The Energy Crisis of Nigeria
An Overview and Implications for the Future

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Preface

For many years now, Nigeria has been facing an extreme electricity shortage. This deficiency is multi-faceted, with causes that are financial, structural, and socio-political, none of which are mutually exclusive.

For the purposes of this paper, after searching through copious amounts of literature, we were able to flesh out most of the financial and structural issues. With only this perspective, we naively attempted to compare cost projections for rural electrification, including both grid extension and decentralized methods. The projected costs are high but not so prohibitive as the current electrification statistics would suggest. We realized that there must be some aspect of the problem that cannot be reflected through numbers and official policies.

To discuss this possibility Julia contacted Professor Babafemi Akinrinade in the Human Rights Department at University of Chicago, a native of Nigerian familiar with the nation's energy situation. After discussing the issue of energy with him at length, it became evident that the energy problem is, at its root, a social one. These social issues are not well documented in the scientific, economic, and policy literature. The discussion with Professor Akinrinade made evident that an understanding of Nigeria's energy situation requires an understanding of the culture at a level deeper than what is available only through reading.

The goal of this paper is not to solve the energy crisis of Nigeria, but rather to introduce the depth and complexity of the issues involved. In the appendix, we describe various strategies that could be used to address the solution. The energy situation in Nigeria is quite different from that of the United States and other more developed countries. Yet alleviation of the global energy crisis will require a coordinated effort on the part of many nations. Thus, it is important to have a general understanding of the nature of problems in areas of the world less familiar to westerners.

Overview: the Energy Crisis in Nigeria

Nigeria is located on the west coast of Africa. It is the continent's most populated country in Africa, with over 150 million people. According to the Nigerian Energy Policy report from 2003, it is estimated that the population connected to the grid system is short of power supply over 60% of the time [1]. Additionally, less than 40% of the population is even connected to the grid [1]. On a fundamental level, there is simply not enough electricity generated to support the entire population.

Table 1: Electricity Supply-Demand Balance Sheet (March 1991)

	Plants Capacities (mw)		Demand Situation (mw)			
	Installed	Effective	Morning Peak	Evening Peak	Highest Demand	Average Demand
Demand	4,633	1,712	1,500	1,800	1,902	1,855
Excesses		-	212	-	-	-
Shortages		2,921	-	88	190	143
Remarks		Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory

Source: Adegbulugbe & Seriki **Ed**. Energy Issues in Nigeria, 1991.

The grid is powered by hydropower and thermal, which itself is composed of fossil fuels (see table below). Within each of these sources there are structural problems that detract from the overall efficiency of the energy producing capacity of each type of infrastructure. This will be described in more detail later.

Table 2
Nigeria's electricity sources

Source	% contribution
Gas	39.8
Hydropower	35.6
Oil	24.8
Coal	0.4

Source: World Bank (2001a).

Although the government has recognized the need for more electricity, it has had great difficulty funding and organizing this endeavor. As an attempt to rectify this situation, the government divided the National Electric Power Authority (NEPA) into two sectors in 2005, one in charge of the generation of power and the other in charge of the distribution of power [4]. As part of this division, the government sought to privatize these sectors in an effort to finance and organize the needed development of infrastructure. This effort on the part of the government takes place in the face of a general population opposed to the prospect of privatization. As a result, the general population often vehemently resists any efforts associated with privatizing the energy sector. This resentment toward privatization spans the majority of the population and, according to a study on utility privatization carried out by Ademola Ariyo, is rooted in the experience of many Nigerians with the introduction of a private sector in the water supply. Prior to the explosion of today's middle class in 1999, a large proportion of the population was in poverty. During this time, water shortages were common. To supplement the government's supply of water during times of deficiency, private sources provided water to people's houses. The price of this water far exceeded the budgets of many families, who were forced to resort to drinking unsanitary water from streams. This created a wide-spread resentment and skepticism of privatization of any utility[2].

This popular attitude towards privatization creates an interesting paradox. The government can only develop the needed infrastructure to provide enough energy for the entire country with the financial support of the private sector; the general populous, however, outwardly opposes the prospect of privatizing the energy sector and sabotages most attempts made by the government to do so. The government's intentions are to help provide electricity to the public, but a lack of communication in the process of privatizing the industry causes an out-cry by the public. This disdain for privatization includes even members of the energy sector itself. These people fear that privatization would cost them their jobs. In fact, there have been suspicions of sabotage by members of the government's own energy sector; however, these allegations have not been proven [4].

The Nigerian Power Sector: Past and Present

The Nigerian Electric Power Authority (NEPA) was established in 1972 by the government-sponsored merger of the Electric Corporation of Nigeria (ECN) and the Niger Dams Authority. NEPA has since operated as a government-controlled monopoly in the domain of power generation, transmission, and generation (although one government source does claim that the monopoly was nominally abolished in 1998 [5]).

In terms of management and performance, NEPA has room for improvement. Poor financial performance stems, as it does in many developing countries, from low productivity, excessive debts, "non-settlement of electricity bills by consumers" and the high fixed costs associated with power production [6] One paper reports that the collection rate from consumers on the power grid is roughly 75-80%, compared with close to 100% in developed countries [7]. The energy sector's marginal products of labor and capital are also low, so that even as prices may run high, costs are inevitably higher than they ought to be. Indeed, Girod & Percebois (1997) aptly note that retail prices can work both for and against national power companies: high prices "increase frauding tendencies of users with a low purchasing power…[and furthermore] in a badly managed company, an increase in prices would in fact be an option for bad management, a relief valve to postpone necessary adjustments" [8]. Predictably, this disorder has caused skepticism among both domestic and foreign lenders, which invariably has made attracting new investors difficult. The financial capital that is available is often improperly allocated or underemployed. Though well intentioned, NEPA has struggled to organize and distribute capital in an efficient way and has thus been a substantial money drain on the Nigerian federal government, which has had to absorb the utility's losses.

Structural problems of the current energy system

NEPA's severe technological deficiencies are prevalent throughout the power system, both upstream and down. For example, with modern technology about 40% of the energy consumed in thermal plants can be converted to electrical energy. In the absence of this technology, as currently the case in Nigeria, this figure can be as low as 12% [9]. Of the power that is produced, there is further loss through transmission. One estimate claims that between 30 and 35% of power generated in Nigerian power stations is lost in this way [7]. By comparison, power losses across lines in the United States usually come to less than a percent, even across greater distances. It is impossible to determine exactly how much of this inefficiency is due to illegal users' tapping the lines, but it seems likely that underinvestment in technology is the greater problem. Lack of modern standardized components and qualified maintenance staff pose serious problems for adequate electricity generation and supply. Various sources indicate that Nigeria's installed generating capacity is between 5000 and 6000 MW [7, 10]. Yet, by the government's own admission, actual output has never exceeded 4000 MW. In reality, the actual output is usually far below this. Never mind that actual electricity demand including off-grid generators is believed to be closer to 10,000 MW [10]!

Below are articulations of the particular problems associated with each aspect of the energy sector.

Hydropower:

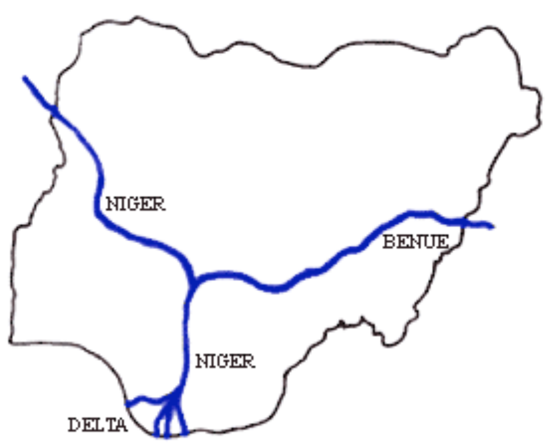
There are many problems associated with hydropower:

i) The current infrastructure of the hydro plants is in dire need of rehabilitation and the actual energy output of the plants is far below their projected capacity.

ii) The output of the hydro plants is highly oscillatory according to the seasonal droughts.

iii) The trends of climate change have led to a continual loss of water. Since the power output of hydro plants is dependent upon the flow of the river, with less water, there is less potential energy to harness, making hydropower a less desirable energy source [1].

iv) Two rivers, Niger and Benue, account for the majority of hydropower generation. Prior to entering Nigeria, the rivers pass through Niger and Cameroon (see figure below). In order to obtain the maximum amount of energy from these rivers, Nigeria must provide incentives to prevent Niger from installing their own dams on the rivers. Thus, a portion of the energy generated by the hydro plants is exported to Niger to compensate for their agreement not to build dams along the river. Thus, Nigeria receives even less of the already dwindling electricity generated form existing hydropower



Source: www.motherlandnigeria.com

Oil and Oil Refining:

Most of the oil extracted in Nigeria is exported: about 2.2 million barrels per day [3]. In 1999, there was very little oil consumption within Nigeria (about 100,000 barrels/day). That year, the country gained independence from military rule and a democratic government was put in place. With this transition came the enlargement of the middle class, leading to an exponential increase in automobile use and thus oil consumption [4]. Although Nigeria is the 11th largest oil exported in the world, the refining capacity of the country is very minimal. The projected refining capacity only supports 445,00 barrels a day, and the actual output of these refineries is far below capacity [3]. Additionally, the refineries do not capture the gas that is given off in the refining process and it is instead burned as flares. In most countries this gas is captured and re-inserted into the ground; however, this process requires additional pressurized tanks. It is estimated that significantly more than half of Nigeria's natural gas is given off as flares. Thus, a huge amount of valuable fuel is simply burned off. This process is also very detrimental to the environment.

Liquid Natural Gas (LNG):

Nigeria has a large source of liquid natural gas (LNG), 163 trillion standard cubic feet [3]. The Nigerian energy sector has begun the development of the necessary infrastructure to utilize LNG to contribute to the national grid capacity. This process involves building pipelines to transport the LNG to the power plant as well as building the power plants themselves to convert LNG to electricity. The construction of the pipelines is still underway; however their stability is marginal as there have been numerous instances of sabotage to the structures themselves. This is not the most pressing problem. Concurrent with the development of pipelines for internal use, a pipeline to divert LNG to parts of Europe was also developed. The motivation on the part of the European nations was to decrease their own dependence on Russian LNG. These pipelines are now functional, and as a result, all of Nigeria's LNG resources for the next six years are tied up in the piping to Europe and consequently there will be no available LNG to use internally [4]. Thus, despite the infrastructure in place, the country cannot harness this energy.

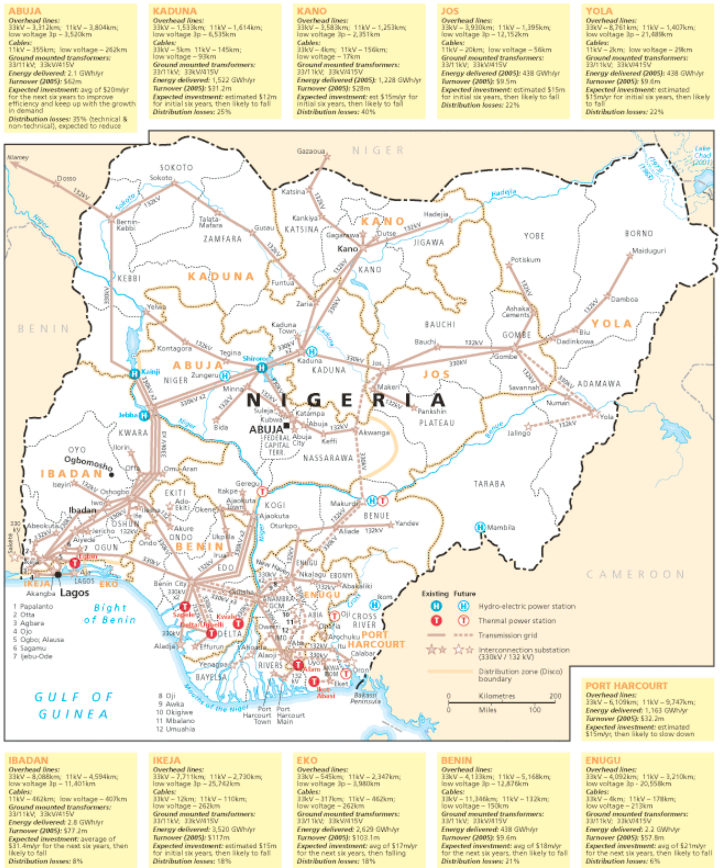
The Grid Structure:

The grid structure is unstable and vulnerable to sabotage (see map below for the layout of the grid). Some of the problems associated with the grid structure are:

i) People are able to connect their residence or industrial enterprise to the grid without a meter. This is one source of how power is leaked during transmission.

ii) There are zoning issues that reek havoc on the system. In some cases, a property will be zoned for a residence; however, these designations are not enforced. Rather than a residence, the property could be used for industrial purposes, which often use more energy. This discrepancy can overwhelm the grid and cuase a transformer to explode.

iii) Due to the prospect of privatization, there is a propensity to physically sabotage the grid system through dismantling parts of the grid itself.



Source: "Nigerian National Electricity Grid." Global Energy Network Institute <http://www.geni.org/globalenergy/library/national_energy_grid/nigeria/nigeriannational electricitygrid.shtml>.

Generators

Due to the lack of reliable electricity, many people and companies supplement the electricity provided by the grid system with their own generators. In fact, most everyone who can afford a generator owns one. According to one approximation, well over 90% businesses have generators [12]. The electricity from private generators is more expensive than that from the national power grid, thus raising the price of domestic goods. Efforts to alleviate this strain are met with opposition from the companies who import generators, as they have created an extremely lucrative industry. There is suspicion that some of the grid system sabotage is from members of this industry.

Fuelwood

In rural areas, much of the energy production is from the burning of fuelwoods. This practice has a host of associated problems.

i) The emissions given off from this process are toxic, especially if done in doors, which is often the case. (see figure 5 below).

ii) There is a trend of deforestation in Nigeria at 300,000 hectares per year [8]. This is mainly due to the the growth of the timber industry; however, deforestation is propagated due to fuelwood burning. The scarcity of wood as a result of deforestation makes the process of cooking with fuelwood even more unsustainable. The average time it takes one person (usually women) to collect enough wood for the day's meals (2.28 on average) is 4-6 hours, [13]. With deforestation the time it takes to collect this wood will only get longer

iii) The overall efficiency of the commonly used three stone stove is less than 10%. Despite the availability of more efficient stoves and cooking fuels, these alternatives have been adopted for both financial and cultural reasons .

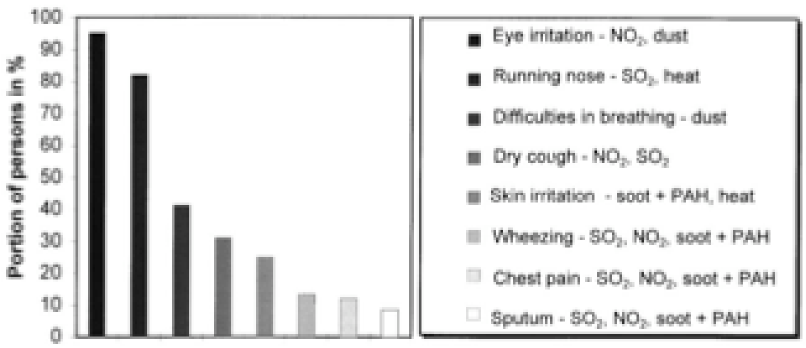


Fig. 5. Health disorders due to wood fires used for cooking and components responsible.

Figure source: [7]

Levels of governmental cooperation

There are three levels of government in Nigeria composed of the national government, 36 state governments and 772 local governments. The energy problems of Nigeria are rampant across the entire country, and thus many of the energy decisions have to be coordinated between all levels of government. There are, however, instances of small-scale grid structures that are fully functional. In fact, one state has developed their own grid and is now selling some of the generated electricity back to the national grid [4]. In this light it is evident that sometimes state and local governments can enhance the local grid structure unilaterally.

Current Energy Policy:

The energy crisis requires additional, physical infrastructure despite political and social resistance. In the energy policy of 2003, NEPA outlines a plan to diversify its energy sector and pursue renewable energy: Below is a breakdown of their plan with regards to each energy form. In particular, NEPA endorses an increase in the utilization of oil, natural gas, tar sands, coal, nuclear, hydropower, solar, biomass, hydrogen, wind and other renewables. The only source of which NEPA advocates reducing use is fuelwood.

Energy form	Policies
Oil	Increase refining capacity Endorse exploration looking for more oil reserves Privatize the oil industry Derive more economic benefits from the oil reserves
Natural Gas	Utilize the nation's NG reserves into the energy mix More gas exploration

	Encourage privatization Eliminate flaring by 2008
Tar Sands	Encourage tar sands exploration driven by the private sector Extract oil from tar sands
Coal	The nation will resuscitate the coal industry for export in an environmentally friendly manner
Nuclear	Pursue nuclear as part of the energy mix
Hydropower	Fully harness the hydropower potential (in particular small-scale) through environmentally friendly means and through the private sector Promoting rural electrification through SHP
Fuelwood	Promote the use of alternative energy sources to fuelwood De-emphasize fuelwood as part of the nation's energy mix
Solar	Help develop the capabilities to utilize solar energy
Biomass	Promote biomass as an alternative energy resource
Wind	Help develop capabilities to utilize wind energy
Hydrogen	Help develop local production capacity for hydrogen
Other renewable	Will remain interested in other emerging energy sources.

Source [3]

Environmental Impacts

The energy industry in Nigeria has severe environmental ramifications, mostly in the form of both pollution and deforestation [3]. The most imminent energy issues for Nigeria are not related to the environment, but to social welfare. Although the immediate environmental ramifications of current practices are not on the scale of the current social needs, irresponsible current environmental practices now could translate into catastrophic impacts in the future. NEPA is not considering the environment as its main priority, but it has pledged to promote energy sector reform only in environmentally friendly means. The main contributors to the air pollution in Nigeria are the gas flares. The government has pledged to cease this activity on December 31, 2008 [3].

Below is an outline of the government's strategy to proceed with energy development in an environmentally friendly means [3]:

i) Putting adequate standards in place
ii) Strengthening the regulatory agencies
iii) Develop definitive goals that must be met
iv) Assess the environmental impact of energy projects
v) Providing alternatives to fuelwood
vi) Encouraging R & D

Considerations for Change:

Simply to fill the void of electricity the country has numerous options given their ample supply of natural resources. One route would be to invest in more oil and gas exploration and utilize more of these sources for direct internal use. Although the NEPA promotes the exploitation of all hydropower potential, this may not be a profitable decision due to the trend of overall diminishing water supply in the country. Long-term investments in renewable energies like solar and wind have the potential to contribute significantly to the electricity deficiency. These technologies, however, have high upfront costs (see Appendix). The adoption of renewable technologies will require reducing the current subsidies on fossil fuels and the import duties on renewable technologies [8].

The theoretical framework of the energy policy outlined by the Nigerian government seems promising, but there is a discontinuity, however, between implementation and theory, rooted in the population's aversion to privatization. Structural reform cannot take place until financial support is in place. This financial support must come in the form of private investments. Financial and subsequently structural reform, however, cannot be implemented until the sabotage of current efforts to privatize the energy sector ceases. A sweeping change of the public's perception of the government at large is required. Increased transparency and education about government processes may decrease feelings alienation. If the negative perception of privatization could be replaced with faith in government electrification efforts, structural reform could proceed. Until this happens, the futile cycle explained in this paper will continue.

Appendix

This section touches on a few options to increase electricity access, especially in rural areas. Statistics and costs are given to present the existing literature on rural electrification. Due to variations across studies such as load estimates, distance from the existing grid, and geographic location, it is difficult to make conclusive generalizations. We note how variation in these factors can affect the technical and financial viability of each option. Options for rural electrification not included in the appendix but worth investigating include hydropower micro-grids and biomass digesters. See "Further reading" for sources on these omitted topics.

Contents

I. Grid Extension

For areas not connected to the grid, grid extension is sometimes the most viable option. Its cost effectiveness compared to decentralized options depends on the types of cables used and the distance of the site from existing power lines. The low expected demand of many rural households is often cited as a reason to stall grid extension, but this claim does not account for the fact that the households with loads of only a few hundred watts can safely be connected to the grid with a lower gauge, cheaper wire than is conventional used in more densely populated areas with heavy demand. Lower gauge wire also allows for the use of less expensive support poles [15]. The upfront costs of grid extension are comprised of cable, installation costs, and a substation if the distance from the existing lines is sufficiently long. Of course the more customers there are who will be connected to these new lines, the lower the average cost of each household's grid connection. The estimated lifespan of grid lines is 50 years [16].

As Nigeria's energy policy currently stands, the electricity cost to consumers depends on the subsidized price, currently around US$0.06/kWh [17]. The subsidized price is at most half the cost of electricity production, and less than half the cost of production and transmission to remote areas [18].

II. Diesel Generators

Today the most common form of off-grid electricity supply is generators running on diesel or gasoline. Generators are used not only by rural households but also by grid-connected households and industries as a more stable supplement to grid power, as mentioned previously. The rural incidence of diesel generators is difficult to estimate, but 96 to 98% of the grid-connected firms surveyed reported ownership of private generators [18].

For these systems, the value of the generator's kVA rating should equal or exceed the wattage of estimated load. The estimated lifetime of a generator is between 10 and 13 years. When calculating the present value of the lifetime costs of fuel, one must consider not only the rising cost of petrodiesel due to Nigeria's limited refining capacity, but also the disparity in Nigeria's official, subsidized price of diesel and the significantly higher price that can be obtained in practice, which ranges from 1.5 to 4 times the official price. The actual market price of diesel is likely highest for the most remote regions. (See Oparaku (2003) for a sensitivity analysis of the life-cycle cost of the entire system with variation in fuel price [19].)

Diesel Generator Life-Cycle Cost Projection:
Discount rate 8%, system lifetime 12 years

Component	Unit Cost (USD)	Quantity	Yearly Cost (USD)	Present Value of Life-Cycle Costs (USD)
50kVA engines	$110, 000 each	2 (rotation of 12 hours/day)		$220,000
Maintenance and spare parts (including engine oil and filters)	10% per year of initial capital cost		$22,000	$245,000
Market fuel price	$1.19/liter, June 2008	14,600 liters year	$17,374	$193,000*

Total	$658,000
Total per kVA	$13,160
Total per Wp	$13

*extremely imprecise if fuel is bought more often than annually and due to high variation in price

Sources: [16, 20]

Formula for Present Value of Life-Cycle Costs

$LCC_{DG} = G + \Sigma$[t from 1 to 12 years] $(M + F) / (1 + d)^t$

G	generator cost
L	installation labor cost
M	annual maintenance and spares cost
F	annual fuel cost
d	discount rate

III. Photovoltaic Systems

Components

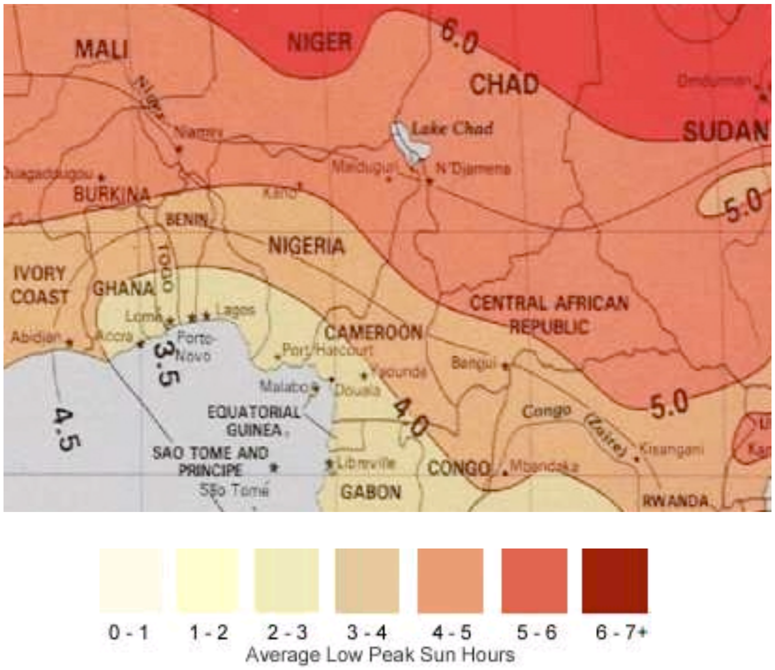
Photovoltaic systems consist of solar panels, a battery, a charge controller, and an inverter. The lifetime of the panels is typically 20 to 25 years, which is considered the lifetime of the total system. The battery allows power to be supplied at night or during cloudy weather. Two types of batteries can be used, deep-cycle and starter batteries. Deep-cycle batteries are more efficient and most commonly used, but starter batteries are already available in Nigeria due to their use in cars. A deep-cycle battery lasts between three and eight years. The charge controller regulates the current added to and drawn from the battery in order to maximize the battery lifetime and for user safety. Because photovoltaic systems produce a direct current, the inverter is necessary only if the end uses of electricity require an alternating current.

Design Considerations

The design of a photovoltaic system must balance the rate of solar energy deposition on a given area with the power required by the load. The measure of total solar irradiance commonly used to assess the input for photovoltaic panels is daily "peak sun hours". The number of daily peak sun hours is equal to the value in kWh of the total amount of direct and diffuse solar radiation incident on a square meter in a day.

As one moves northward through Nigeria, average irradiance increases, despite Nigeria's location in the northern hemisphere. This gradient is explained by the movement of the Guinea trade winds and the associated geographic variation in intensity and duration of the rainy and dust storm seasons. (A study by the U.S. National Academies and the Nigerian Academy of Science (2007) suggests that battery replacement occur during the rainy season, in order to bolster customers' interest in their systems when capacity is at its lowest. In order to maintain optimal system functioning during the opposite season of dusty Harmattan winds, it is important that customers wipe the dust off their panels daily [21].) Lagos and the rest of the coast in the south of Nigeria receive between 3.5 and 4.0 peak sun hours at minimum. The northern region of the country receives between 5.0 and 5.5 peak sun hours at minimum.

Yearly Minimum Peak Sun Hours



Source: [22]

In addition to the minimum number of daily peak sun hours, other factors used to determine the needed capacity of the panels include the load power requirement (adjusted for daily and weekly use duration) and battery storage and discharge efficiencies. Not only will the estimated load determine the scale of the system, but the scale of the system—whether it provides power to an individual household or an entire village—also has implications for how load may vary beyond initial estimates. Users of off-grid photovoltaic systems must be acutely aware of the capacity of their system and must maintain their load below the capacity threshold. In many communities around the world where village-sized systems have been donated by a university or non-governmental organizations, they have exhibited the tragedy of the commons, quickly deteriorating due to overuse. For this reason, it has been recommended that off-grid photovoltaic systems be installed only for individual households [21]. Furthermore, village-scale systems often have no apparent owner in charge of maintenance and repairs, which cease when the donor organization's trial period is over. This recommendation is reasonable, since it is not clear that village-scale systems deliver cheaper power. For capacities above 100 peak watts, costs increase approximately linearly with capacity [23].

Economic Feasibility

Photovoltaic systems have extraordinarily high upfront costs compared with grid extension and individual gasoline or village-sized diesel generators. The panels account for the highest upfront cost, and over an estimated 25-year system lifetime, the replacement of batteries every 3-8 years accounts for the highest total costs. When the load required is sufficiently low (on the order of a few hundred W) and the distance from the grid sufficiently far or diesel prices sufficiently high, the present value of the life-cycle cost of photovoltaic systems is still lower than those for grid extension or diesel generators [16,19].

The payment of the costs of photovoltaic systems can be smoothed with finance, as has been done in other countries. In India, for example, a private firm went to great efforts to explain to banks the benefits of financing loans for rural photovoltaic systems. Customers now pay 10% of the cost of their systems upfront and take out a loan for the rest [21]. The loans cover a maintenance and repair contract in addition to initial capital costs, in order to further smooth the payment schedule [15]. The U.S. National Academies and the Nigerian Academy of Science have prepared a case study of a hypothetical Nigerian firm that would also produce, install, and service photovoltaic systems [21].

A Note on Comparing the Existing Literature

It is difficult to compare studies, because of variations in almost every parameter, which are not always clearly noted. For example, in addition to variation in load configuration, Oparaku's study uses a site that is only 1.5km or so from the grid, while Bugaje's site is 50km from the nearest power line! With 50 km of grid extension, the life cycle costs of Bugaje's photovoltaic system are less than 5% cheaper than grid extension. If Bugaje's site were 10km closer to the grid, his conclusion would be reversed, in favor of grid extension over a decentralized photovoltaic system [16,19].

Photovoltaic Systems (continued)

Formula for Present Value of Life-Cycle Costs

$LCC_{PV} =$
$(P + B + W + C + I + L) + \Sigma[t \text{ from 1 to 25 years}]\ M / (1 + d)^t + \Sigma\ [tB = 5, 10, 15, 20 \text{ years}]\ (B + L_B - S_B) / (1 + d)^{tB} - S_P/(1 + d)^{25}$

P	panel cost
B	battery cost
W	wire & hardware cost
C	charge controller cost
I	inverter cost
L	installation labor cost
M	annual maintenance cost
d	discount rate
L_B	battery replacement labor
S_B	salvage value of battery
S_P	salvage value of panel

Photovoltaic System Life-Cycle Cost Projection:* Discount rate 8%
System lifetime 25 yrs, battery lifetime 5 yrs, charge regulator lifetime 10 yrs

Component	Present Value of Life-Cycle Costs (USD)
100 W_p module (crystalline silicon)	$600
12 V SLA battery	$300
1st replacement, 5 yr	$204
2nd replacement, 10 yr	$139
3rd replacement, 15 yr	$95
4th replacement, 20 yr	$64
Charge regulator	$60
1st replacement, 10 yr	$28
2nd replacement, 20 yr	$13
Mounting structure	$140
Set installation	$80
Total	$1723
Total per Wp	$17

Source: [23]

*Estimation of physical capital lifecycle costs come from a study from Ghana but are consistent with piecemeal information available in the literature on Nigeria. The range of peak sun hours is similar for the two countries, and both currently import the majority of photovoltaic system parts [23].

IV. Wind Power

A renewable alternative to provide electricity to homes and potentially communities not presently connected to the grid is wind energy. Windmills were used in Nigeria as early as the mid 1960s. In the northern regions of Sokoto and Garo, over 20 homes and a school used windmills to pump water. The following decades saw the prices of fossil fuels drop and therefore with cheap energy, wind power was not an appealing alternative. Investment in windmills ceased and the infrastructure deteriorated. The existing infrastructure is obsolete, but research into the feasibility of wind power in certain regions has suggested the physical potential for this type of power generation is high in some regions of Nigeria.

Design Considerations

Specifically in regions with an adequate wind presence, the amount of potential power is dictated by the size of the windmill. Windmills vary in size with small windmills used to pump water or provide power for cooking and refrigeration. Medium windmills provide electricity for one or more homes. Large windmills or utility scale windmills are capable of providing power for entire communities. Often these larger windmills are connected to a mini-grid as to reduce the overall necessity for fossil fuels. In the case of Nigeria, the studies focused on medium size windmills generating between 850 and 1500 kW.

Three separate studies have measured the average wind speed in various parts of the country for periods ranging from three to ten years. The table below shows average wind speeds in three regions: Sokoto in the northwest, Borno State in the northeast, and Orwerri in the south. At wind speeds of 3.5 m/s or greater, wind power systems can provide energy at costs cheaper than photovoltaic, diesel, and grid extension, therefore making Sokoto and Borno State ideal locations for wind power systems [24, 25, 26].

Location	Avg Wind Speed (m/s)	Heigh (m)	Feasibility
Sokoto [24]	3.78	10	YES
Borno State [25]	2.93	10	NO
Borno State [25]	3.98	25	YES
Orwerri [26]	2.8	10	NO

Wind Power (continued)

Economic Viability

As would be expected, the costs of wind power electricity generation are significantly less in regions with a high average wind speeds. 75-80% of these costs are upfront costs of physical capital and installation. The remaining costs are dispersed over the life of the wind power system and are comprised of operating, maintenance, and insurances costs [26]. Although the wind power generation is financially competitive with grid extension and diesel generators in most regions, the costs are declining. One paper estimates the effects of the experience curve in Nigeria to reduce the costs of wind power between 9% and 17% every time the installed capacity doubles.

Cost Projections

Installed wind power capacity cost	N144,000-N999,000 per kW

Energy Costs per kWh by Wind Speed (1 USD = 180 Naira, N)

High wind speeds	N64.00 to N80.00
Low wind speeds	N96.00 to N128.00

Source: [26]

Energy Costs per kWh over Time

1980 average energy cost	N140.80
2007 average energy cost	N65.60

Source: [26]

Conclusion

Wind power has shown great potential in the northern regions yet its practicability in northern Nigeria is still not certain. The real costs of installing a wind power system are extremely high with 80% of the costs coming up front making factors such as the discount rate very important. Over the lifecycle of the windmill, wind power is shown to be a more productive alternative in the northern regions, but the funding for such a large project is not as clear. Further, Nigeria's lack of knowledge increases the direct costs because all installation and other costs must be outsourced. But, as the experience curve below indicates, the innovation in wind power technology will prove cost effective in the long-term. Further, Nigeria would be able to lower some of the initial costs after the first installations by installing and maintaining the windmills in-house in the future.

V. Barnes' review of pricing policy

Impact of energy pricing and supply policies on rural people and urban poor

Supply policy	Energy pricing policy: Subsidized prices	Market prices	Fuel taxation
Limited or targeted supply	Subsidy is redirected away from poor to other groups	Higher-income groups are served first	Traditional fuel prices are unaffected by those of alternatives
	Rural and poor people lack access to fuel	Rural and poor people lack access to fuel	Rural and poor people lack access to fuel
Unlimited or untargeted supply	Modern fuel subsidies mean lower prices for traditional fuel	Traditional fuel prices are capped at price of alternatives	First costs of service, along with fuel costs, constrain poor from purchasing fuel
	Rural and poor people can access service, but it is fiscally unsustainable	Rural and poor people can access service, and it is fiscally sustainable	Rural and poor people can access service, but it is expensive
	Poor benefit from lower fuel prices, but other income groups benefit more	First costs of service constrain poor from purchasing modern fuels	Traditional fuel prices are often high because of higher-priced alternative fuels

Source: [15]

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