducing the Cost of Grid Extension.* Washington, DC: World Bank, 2000.

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INTERNAL COMBUSTION ENGINE

In Africa there is a vast field of study that has only partially been systematically researched or analyzed. Since the start of the twentieth century this field has become so pervasive as to have become unnoticed as a simple fact of everyday life, much as the clothes that one wears, and the food that one eats. This is the field of the interaction between people and the Internal Combustion Engine (ICE). Internal combustion