A BOTTOM-UP APPROACH TO ENERGY POLICY PLANNING IN WEST AFRICA: THE CASE OF DISTRIBUTED GENERATION OF RENEWABLE ELECTRICITY

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Abstract
Africa's quest for economic development will require the increased availability and use of its abundant energy resources. However, most of its rural population remains without access to modern energy services, and urban residents typically only enjoy an intermittent supply of electricity. Nevertheless, the dominant approach to energy planning continues to be top-down and centralized, emphasizing electricity generation from large dams or fossil-fueled plants and subsequent grid extension to reach more customers. The purpose of this paper is to compare the current "Master Plan" of the West African Power Pool (WAPP) with Distributed Generation (DG) as an alternative paradigm for electrification in the subregion. The "Master Plan" addresses subregional power supply shortage through centralized planning, while "DG" offers a more democratic approach, and stresses small-scale, on-site generation of clean power from the sun, wind, or biomass. First, the paper analyzes the two approaches with respect to three of the main characteristics of Appropriate Technology as outlined by E.F. Schumacher[1], namely: resource sustainability, suitability as „intermediate technologies" and ownership. In the context of resource sustainability, it also evaluates the two approaches with respect to their demand for water, which compete with other uses such as irrigation, drinking, and sanitation. Finally, the paper explores the dominant environmental values in traditional West Africa such as „eco-bio-communitarianism" or the „ethics of nature relatedness", implying a communal societal ethos and a quest for balance with the environment. The main policy recommendation is that the adoption of DG technologies should be grounded in these values, which can provide an ethic, an internal logic, and an epistemological basis for energy planning in the subregion.

INTRODUCTION

Distributed generation (DG) refers to a set of small-scale technologies and approaches to energy management that generate power in close proximity to its point of consumption, and renewable energy technologies generate electricity from the sun, wind, waste or biomass [1]. Together, they can help reduce greenhouse gases and other harmful byproducts of traditional sources of power such as oil, natural gas, coal or nuclear energy, and offer many other advantages in large part due to their flexible nature. A wide range of synonymous terms have been used to describe the concept of DG in the literature such as "distributed power", "distributed resources", "embedded resources", "micro-power", "modular power", "on-site generation" and "self generation". It is also used reciprocally with "combined heat and power" (CHP), "cogeneration" or, "trigeneration" because they generate electricity near the site of its use [1].

[1] Schumacher, E.F., *Small is Beautiful: Economics as if People Mattered* (Vintage Books, 1993)

However, the concept is not new and was discussed in the U.S. under the term “soft energy path” in the 1976 essay by Amory Lovins entitled “Energy Strategy: The Road not Taken”, which offered a radical shift and a mutually exclusive path from traditional, centralized, fossil-fueled generation which he called the “hard energy path” [2]. Lovins, who was influenced by the concept of Appropriate Technology, held that the two energy paths were distinguished by their antithetical social implications and provided technical arguments to show that the more socially attractive system is also cheaper and easier to manage [3]. Similarly, in a keynote address at an international symposium in Kinsasha, Zaire (now the Democratic Republic of Congo) in 1985, the late Senegalese Professor Cheikh Anta Diop, cited the early evidence for anthropogenic climate change and outlined the future potential of clean energy in the form of thermonuclear energy, hydrogen energy or centralized solar power on the African continent[4] Nevertheless, he insisted that it was imperative for African engineers to master the construction of small hydroelectric dams, bioenergy for rural industrialization and the decentralized use of solar and wind power in order to meet the immediate challenges of healthcare and food security [4]. This conceptualization corresponds to what is known within the Appropriate Technology literature as “intermediate technology”.

Background:

The West African subregion is comprised of 16 independent states which established a community in Lagos, Nigeria in May 1975 known as ECOWAS (Economic Community of West African States), cutting across linguistic, historical and cultural differences for the purpose of economic integration [5]. Only about 20% of West African households have access to electricity and the per capita electricity consumption is 88 kWh per year as compared to 11,232 kWh in the U.S. with 100% electrification, that is, more than 120 times as high [6].

ECOWAS has established two flagship energy programs in order to meet the expected increase in demand in the region, namely: 1.) The West African Power Pool (WAPP), which in its primary document known as the “Master Plan”, states that its role is to integrate the national power utilities into a unified regional electricity market, to quadruple inter-connection capacities within the next 20 years, and to generate additional electricity capacity [7], and 2.) The West African Gas Pipeline (WAGP) whose purpose is to construct a 600 km pipeline to transport natural gas from Nigeria to Benin, Togo and Ghana for electricity generation and industrial purposes [8]. ECOWAS also recently created the Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) in Cape Verde in July 2010, which is intended to create markets, formulate policy, and build capacity for the deployment of energy-efficient and renewable technologies [9].

The Master Plan identifies oil, gas and hydropower as the primary energy resources in the region and selects natural gas as its choice for new power generation [7]. In addition to new power generation, the focus of the WAPP is on building a robust grid that facilitates long distance transmission as a viable solution for energy-scarce landlocked countries, and the regional integration of national markets that can provide economies of scale for countries that are too small to justify large scale generation plants such as Togo, Benin, Burkina Faso and Niger [8]. The WAPP model divides the states into two zones in order to implement its proposed developments through 2020[2], each of which has a few main suppliers. In Zone A, Ghana has two hydroelectric power plants, the large Akossombo dam and the smaller Kpong

[2] Zone A includes Nigeria, Niger, Benin, Togo, Ghana, Côte d'Ivoire and Burkina Faso, while Zone B consists of Mali, Mauritania, Senegal, Gambia, Guinea, Sierra Leone, Liberia and Guinea Bissau.

dam, along with one thermal plant. Côte d'Ivôire has a large thermal plant at Vridi and five hydroelectric dams, while Nigeria has dams at Kainji, Jebba and Shiroro. In Zone B, Mali has the Manantali dam, while Senegal has the Diama dam. Construction began for the Felou hydroelectric project in Mali in 2009 [10].

The only mention of a DG technology cited in the Master Plan is that cross-border transmission is more beneficial than "local generation from relatively inefficient small-scale diesel generator sets" [7]. All the same, a few country-level electrification schemes based on DG are underway. In Ghana for instance, the government has been reported to be installing photovoltaic (PV) and hybrid PV/diesel systems as part of its commitment to bring electric service to every community of 500 or more people by 2020 [11]. However, most of such initiatives are not the result of direct government or utility policy, but pilot projects which have been funded by non-governmental organizations or multilateral organizations [12].

Centralized versus Distributed Generation: Which is more "Appropriate"?

This section first compares the different types of technologies with respect to the technical characteristics and costs. Table 1 below shows the efficiency characteristics of DG and conventional technologies as well as their respective technical challenges and advantages.

Table 1. Characteristics of some Distributed Generation and Conventional Technologies[13]

Technology	Characteristics			
	Thermal Efficiency	**Capacity**	**Challenges**	**Advantages**
Wind Turbine	N/A	1 kW – 5MW	Intermittency	Free fuel, declining production costs
Solar PV (Individual Cell)	7 – 17 %	1 W – 10 kW	Intermittency, low capacity, high cost	Free fuel, compactness
Biomass Generator	40%	20 - 50 MW	Air pollution, low fuel energy density	Widely available fuel
Small Hydro	N/A	200 W - 10MW	Low storage capacity, seasonal	Free fuel
Large Hydro	N/A	10 – 14,000 MW	High capital cost, biodiversity loss, displacement of people	Inexpensive fuel (but can be competitive)
Natural Gas	25 – 30%	200 – 1000 MW	Transmission losses, GHG emissions, price volatility	Burns more efficiently than coal or biomass

Table 1 above shows that although natural gas plants are more efficient than solar PV, they emit greenhouse gases and the price of the fuel is volatile. Conversely, though wind and solar are intermittent, they are more compact and the fuel is free. Biomass generators create some air pollution but generating energy from waste is preferable to the methyl halide emissions from widespread domestic burning[14]. The high capital cost of DG is usually cited as an impediment to its adoption but an analysis of the levelized cost of electricity (LCOE) in the U.S., i.e. the total cost over the lifetime of a plant which includes initial investment and operating costs, reveals that DG technologies such as wind and landfill gas are actually cheaper than some conventional technologies such as coal, nuclear, or an integrated gasification combined cycle run on either natural gas or coal [13].[3] Both the centralized and distributed approaches are further explored below with respect to three of the main characteristics of Appropriate Technologies outlined by E.F. Schumacher:

[3] LCOE ($/kWh) in 2005: Wind =0.03; Landfill gas = 0.03; Natural gas = 0.04; Nuclear = 0.04; Biomass = 0.05; New hydro = 0.06; Solar, PV_30% = 0.24. **[13]**

1. Resource Sustainability:

The WAPP Master Plan emphasizes new electricity generation from two fossil fuels, oil and natural gas, and one renewable source, hydropower. Despite their abundance in some countries in the subregion, both oil and natural gas are non-renewable, fossil-based energy sources that will be exhausted long before they can be replenished. This situation will become more acute given the rise in global demand, which is also bound to ultimately increase the prices. As a former U.S. energy secretary is reputed to have said, "making electricity from natural gas is like washing your car with champagne" [15]. Secondly, even though natural gas burns much cleaner than coal or oil, it still releases carbon dioxide and nitrogen oxides as well as methane if it burns incompletely, thereby causing air pollution and contributing to climate change [16]. Thirdly, electric power production from nuclear and fossil-based plants consumes a significant amount of water for power plant cooling that is usually drawn from rivers and lakes, and sometimes degrades water quality [17]. This competes with vital needs like drinking, fishing, or irrigation. Renewable energy systems, on the other hand, typically have little or no need for water for cooling purposes. In addition, low power solar PV has been shown to be important for water purification as well as for pumping water in Sokoto, Nigeria [18]. Distributed generation in the form of transitional technologies that are built at an appropriate scale can use fossil fuels for a short time in order to serve as a bridge to an economy based on energy income, i.e., based on renewable energy [2]. Examples of such technologies include the use of industrial waste heat for generation in CHP systems or hybrid PV/diesel systems. These would also minimize water use.

Hydropower is considered a renewable resource but this can sometimes depend on whether it is generated from small or large dams. Large dams, which are capital-intensive, tend to radically change the flow of the dammed river leading large areas of land such as wildlife habitats or farms to be flooded and displacing local peoples [19]. For instance, despite the positive impacts on the economy, industry, tourism, fishing and so on, since the construction of Akossombo dam in Ghana, there has been an increase in water-borne diseases such as malaria, the loss of land and property and the breakdown of some traditional practices linked to submerged sacred places [20]. Small dams or run-of-the-river schemes, on the other hand are inexpensive, only divert part of the river through a turbine and harness the natural gravity of a river flow to produce electricity from the upstream part which then flows back into the river thereby reducing the land-use impacts [19]. While small dams are more typical of an appropriate technology, it is also possible for large dams to be managed more appropriately. A useful example can be drawn from the emergence of the ancient civilization of Egypt (~3300 B.C.-525 B.C), which experienced an annual flooding of the Nile River that had an overwhelming effect on any one of the small, independent nomes (provinces) that later made up the kingdom. As a result, its citizens were forced to overcome their individual, tribal and clanic allegiances, and to unite under a supranational authority in order to coordinate their work, constructing the famous hydraulic projects for irrigation and water storage that protected them from natural disasters such as floods or droughts, and permitted the culture to flourish for 3,000 years [21-22]. If, for example, both the people living upstream (where the dam is constructed and floods its reservoir area), and those who live downstream (where future impacts occur) along a river are informed continuously about the potentially negative impacts of a dam, are compensated adequately for any loss, and are involved in the project from the beginning, then a better argument can be made for the "appropriateness" of such large infrastructures [23]. Furthermore, hydrological studies have observed a „climatic anomaly", characterized by low rainfall in Benin, Togo and Ghana since the 1980s, leading to low seasonal capacity and reduced lake levels [24]. This situation affects electricity output and calls for alternative energy options to be pursued intensely.

2. Suitability as Intermediate Technologies:

An intermediate technology can be defined as one that is fairly simple, understandable and suitable for repair on the spot [25]. It is more productive than most indigenous technology but is also much cheaper than highly capital-intensive technology. As a result, it lends itself better to providing meaningful employment, especially in rural areas, and is the precondition of capital, goods, or wages, which are the touted goals of development policy [25]. In deploying DG, the widely cited problem of storing electricity in DG is primarily a consequence of attempting to improve, recentralize and redistribute inherently diffuse energy flows such as sunlight or wind [2]. While it is true that storage is difficult on a large scale, if done on a scale that matches most end-use needs, then daily or seasonal storage of low or medium-temperature heat should be straightforward with water tanks, rock beds or fusible salts at the point of use [2]. Another way of addressing this problem is through the use of hybrid devices such as solar-wind devices which combine a micro-wind hydraulic system and solar collectors and optimize their efficiency where both sources are available intermittently [2, 26]. All the energy from these sources need not first be converted into electricity in order to be useful to a given household or community. Windmills would work well for directly pumping water to irrigate the soil and supplying water to cattle in impoverished and semiarid regions [27]. Similarly, solar energy can be used for water heating, drying and other applications.

DG technologies would also promote technological learning in the rural and peri-urban areas which would increase the penetration rate of the technologies, reduce cost and encourage innovation [28]. One example of this is the development of Vertical Axis Wind Turbines which offers portability and can take advantage of local materials e.g. bicycle parts for all rotating parts and PVC pipe for blades, and skills such as carpentry or metal working that are locally available and accessibility [2, 26].

3. Ownership:

The issue of ownership is very important in West Africa due to its status as an impoverished and economically dependent region. The roots of this dependence lie in the integration of Africa"s economies into the global economic system in a subordinate position, thereby leading to extroverted economic activity [29]. In the last two decades, the focus on electricity reforms on the continent has been on privatization of the national utilities in the context of the market reforms promoted for the region by the International Financial Institutions (IFIs) [30]. An excellent treatment provided by Pineau (2008) shows that the majority of the funding secured for ECOWAS will be spent through "International Competitive Bids" (ICB), which give local firms only a very small chance of competing with Western companies. For instance, out of $125 million earmarked for the Zone B-WAPP project, 85% (about $ 106 million) will be spent through ICB [31]. The WAPP funds are to be secured through large loans at least for the planned duration of the project and beyond, making it likely that the countries of the region will become even more indebted than they previously were unless the ensuing economic growth compensates for this situation [31].

In contrast to the capital intensive and costly large plants, distributed generation offers much more flexible financing options that could lead to ownership of the projects within a short period of time as opposed to a debt burden that could last for several decades. For instance, the micro-credit approach developed by the Grameen Bank, has been demonstrated to be a cost-effective way of funding these initiatives for the rural poor in Bangladesh [32]. Furthermore, off-grid solar home systems in rural Ethiopia have been demonstrated to be more profitable in terms of pay-back period than both the kerosene lamps that are typically used and on-grid PV installations in many industrialized nations [33]. In East Timor, a model which subsidized capital costs of solar PV but sought to recover operating costs was demonstrated to be more effective than a purely market-driven approach at increasing rural electrification rates [34]. ECOWAS could also take on the role of helping to secure funding for incubators where universities and technical schools collaborate with regional or international experts - an initiative that should lead to skilled personnel taking over the system, thereby allowing external sponsorship to be phased out within five years or less [11].

Toward an Epistemology for an African Energy Policy:
In discussing underlying values of different economic systems, Schumacher argued that "no system, or machinery or economic doctrine stands on its own feet: it is invariably built on a metaphysical foundation, that is to say, upon man"s basic outlook on life, its meaning and its purpose" [25]. In the same vein, many scholars have called for a more contextual deliberative policy analysis to counter the traditionally linear, positivistic, and technocratic analyses that appear to provide only value-neutral solutions [35].

In agreement with this context-oriented perspective, energy planning in West Africa should also be epistemologically rooted in the philosophies and the best of the cultural traditions on the continent. The moral ideal in Ancient Egypt, known as Maat, was based on a sense of the unity of being of the universe, and required respect for nature, the shared heritage of the environment with other humans, and a moral obligation of restoration, that is, healing and repairing the world [36]. The main value system in traditional West Africa has been described as eco-bio-communitarian, implying a communal societal ethos and a quest for balance with the environment [37]. Another ethical paradigm, known as the "ethics of care" or "ethics of nature relatedness", like the other two, is anthropocentric but recognizes that humans depend on nature for their survival [38]. When applied to energy policy, this ethic could inform the increased adoption of energy efficiency measures, energy conservation, and the promotion of benign technologies or „technology with a human face" in Appropriate Technology parlance.

Conclusions:
West Africa has sufficient renewable energy sources that could power all its needs [39]. Furthermore, it is a tropical region and therefore has abundant sunshine particularly in the Sahelian or semi-arid parts. Its long coast line makes it suitable for wind generation and it has waste biomass from its extensive agrarian base [27]. In order to fully harness this energy, the subregion would have to transition its economy to one that is based on energy income rather than depletable fossil fuels, thereby conserving its increasingly scarce water resources.

Based on the analysis presented in this paper, one recommendation is that in order to encourage resource sustainability, the countries in West Africa should leapfrog the conventional technologies by adopting renewable DG technologies [40]. The WAPP should first try to improve rather than expand the current grid, with respect to managing large dams, for instance, and then seek ways to reliably incorporate DG into it. It can simultaneously expand electrification by installing off-grid applications in remote areas and could develop special micro-grid networks in order to allow for the harmonization of these novel technologies in cities or denser areas [19]. However, these initiatives should emphasize the use of local skills and materials as much as possible with a view toward creating work opportunities rather than a disproportionate emphasis on efficiency, technical sophistication or profits. In addition, many policy incentives can be adopted to promote renewable DG such as subsidies for families and poorer communities, as well as encouraging community-based or traditional financing mechanisms in order to promote widespread ownership.

Finally, the theory and praxis of energy policy in West Africa should be systematized based on an explicit set of enduring values, ideas and commitments, and an epistemology that is easily recognizable and generally accepted by the residents of the subregion.

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Charcoal as an Alternate Energy Source among Urban Households in Ogbomoso Metropolis of Oyo State

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Abstract
The study was conducted to examine the current use of Charcoal as an alternate energy source among urban households in Ogbomoso metropolis of Oyo state. The types of energy sources available, reasons for the use of charcoal, frequency of charcoal use and constraints to the use of charcoal were determined. All households in the three urban local Governments constitute the study population. Thirty households were randomly selected from the three LGAs to give a total of ninety households. In all ninety women were randomly selected from the household chosen. Information was gathered through the use of a well structured interview schedule. Data were described using frequencies, percentages while regression was used to determine the relationship between socio-economic characteristics and frequency of use of charcoal. The results shows that majority of the women regardless of their economic status combine the use of charcoal with other source of energy in their household, most of the women found charcoal convenient, cheap and neat as source of energy. However, they experienced hike in price and scarcity as constraints especially during the rainy season.There are significant relationship between occupation[β= 0.572], family size [β=0.39]), years of schooling [β= 0.129], age [β= -0.08]) and frequency of use of charcoal. The implication of the result of the study is that the use of charcoal has become an established trend among the urban residents in the study area.

INTRODUCTON

Women as the primary consumer of energy at household level undergo a lot of drudgery due to the use of bio-fuels, walking kilometers to collect fuel-wood and expended time and energy in the fuel-wood collection and transportation [7]. Household energy use for cooking happens to be exclusive responsibility of the women folk in traditional African households. As energy consumers, women are important stakeholders in the design and choice of household energy technologies. This informs their important roles in the development of cooking equipment such as earthen cooking stoves, kerosene stoves, charcoal pot etc. hence for energy sustainability appropriate technology must be put in place for the usage of the primary consumer [3]. Energy is an essential ingredient for socio-economic development and economic growth and the provisions of energy services are pre-requisites for economic development and an improved standard of living. [1&6]. A rapidly increasing population, increased urbanization, rapid industrial and economic development and an increased drive towards rural development are some of the factors responsible for the increase in energy consumption [1]. The household sector is the largest energy consumer in the economy, accounting for about 90% of the traditional fuels, especially fuel wood, and 25% of the commercial energy [4]. In many developing countries, particularly in rural areas, traditional fuels, such as fuel wood, charcoal and agricultural waste, constitute a major portion of total household energy consumption [4]. He further stressed that efficiency of a traditional fuel wood cooking stove is as low as 10 - 12 percent, compared with a Liquefied Petroleum Gas

[LPG] stove efficiency of more than 40 per cent. The key determinants of energy demand in the household sector include: Prices of fuels and appliances; Disposable income of households; Availability of fuels and appliances; Particular requirements related to each; and Cultural preferences.

The urban household energy use patterns in Nigeria as found out by [2] with respect to income groups, fuel preferences, sources and reliability of energy supply and expenditure was found to be LPG, kerosene, fuel wood, charcoal and electricity. Dependence on biomass fuels is rapidly giving way to the use of fossil fuels [especially LPG and kerosene] and electricity in urban households, the reasons been that of convenience, cleanliness and social status. He further stressed the dominance of kerosene, LPG and electricity in all the high income groups, while fuel wood is used mostly in the low-income groups. Although with increase in disposable income and changes in lifestyles, households tend to move from the cheapest and least convenient fuels [biomass] to more convenient and normally more expensive ones charcoal, kerosene] and eventually to the most convenient and usually most expensive types of energy [LPG, natural gas, electricity]. However, due to the inability of the refineries to operate at full capacity since 1993, because of poor maintenance, there are frequent shut-downs leading to crippling shortages. Marketers regularly take advantage to hike the prices of fuels by 300-500%. As a result, most households have to fall back to using charcoal and sawdust. Hence, this study examined the use of charcoal among urban households in Ogbomoso Area of Oyo State and provides answers to the following questions:
[i] what are the socio- economic characteristics of the respondents,
[ii] what are the types of energy available to households,
[iii]what is the frequency of use of charcoal among the households,
[iv]what are the reasons behind the use of charcoal and
[v] what are the constraints to the use of charcoal in the study area.

Objective of the Study
The general objective of the study is to investigate the use of Charcoal as an Alternate Energy source among Urban women in Ogbomoso Metropolis of Oyo State. The specific objectives are to:
[i] identify the socio- economic characteristics of the respondents,
[ii] examine the types of energy available to households,
[iii] investigate the frequency of use of charcoal among the households,
[iv] examine the reasons behind the use of charcoal and
[v] determine the constraints to the use of charcoal in the study area.

Materials and Method
The study is carried out in Ogbomoso area of Oyo State. Three Local Governments was purposively selected because of its urban nature. Multi- stage sampling technique was employed for the study. Simple random sampling technique was used to select 30 households each from the 3 LGA using the list of household register to give a total of ninety households. From each of the household selected, one woman was interviewed to give a total of 90 respondents in all. A well-structured interview schedule was used to collect information from women in the household. Statistical tools used in analyzing the data included the frequency counts, mean, weighted mean scores, percentages and regression.

Measurement of Variable
The dependent variable of the study is the frequency of use of charcoal among the households while the independent variables are socio-economic characteristics of the respondents, types of energy available to households, the reasons behind the use of charcoal and the constraints to the use of charcoal in the study area. The dependent variable was measured using three point Likert Scale to measure the frequency of use: very frequent [3 points], frequent [2 points] and fairly frequent [1 point]. The maximum score for frequency of use is 18 points while the minimum scores is 0 points

Result and Discussion
Socio-economic characteristics

The data in Table 1 presents the socio-economic characteristics of respondents. The result shows that about 42.2 percents of the respondents are between 31 and 40 years, 27.8 percent are in the range of 21-30years, 17.8 percent are between 41-50 years, 6.7percent fell between 51-60 years, 4.4 percents are 61 and above years while only 1.1 percent is 20 years and below. About 60 percent of respondents are Christian 37.8 percent are Muslims while only 2.2 percent are traditionalists

Majorities [72.2%] of the respondents are married, 8.9 percent are widowed, 3.3 percent each are separated and single respectively, while only 1.1 percent is divorced. About 27.8 percent of the respondents are teachers, 17.8 percent are artisans, 16.7 percent are civil servants, 14.4 percent are traders, 5.6 percent are bankers while 4.4 percent are farmers.

About 40 percent of the respondents have family size of 3-4 members, 33.3percent have between 5 and 6 family members, 13.3 percent had between 7-8 members, 6.7 percent had 2 and below family members while only 4.4 percent had 9 and above family members. About 24.4 percent of the respondents have their average income between ₦1000-10000, 22.2 percent each of the respondent had between ₦21,000-–₦30000 and ₦11,000-20,000 respectively. About 11.1 percent had between ₦ 31,000-–₦40,000, 7.8 percent each had between ₦41,000-–₦50,000 and 61 and above respectively while 3.3 percent had between ₦51,000- ₦60,000.

About 35.6 percent of the respondents had their years of secondary schooling between 13-16 years, 20 percent had years of schooling of 17years & above and 10- 12 years respectively, 16.7 percent had between 1-6 years while only 6.7 percent had their years of schooling between 7-9 years.

About 36.7 percent of the respondents had years of experience in the use of charcoal between 6-10 years, 30 percent had between 1-5 years, 20percent had between 11-15 years,8 .9percent had been using charcoal between 16-20 years, 4.4 percent had 26 years and above while only 1.1 percent had experience between 21-25 years.

The result of the study conforms to [2] that charcoal use cut across all income groups but high percent of users was more prevalent among low income groups. The educational status of the respondents notwithstanding, cut across the different educational levels.

Table I: Distribution of respondents by socio-economic characteristics

Social-economic characteristic	Frequency	Percentage
Age	1	1.1
≤20 years	25	27.8
21-30	44	42.2
31-40	20	17.8
41-50	6	6.7
51-60	4	4.4
61 years and above		
Religion		
Islam	34	37.8
Christian	54	60
Traditional	2	2.2
Marital Status		
Married	65	72.2
Separated	3	3.3
Widowed	8	8.9
Divorced	1	1.1
Single	3	3.3
Occupation		
Civil servant	15	16.7
Teacher	25	27.8
Trader	13	14.4
Farmer	4	4.4
Artisan	16	17.8
Banker	5	5.6
Family size		
≤2	6	6.7
3-4	36	40.0
5-6	30	33.3
7-8	12	13.3
≥9	4	4.4
Income		
1000-10000	22	24.4
11-20000	20	22.2
21-30000	20	22.2
31-40000	10	11.1
41-50000	7	7.8
51-60000	3	3.3
61 and above	7	7.8
Years of schooling		
1-6years	15	16.7
7-9years	6	6.7
10-12years	18	20.0
13-16yaers	32	35.6
17 years and above	18	20.0
Years of experience on the use of charcoal		
1-5years	27	30.0
6-10years	33	36.7
11-15years	18	20.0
16-20years	8	8.9
21-25years	1	1.1
26 years and above	4	4.4

Source: Field Survey, 2010

Sources of Energy to Household

The data in table II shows the distribution of respondents by sources of energy available for household use. The result shows that a hundred percent each of the respondents claimed kerosene and charcoal as their energy source to their households. About 83.3 percent claimed firewood as one of the energy source available, 55.6 percent claimed electricity, 50 percent claimed gas while 35 percent claimed sawdust as one of the energy source to household use. The result implied that all these sources are available for use but the use of any is dependent on the preference of the user and availability of each. This result is in accordance with [3] and [4] that most household in developing countries rely on fuel-wood, charcoal and agricultural waste as their energy source.

Table 2: Distribution of respondents by sources of energy to household

Sources of energy	Frequency	Percentage
Fire wood	75	83.3
Charcoal	94	100
Kerosene	98	100
Gas	45	50.0
Electricity	50	55.6
Saw dust	35	38.9

Source: Field Survey, 2010 *Multiple Response

Frequency of use

The data in table III shows the ranking of respondents by frequency of use of the energy available. The result shows that charcoal ranked highest with Weighted Mean Score [WMS] of 2.05. This is followed closely by kerosene with WMS of 2.04. Next in the order is firewood with WMS of 1.2. Others are in the following order: electricity [1.04], Gas [0.6] and sawdust had been the lease with WMS 0.33.

The result implied that charcoal is the most frequently used energy among the household in the study area. This is probably because of its relative availability and cheapness compared with other source of energy. This conforms with [2] that most households are fallen back to using charcoal and sawdust except that only few of the respondent in this study made use of sawdust probably because of the difficulty involved in making it or that the increase in the disposable income and changes in lifestyle have affected the decision taken.

Table 3: Rank order of respondents by frequency of use of energy source

Frequency of use of energy	WMS
Fire wood	1.2
Charcoal	2.05
Kerosene	1.57
Gas	0.6
Electricity	1.04
Saw dust	0.33

Source : Field Survey, 2010

Reason for the use of charcoal

The data in table IV shows the distribution of respondents by reasons for the use of charcoal. The result shows that majority [93.3%] of the respondents use charcoal because it is cheap relative to other energy source. About 46.7 percent use because it makes the pot neat and not blackened like others, 43.3 percent use it for is relative availability, 32.2 percent use it because to them it is easy to make and once made you have no business remaking until the whole thing is burnt out while 20 percent use it because the food cooked on charcoal is more tender or well cooked. This result confirms the earlier studies [2] and [4] that the usage of energy is dependent on a number of factors that the consumers have to make.

Table 4: Distribution of Respondents by reasons for the use of charcoal

Reason for charcoal use	Frequency	Percentage
It is easy to make	29	32.2
It is cheap	84	93.3
It makes the pot very neat	42	46.7
It is readily available	39	43.3
Food cooked on charcoal is tender	18	20.0

Source : Field Survey, 2010

Constraint to charcoal use

The data in table 5 shows the distribution of respondents by the constraints faced. The result shows that majority [93.3%] of the respondents confirmed that charcoal is very laborious to set it on fire at the initial. About 88.9 percent said it requires some technicality to set the initial fire on before use, 77.8 percent complained of its scarcity and high price at raining season while 48.9 percent expressed its not been readily available because of the competition for its use nowadays. The result implies that despite its constraints, its use still ranked highest, it means that the regular hike in the prices of other fuels coupled with the irregularity and erratic supply of electricity notwithstanding, respondent found it easier to cope with the constraints experienced with charcoal use.

Table 5: Distribution of respondents by constraints to the use of charcoal

Constraints to the use of charcoal	Frequency	Percentage
Not readily available	44	48.9
Very expensive	70	77.8
It is laborious to use	84	93.3
It requires some technicality before use	80	88.9

Source: Field Survey, 2010

Test of Hypothesis

The data in Table 6 shows the relationship between socio- economic characteristics and frequency of use of charcoal. The result show that there is a positive and significant relationship between occupation (β= 0.572), family size (β =0.391), education (β = 0.129) and frequency of use of charcoal. There is a negative and significant relationship between age (β = -0.081) and frequency of use of charcoal. However, a positive and insignificant relationship exist between years of experience (β= 0.069) and a negative and insignificant relationship between marital status (β= -0.086) and frequency of use of charcoal. The result implied that there is greater tendency for larger family to use charcoal for cooking because of the volume of food to cook and the frequency of cooking. However, the positive relationship of occupation and education with use of charcoal is unexpected but it might be due to inconsistency or erratic supply that is the order of the day in the supply of other sources of the available energy. The negative relationship of age implies that the older you are the less the energy and appetite to eat hence the less desire to cook therefore the greater tendency to change to other source of energy that are easy and more convenient to use.

Table 6: Relationship between socio-economic characteristics and charcoal frequency of use

MODEL	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta	B	Std. Error
[Constant]	6.468	2.215		2.921	.004
Age	-.081	.042	-.242	-1.932	.056
m. status	-.086	.363	-.025	-.236	.814
Occupation	.572	.227	.280	2.521	.013
family size	.391	.193	.228	2.020	.046
Income	-1.10E- 005	.000	-.064	-.603	.548
Yrs of school	.129	.073	.208	1.757	.082
yrs of exp	.069	.057	.147	1.204	.232

Source: Field Survey, 2010

Conclusion and Recommendation

Majority of the respondents are in their active years of life with mean age of 38years. About 72.2 percent are married with majority of them with good education. The result of the study shows high usage of charcoal and kerosene among the other energy sources which are in accordance with the national energy policy recommendation. Although, recommendation was also made in favour gas and electricity but there usage is still very low probably because of the initial cost of its appliances and its unsafe characteristic nature. Now that the shift has been towards charcoal and kerosene, it is recommended that people should be encouraged in the rural areas to grow more trees to serve as replacement to avoid deforestation which could bring charcoal out of the reach of the masses again. Functioning and efficient regulatory body should be put in place to monitor the activities of the marketers to stop their exploitation on the public on the other sources of energy. Also appropriate equipment should be designed and made available, affordable and accessible to the general masses for usage.

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DESIGN OF PV SOLAR HOME SYSTEM FOR USE IN URBAN ZIMBABWE

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Key words: Photovoltaic modules, insolation, charge controller, system sizing, continuous wattage, surge wattage.

Abstract
Zimbabwe is currently experiencing daily load shedding as the utility power company; the Zimbabwe Electricity Supply Authority (ZESA) is failing to cope with the ever increasing energy demand. Selbourne Brooks is one of the new up-market suburbs in the city of Bulawayo where residents have been waiting to be connected to the grid for more than five years. A feasibility study was conducted in the area to establish the status and potential of Solar Home System (SHS) as an alternative source of energy for urban dwellers in Zimbabwe. This paper explores the issues mainly related to system requirements and availability, policies, standards, awareness, participation and investments all of which are major ingredients of sustainable implementation of the solar project in Zimbabwe. Insights into how system sizing can help in implementing PV Systems in Africa in a sustainable way are also included in the analysis. An energy audit was carried out in both the high density residential areas and low density residential areas. It was established that in Zimbabwean urban areas, on average, households in the high density areas were allocated 1.7kVA while those in the Low density suburbs were allocated 13.5kVA. Energy consumption differed from household to household as it was mainly influenced by both the number and the type of appliances per individual household. A system capable of supplying energy of 13.5kVA was designed and component sizing was carried out. Major system components such as the photovoltaic modules, the charge controller, battery array and inverter are specified assuming insolation levels of eight average sun hours per day. An estimate of the total system costing is included together with the possible ways of lowering system costs without compromising on the total system performance.

INTRODUCTION

Zimbabwe is geographically located in the Savanna region and this implies that solar energy systems would be very efficient in this part of the world. Most areas in this country, both in urban and rural areas have not been connected on the utility grid due to a number of challenges including lack of funds for government to implement such projects. However, for even some of the urban dwellers who can afford the cost of installing the systems, awareness and inaccessibility of reliable and sustainable systems has been the major setback in the adoption of Solar Home Systems (SHS) as an alternative solution to their energy crisis. Available systems have very limited applications such as lighting, mobile handsets charging, powering radio and television sets. These systems are viewed as ideal for rural households and have been adopted widely in some rural areas of Zimbabwe. The ever intensifying energy crisis in Zimbabwe have seen the majority of urban dwellers turning to Green House Gases (GHGs) emitting generators to meet part of their essential energy demand. The designed systems were based on general energy demands of urban consumers.

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When designing a solar system, the essential issues to consider are the sunlight levels in the area i.e. (insolation) and the total power requirement. The optimum performance of a photovoltaic panel is obtained when it's correctly aligned to the sun i.e. when the sun is directly overhead. This usually equates, as a fixed mounting, to an alignment of around latitude ±15 degrees[1]. There may only be around eight hours of full sun, due to reflection off the panel and the amount of atmosphere the light has to pass through. This will naturally be least when the sun is directly overhead which is often termed solar noon. When selecting the site for the PV array, a spot should be considered, that is un-shaded between the hours of 10 a.m. to 2 p.m. on the hemisphere's shortest day since the seemingly inconsequential shading from a tree branch can cause a substantial reduction in generated power. To offset the effects of low insolation, additional panels or larger panels with a higher output or panels designed to track the sun's passage across the sky may be installed, this helps in maximizing on correct orientation (although the depth of the atmosphere cannot be overcome). Concentrator panels, with a lens arrangement designed to better concentrate weak sunlight onto the cells are another alternative option. Unfortunately these options introduce one of the biggest constraints on a system's size that is system costs. Solar panel output is measured in watts and is usually supplied at a nominal 12V although this may well be up to 17V effective output. Panels can be wired in series (+-+-) to increase voltage, parallel (++--) to increase amperage. A series/parallel wiring, where sets of panels already wired together in series are wired together in parallel may also serve to increase both voltage and amperage. The distance between the various components of the system should also be considered when choosing the nominal DC voltage. The greater the distance, the greater the voltage drop and a higher voltage will travel further than a low one around the same cabling. 24V or 48V nominal systems will avoid having to use more efficient cabling, especially if the batteries are a considerable distance from the solar panels.

System Description

Solar home system is generally designed and sized to supply DC and/or AC electrical appliances. This consists of PV **solar module** connected to solar charge controller, inverter and a battery/ or battery bank. The generated DC power is stored into batteries through a charge controller and converted to AC power by the inverter for supplying AC loads. The renewable electricity is produced as Direct Current (DC). The DC electricity from the panels passes through a grid-interactive inverter, which converts the DC electricity into Alternating Current (AC). The AC electricity is then used by the appliances operating in the house. If more electricity is produced than the house needs then the excess will be fed into the main electricity grid. Conversely, when the renewable system isn't generating enough electricity to power the house, the house will draw power from the grid. Grid interactive systems eliminate the need for a battery backup for when the sun doesn't shine [2]. In effect, the grid serves as your battery. The major components are briefly described below.

The PV modules

Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance. The solar panel, the first component of an electric solar energy system, is a collection of individual silicon cells that generate electricity from sunlight. The photons produce an electrical current as they strike the surface of the thin silicon wafer. The most efficient and expensive solar panels are made with Mono-crystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Polycrystalline cells are a little less expensive and slightly less efficient than Monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals [3].

The Batteries
Batteries are rated by the amount of current they can supply over a period of hours i.e. in ampere hours (Ah). The design should ensure enough Ampere-hour capacity to take account of any bad weather periods. An additional one-fifth capacity is thought to be sufficient to cover this eventuality.

The Inverter
The inverter should be capable of coping with the power surges caused when starting certain appliances, especially those incorporating high-power. The minimum surge rating will be roughly twice that of the continual wattage the system is calculated at.

Methodology
The study involved field visits to the sites (Selbourne Brooke residential area (low density) and Emganwini residential area (high density)). Three households were selected randomly for the energy audit. The most common household appliances were listed together with their power ratings. Interviews were conducted to establish the number of hours the different appliances were most likely to be kept on. A desk study was also carried out to obtain technical information from the utility company (ZESA) related to the generation and distribution of electricity to consumers in different residential zones in the city of Bulawayo. Using data from both the technical visits and the desk study, a generalized list of household appliances was drawn. The list was then used to come up with a general charge utilization table which was then used for system sizing.

System Sizing
The first step to sizing a solar electric system is to determine the average daily energy consumption. The average daily energy consumption should be as accurate as possible, and ways to conserve power should be considered as well because the total energy consumption will determine the size of the system.

The PV Solar Array Sizing
Two important factors in solar array sizing are the sunlight levels (i.e. insolation values) of the area and the daily power consumption of your electrical loads. Taking the peak insolation of 8 hours for Zimbabwe, and assuming also that the battery efficiency is 80% and Panel Efficiency is also 80% then the Panel Catalogue Power was determined using the following relationship;

$$Panel\ Catalogue\ Power = \frac{Average\ Daily\ Energy\ Utilization}{Panel\ Loss\ factor \times\ Peak\ \boldsymbol{h}ours \times\ Battery\ disc\boldsymbol{h}arge\ efficiency.}$$

Therefore numbers of 235 W (or/ higher) Mono/Polycrystalline panels that will be required were evaluated.

$$No.of\ Panels\ = \frac{Panel\ Catalogue\ Power}{Panel\ Rating\ \times Panel\ loss\ factor}$$

Charge Controller Sizing
The controller size was determined as follows;

$$Current\ Rating = \frac{Panel\ Catalogue\ Power \times Panel\ Efficiency}{24\ \boldsymbol{h}rs}$$

Inverter Sizing

Inverters are rated in continuous wattage and surge watts. To properly determine inverter size, the power requirements of the appliances that will run at the same time are summed up and 25% - 30% of the sum is added for safety reasons.

$$Inverter\ Size\ = load\ size \times Safetly\ factor\ \left(\frac{1.3}{1.25}\right)$$

Battery Sizing

The size of the battery bank required will depend on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used.

$$Battery\ Load = \frac{Average\ Daily\ Energy\ Utilization}{Battery\ Voltage}$$

The battery should supply the required load plus the distribution losses. It should also supply the load for 3 days of autonomy in the absence of the sun. Therefore, the required battery Ampere-hour was also evaluated.

$$Battery\ Ampere - hour = \frac{No.of\ Days\ of\ autonomy \times Battery\ Load}{Depth\ of\ Discharge \times Distribution\ losses}$$

Therefore the batteries ampere-hour required and total voltage they must supply to the inverter including the total power rating was determined.

RESULTS AND DISCUSSION

Charge Utilization Table

The following charge utilization table was used to keep track of each appliance to be powered by the system and the amount of time it will be in use.

Table 1: Charge utilization Table

Appliance	Power Rating (W)	Number of usage hrs per Week (h)	Watt-hours per Week (Wh)
CD/ DVD player	35	35	1225
Fan	40	28	1120
Kettle	1000	7	7000
Desktop Computer / Laptop	170	12	2040
Hair Drier	1000	3	3000
Iron	1000	7	7000
Microwave	1000	7	7000
Refrigerator	150	70	10500
Toaster	900	3	2700
Colour T.V.	150	35	5250
20 HB LEDs	11	56	12320*[2]
Stove	2000	16	32000
Satellite dish Decoder	30	35	1050
TOTAL WATTAGE PER WEEK			**72885**
AVERAGE WATTAGE PER DAY			**10412**

Table 2: Summary of Specific System Components

[2] DC Value for HB-LED not used in calculations

Component	Quantity/ Rating
Solar Array Size	9
Charge Controller Size	60 Amp
Inverter Size	13.5 kW
Battery Load	200 Ah
Total Battery Amp-Hr	1627 Ah
Battery Bank Size	16

The batteries required should be 200AH, and should be wired in such a way that they supply 24 Volts to the inverter with a rating of 2035 AH. Therefore 16 200AH, 12 Volts connected in a series/parallel connection are required.

Table 3: System Cost Evaluation

COMPONENT	UNIT COST US$	QUANTITY	TOTAL US$
235W Mono/polycrystalline PV Modules	553	9	4977
Heavy Duty Solar Mountings(Row of 9 Panels)	621	1	621
12V 200Ah Batteries	524	16	8384
13.5 kW Inverter	7932	1	7932
60 Amp Charge Controller	563	1	563
TOTAL COST			**22477**

Conclusion and Recommendations

This study has presented the components required for the design of a stand-alone photovoltaic system that will power all electric appliances at a medium-energy-consumption residence in Selbourne Brooks in Bulawayo. The factors that affect the design and sizing of every piece of equipment used in the system have also been presented. Over and under-sizing have also been avoided to ensure adequate, reliable, and economic system design.

A cost estimate for the whole system is also provided. The same procedures could be employed and adapted to applications with larger energy consumptions and could also be employed for other geographical locations, however, the appropriate design parameters of these locations should be employed. The capital cost of such systems is relatively high and the payback periods are more than 10 years, however, the benefits and the environmental impact should not be underestimated.

The recommendation would be that, the governmental role has to be present and influential in encouraging people to turn to such alternative energy systems. This role should encourage and support renewable energy research and should provide technical assistance to potential users. Another way would be through facilitating the import of the equipment used to construct such systems, especially the import of low dc-voltage appliances, that are still absent from the local market. New energy policies should be endorsed that allow tax exemption and rebates or at least minimal taxes on equipment used in photovoltaic systems. In addition, policies that allow utility-interactive systems are needed to enable the purchase of surplus solar energy from users. The national utility company should adopt the smart grid technology and publish feed-in tariffs which will encourage the adoption of the solar home systems. Furthermore the private sector must be encouraged to invest in this market in return for exemption and other benefits.

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Appendix

Continuous wattage is the total watts the inverter can support indefinitely.

Surge wattage is how much power the inverter can support for a very brief period, usually momentary.