Demand Analysis and Optimization of Renewable Energy

Sustainable Rural Electrification of Mbanayili, Ghana

By:

Peter N. Bailey

Oracha Chotimongkol

Shinji Isono

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Faculty Advisors:

Associate Professor Gregory Keoleian

Associate Professor Michael Moore

Abstract:

Nearly ninety percent of people in rural northern Ghana are without electricity. Many off-grid projects undertaken by the Ghanaian Government to provide electricity to this region have been largely unsuccessful due to the fiscal burdens that prevent the coverage of operational and maintenance costs. This case study project proposes a sustainable electrification system and implementation plan for Mbanayili, a village in northern Ghana. The term "sustainable" is used in reference to two factors: 1) the fiscal sustainability of the villagers to maintain and pay for electrification, accomplished by using a manageable and affordable power generation system and 2) environmental sustainability, through the use of renewable energy. In order to minimize costs, partial electrification was proposed: electrifying a multifunctional community center as opposed to each individual residence.

An on-site needs assessment was conducted in the summer of 2006 and questionnaire responses from 133 villagers was used to determine preferences for electric appliances and related activities (e.g., education and entertainment) as well as villagers' willingness-to-pay for electricity. After the data were analyzed, a power consumption load curve for the community center was derived. The National Renewable Energy Laboratory's Hybrid Optimization Model for Electric Renewables (HOMER) software was then used to design the optimal power generation system. A hybrid energy system, consisting of both photovoltaic (PV) arrays and a generator, was determined as the optimal configuration (benchmark model) to meet villagers' ideal load curve. The feasibility of supplementing a fraction of fuel usage with a locally produced biofuel (Jatropha) was also investigated. Using demand side management (DSM), an alternative system was designed to meet financial sustainability requirements. This system consists of only PV arrays. Lastly, a multi-stage implementation plan was proposed (using DSM and a revenue generation scheme) to expand electricity generation capacity over time.

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Abbreviations:

AC	Alternating Current
Ah	Amp hour
ANOVA	Analysis of Variance
ASTM	American Society of Testing and Materials
BD	Biodiesel
CBI	Cost Benefit Index
CDM	Clean Development Mechanism
CFL	Compact Fluorescent Lamp
CIA	Central Intelligence Agency
COE	Cost of Electricity
DANIDA	Danish National International Development Assistance
DC	Direct Current
DSM	Demand Side Management
EC	Energy Commission
ECG	Electricity Corporation of Ghana
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GLSS4	The Fourth Ghana Living Standard Survey
GOG	Government of Ghana
ha	Hectare
HOMER	Hybrid Optimization Model for Electric Renewables
IEA	International Energy Agency
IMF	International Monetary Fund
IPP	Independent Power Producer
Jatropha	Jatropha Curcas Linn.
JICA	Japan International Cooperation Agency
K	Diesel
KAKUTE	Kampuni ya Kusambaza Teknolojia

KNUST	Kwame Nkrumah University of Science and Technology
kW	Kilowatt
kWh	Kilowatt-hour
L	Liter
LPG	Liquidified Petroluem Gas
m/s	Meters per Second
NASA	National Aeronautics and Space Administration
NED	Northern Electricity Department
NES	National Electrification Scheme
NGO	Non Governmental Organization
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
OEM	Original Equipment Manufacture
PC	Personal Computer
PPA	Power Purchase Agreement
PPP	Purchasing Power Parity
psi	Pounds per Square Inch
PSRC	Power Sector Reform Committee
PURC	Public Utilities Regulatory Commission
PV	Photovoltaic
RE	Renewable Energy
RESPRO	Renewable Energy Service Project
RPM	Revolutions per Minute
SEC	State Enterprise Commission
SHEP	Self-Help Electrification Program
SHS	Solar Home System
sq km	Square Kilometers
SWERA	Solar Wind Energy Resource Assessment
TPA	Third Party Access
TSO	Transmission system operator

TV	Television
UNDP	United Nations Development Programme
UN Energy	United Nations Energy
US Census Bureau	United States Census Bureau
USD	United States Dollar
VAP	Value Added Performance
VRA	Volta River Authority
WAGP	West African Gas Pipeline
Wh	Watt-hour
WHO	World Health Organization
WTP	Willingness to Pay

Executive Summary

Project Summary

This project, by conducting a case study, proposes a sustainable electrification system and implementation plan for Mbanayili, a village in northern Ghana that is currently unelectrified. To achieve this, both demand side and supply side analyses were evaluated. The term "sustainable" is used in reference to two factors: 1) the fiscal sustainability of the villagers to maintain and pay for electrification, accomplished by using a manageable and affordable power generation system and 2) environmental sustainability, through the use of renewable energy. The Government of Ghana (GOG) created an electrification initiative, the National Electrification Scheme (NES), which intended to provide electricity to all villages with more than five hundred inhabitants by the year 2020. Due to insufficient funding and inefficient electrification strategies, this goal may not be feasible; some rural electrification projects that exist under the auspices of the NES are failing and other attempts by the government to provide electricity in the sparsely populated regions of northern Ghana have been largely unsuccessful.

To engender a successful rural electricity project and mitigate the financial burdens of the GOG, development and implementation of cost-effective measures that conform to a community's ability to pay are essential. In a collaborative effort between the authors and students from various disciplines, a multifunctional community center was conceived of and designed in an attempt to maximize the benefits for villagers, while maintaining costs within the village's ability to pay. The optimal suite of electrical amenities and system configurations was determined with the following procedures and illustrated in Figure E.1. First, an on-site needs assessment was conducted in the summer of 2006, accomplished with questionnaire responses from 133 villagers, to establish their ability to pay and their desired electricity needs. After this data was analyzed, a power consumption load curve was derived for the village and modeled using the National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewables (HOMER) software. HOMER was then used to design the power generation system. Due to the government's expressed interest in expanding domestic biofuel production and spurring economic development from a promising local plant, Jatropha Curcas

L., research was undertaken to incorporate this into the analysis. After the costs were obtained for the benchmark power generation system, economic analysis was conducted to determine the optimal system configuration, ensuring that the operations and maintenance costs do not exceed villager's ability to pay; this was facilitated by the use of demand side management (DSM).

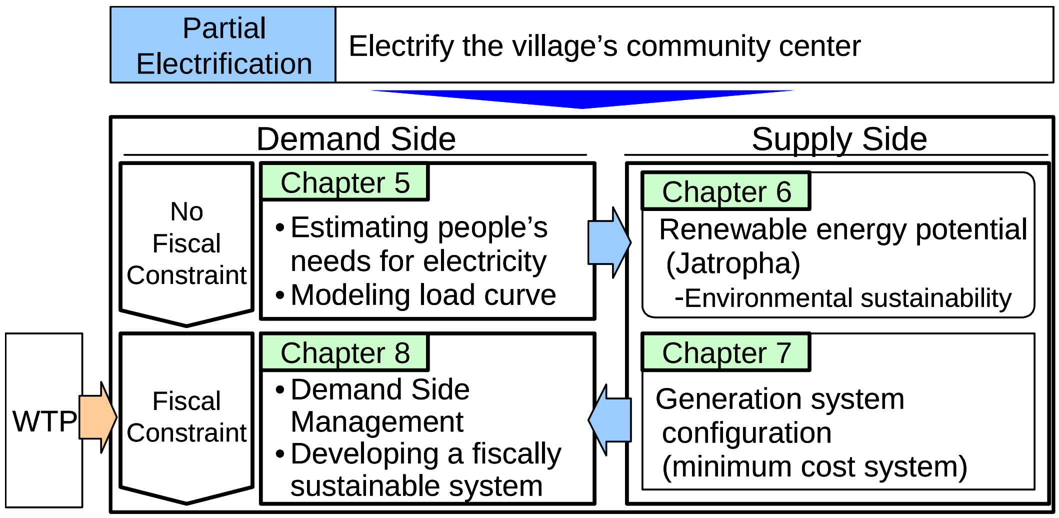

Figure E.1: Research Methodology Overview

After completing this research, we propose a sustainable electricity generation system and implementation strategy to increase the quality of life for village residents, hoping also to advance the understanding of the inherent challenges of rural electrification in the developing world.

Background: Power Sector Reform and Electrification Strategies (Chapter 2)

Ghana's power sector is a vertically integrated, state monopoly governed by the Ministry of Energy, which is responsible for policy development and coordination of the power sector (Edjekumhene, 2001). The several institutions involved are: 1) the Volta River Authority (VRA), which is responsible for generation, transmission, and construction of the transmission system. The VRA dominates generation as well as controls transmission and distribution activities; 2) the Electricity Corporation of Ghana (ECG), which is responsible for the distribution of electricity in Southern Ghana, where 80% of the country's electricity consumption exists; 3) the Northern Electricity Department (NED), which is responsible for distribution of electricity in the sparsely populated regions of Northern Ghana, and 4) the State Enterprise Commission (SEC), which acts as a regulatory body.

In 1989, the NES was initiated to facilitate the expansion of the electricity supply to predominately rural inhabitants. Under the NES master plan, 4,221 communities with populations exceeding 500 were chosen as ideal candidates for electrification (JICA, 2006). At its inception, the NES created a mandate called the “life line” subsidy, which required the NED to provide electricity to customers who pay flat uneconomic rates. Despite this mandate, there were only minor improvements in network expansion and rural electrification, due to both financial difficulties from operational inefficiencies, and a lack of funds for increasing reliability and overall performance (ECA, 2003). The GOG continues to keep tariff prices artificially low, in part due to the political ramifications of passing on the actual costs of generation to the public. This places political pressure on representatives seeking election to provide the public with electricity, even if it is not economically viable. Both the ECG and the NED have incurred massive financial losses over the past decade, placing considerable economic strain on the government (ECA, 2003).

The Self Help Electrification Program (SHEP), initiated in 1990, was created with the expressed intent of fostering the NES' master plan. The SHEP functions by providing low voltage grid connection and in-house wiring for a small fee, provided that the community purchases the utility distribution poles and is situated no farther than 20km from the nearest grid connection. Although the NES was generally heralded as a success, because from the period of 1989 to 2000, national household electrification in Ghana increased from 15% to 43%, it is not without criticism. Payment default, especially by rural inhabitants, places considerable burden on the project’s fiscal stability, which prohibits investment in future network expansion (JICA, 2006); and a lack of cohesive planning causes inefficient allocation of the distribution network.

Due to Ghana's dependence on hydropower, as high as 99% before 1992, the multiple prolonged droughts of the 80's and 90's, coupled with increased electricity demand, caused widespread power shortages (Edjekumhene, 2001). In 1993, in response to the increased demand for generation, transmission, and distribution infrastructure, as well as for the improvement of existing facilities and services, the GOG developed a plan to construct a thermal combined cycle power plant. In response to their request for funding from the World Bank, the GOG was met with an announcement that the World Bank would provide funding only if the GOG reformed its power sector (Edjekumhene, 2001). Privatization is the primary tool in power sector reform, and the GOG both recognized this trend and assented to give their full effort to reforming their power sector and attracting the needed private investors.

The Renewable Energy Service Project (RESPRO) was initiated in 1999, with financial backing from the Global Environmental Facility (GEF), the GOG, and NREL. From its inception to the present, the RESPRO has had budget shortfalls, despite implementing a fee-for-service approach. The financial instability of the program is caused by the high transaction costs of collecting payment, maintenance, and the installation of PV systems in the sparsely populated northern regions of Ghana. Insufficient operational funds available for maintenance, coupled with a reactionary maintenance regime, culminated in many installed systems becoming defunct. This further contributes to the lackluster perception that Ghanaians have of off-grid energy systems, which they often believe to be inferior to on-grid electricity. In 2002, GEF funding for the project ceased, and now it is being restructured as an NGO (JICA, 2006).

The difficulties exhibited by the projects above further underscore the necessity for comprehensive field research and long-term contingency strategizing.

Community Center (Chapter 3)

To circumvent the financial difficulties of electrifying widely dispersed homes in Northern Ghana, something many projects have attempted in the past, a collaborative effort was undertaken, the culmination of which is a multi-functional community center, shown in Figure E.2 (Mechtenberg and Buaku, 2006). Comprised of one versatile open area, one private room used for health services, one storage room to house energy production components, and a centralized cistern to capture rainwater, the community center is capable of accommodating one hundred people at a time.

Figure E.2: Schematic of Community Center (Mechtenberg and Buaku, 2006)

Mbanayili: An Overview (Chapter 4)

Mbanayili, a village of approximately 1,000 households and 4,050 residents, lies 15km northwest of Tamale, the largest city in Northern Ghana, and 7km from the nearest electricity grid connection. While Ghana's national language is English, the inhabitants of Mbanayili only speak Dagbani, which necessitated the use of a translator during field research. The average monthly income of Mbanayili men is 147,661 Ghanaian cedis (16.40 USD), and of women is 57,453 cedis (6.40 USD), which is considerably lower than the national average of 24.20 USD.

The current primary energy sources of the village are firewood, charcoal, and kerosene, which are predominantly used for cooking and light. These items consume 85% of their total income.

The main problems of the village, as determined by the local leaders, are a lack of both healthcare and educational facilities. The villagers believe that electrification will help to solve these problems and facilitate economic welfare and a higher standard of living (Alhassan, 2006).

Field Research (Chapter 4)

Using a questionnaire, interviews (many inhabitants are illiterate) were conducted to comprehend the villagers' electricity needs and priorities. Data were acquired on basic demographic information as well as the villagers' preferences for electrical appliances, activities requiring them, and the times of day that they desired to use them. These interviews were given to 133 people, determined by a random sampling of the village's residents, though because many women were otherwise engaged during the time of the field research, more men were interviewed than women: 94 men and 39 women.

Demand Analysis (Chapter 5)

To ascertain the prioritization of villagers' preferences for various activity categories (i.e., education, entertainment, etc.), they were allocated a limited number of points to allot to their preferred categories (chosen from a list of six), beginning with three points and progressing to ten. With this method, three point allocation data reflects their priorities under the most constrained circumstances, while the ten point allocation data illustrates their priorities under more generous circumstances.

To elucidate the respondents' prioritization of specific activities within these categories (i.e., cooking, television, etc.), a set of eight questions was posed to each respondent. Each question asked for the preference of one of two activities and showed the amount of time that each activity could be maintained using the same amount of energy (i.e., television: 60 min vs. computer use: 20 min).

Data were also collected regarding the villagers' preferences for time allocation for categories and then specific activities, data that were then pooled with the results of the above analysis to create an activity schedule. Specific appliances were chosen to correspond with each activity. Electricity requirements of these appliances were combined with this activity schedule to create the power load curve, which is comprised of power consumption for all 8,760 hours in a year.

Biofuel Production and Economic Development (Chapter 6)

In 2004, biodiesel derived from Jatropha Curcas L. fruits was proclaimed to be a mature, commercially viable technology that could provide Ghana with "immense benefits" (Akuffo, 2004). The most notable benefits from establishing biofuel markets in Ghana would be: the displacement of oil imports, which are a major contributor to the country’s astounding debt (oil imports comprise 28% of the total energy supply and 10% of GDP); the emergence of new markets to supplement existing agricultural industries; increases in the country’s Gross National Product; and employment opportunities, especially in the rural northern regions (Akuffo, 2004; UN Energy, 2006).

Jatropha is particularly well adapted to grow in Ghana, as it requires arid or semi-arid, low altitude environments and can flourish on marginal soils that lack substantial nutrient content. Oil products derived from Jatropha seeds and kernels have recently prompted significant interest in determining whether or not these products can foster rural economic development. Jatropha oil can be utilized in an array of products that do not require prohibitively intensive capital investments, such as biofuel production and soap manufacturing; this is promising for the creation of adaptive, small-scale industries. However, the revenue generation potential for Jatropha products, namely unesterified Jatropha oil, biodiesel, and soap, is entirely predicated on local market demand. Unless Jatropha biodiesel production costs remain competitive with retail diesel prices, its suitability as a fossil fuel substitute will not be possible, although its potential for localized revenue generation remains (Akuffo, 2004; Henning, 2004; Henning, unknown).

In the opinion of the authors, Jatropha production seems promising for use as a biofuel and for spurring economic development, but warrants further research to determine if it is viable for this particular village. Further investigations should answer the following simple, yet fundamental questions:

Technical

- What is the oil content of plant varieties available in Ghana?
- Does the village have a land surplus to be dedicated to Jatropha cultivation?[1]
- Will growing Jatropha negatively impact existing crops?
- What are the anticipated seed and oil yields for Mbanayili?
- What is the probable oil recovery from technologically feasible extraction methods?
- How much technological education will the village residents require for cultivating and processing Jatropha?

Economic

- Do current markets exist for Jatropha in or around the vicinity of Mbanayili?
- If so, what is the current and projected market price?
- What is the potential profitability of cultivating and selling Jatropha products in local markets?
- For what purpose/products is Jatropha currently cultivated?
- What is the most advantageous use of Jatropha for Mbanayili?
- What funding avenues are available to facilitate project deployment?

Supply Side Analysis: Optimal Generation System Modeling (Chapter 7)

Optimal off-grid energy system configurations for powering the community center were evaluated with the load curve data derived from the needs assessment questionnaires. Results from the needs assessment were converted into text files, representing hourly energy

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[1] Using a conversion factor yielding approximately 2,000 L of Jatropha "feedstock" oil per hectare, the lower limit land area requirement for the village to supply ample fuel to power the generator with blended or pure biodiesel would be approximately half a hectare (Fulton et al, 2006). The upper limit land area requirement (2.225 ha/yr) was calculated using seed oil yields of 5kg/L (Henning, 2004) and land seed yields of 2,000kg/ha (Heller, 1996).

consumption for both the AC and DC sector loads for an entire year (8,760 hrs). The HOMER software was the primary tool used to determine the best option, in terms of net-present-cost (NPC), for supplying electricity to the community center in Mbanayili.

The hybrid energy system that the HOMER software determined to be optimal incorporates the use of renewables and consists of three primary functions: power production, energy consumption, and storage. Power production relies on a PV array and a diesel generator.[2]

Capital and replacement cost assumptions were taken from JICA's report (2006 citing the RESPRO), and while O&M costs are difficult to assess, they are minimal with routinely maintained energy systems (JICA, 2006). For this reason, "system fixed O&M costs" were designed to provide sufficient funds for a full-time employee to manage, maintain, and provide security for the community center; the wages would be $1/day, which is nearly twice the average pay for villagers.

Using NPC, the hybrid optimal system configuration for this scenario consists of: a 0.5 kW PV array; a 1.5 kW diesel generator; five 200 Ah batteries; and a 1.5 kW converter. As shown in Figure E.3, the initial capital costs are fairly evenly distributed amongst the PV array, the diesel generator, and the battery bank. Annual O&M costs are primarily attributed to operating the generator and maintenance wages. With the benchmark parameters, the software calculates a yearly diesel fuel usage of 890 liters at a cost of $579 per year.[3]

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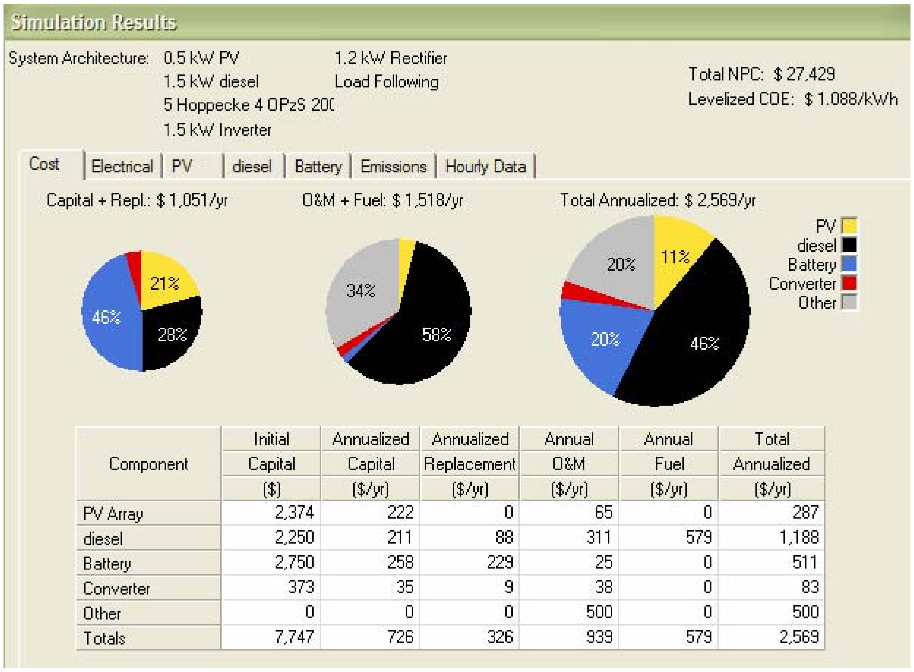
[2] These power generation sources were selected for a number of reasons: a diesel generator allows for either straight diesel or biodiesel fuel blends of any ratio to be evaluated (at least in theory), which conforms to the GOG's expressed interest in expanding the usage of Jatropha Curcas L. (see Chapter 6). Furthermore, PVs and diesel generators have been used extensively in similar applications in Northern Ghana. Other resources such as mini-hydro and wind were also investigated, but eventually determined to be either unrealistic or less effective for this particular application. (see Appendix 3)

[3] A 1996 Global Environmental Facility report, which suggests rural electrification options for Ghana's Mamprusi East District, estimated the cost of a PV/Diesel hybrid electrification system would be $1.30/kWh for 834 houses. In this HOMER simulation, the cost of hybrid electricity is $1.088/kWh for the community center.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	2,374	222	0	65	0	287
diesel	2,250	211	88	311	579	1,188
Battery	2,750	258	229	25	0	511
Converter	373	35	9	38	0	83
Other	0	0	0	500	0	500
Totals	7,747	726	326	939	579	2,569

Figure E.3: Benchmark Optimization Cost Results

Financially Sustainable System Modeling (Chapter 8)

In order to create the optimal system of appliances and activities for the community center, research was conducted using the HOMER software and villager's desired electricity needs, from data that were collected from the questionnaires. It is necessary that this system comply with the sustainability rule, which states that the annual expenses of several aspects of the generation system must be equal to or below the villagers' willingness-to-pay (WTP), and DSM was employed to fulfill this goal. The annual costs for the generation system usually entail replacement costs, operational and maintenance costs, and fuel costs. For this analysis, the fuel costs were omitted overall and one simulation was conducted using only operation and maintenance costs. A second simulation took into account both operation and maintenance costs as well as replacement costs. The omission of fuel costs was done because there is reason to believe that these costs can either be covered by Jatropha production, the extra income that the villagers will have when they do not have to spend it on current fuel expenditures, or a combination of the two. The WTP of the village as a whole is 720 USD/year. This was set as the financial limit during the analysis.

Multiple simulations were conducted. The first simulation used ten point allocation data and conducted sustainability analysis that required the village to cover only operation and maintenance costs. It analyzed a schedule that allowed every appliance that at least 50% of the villagers wanted. This went far beyond the village's WTP, and it was determined that a system would have to include only the appliances that at least 80% of the villagers wanted if the system is to meet the sustainability rule, and this would often allow the use of only lights for many of these activities. It was therefore decided that a cost-benefit-index (CBI) must be used to curb some of the more expensive appliances and allow for more variation in appliance usage. The CBI analyzes the cost of the activity vs. the benefit of the activity (this benefit is derived from the allocation preference data). Using the CBI, it was determined that the cooking stove, an appliance that at least 80% of the villagers wanted, had the highest CBI and was therefore removed from the appliance options. Once removed, an activity schedule was created that adhered to the sustainability rule.

The second simulation was conducted using a sustainability criterion that required the villagers to cover operation and maintenance costs as well as replacement costs. This simulation, taking DSM into consideration, also omitted the cooking stove, which reduced the peak electricity load. This simulation used several methods to increase the variation and availability of appliances, and lower total system costs. Using allocation data for activity categories, the percentage of the adoption criteria for popular categories was lowered, while for the less popular categories it was raised, thus leading to the omission of the least popular categories. Simulation II also conducted these percentage shifts within specific activity categories. Using different combinations of these adoption criteria, twelve different patterns were created. This total number of patterns includes Simulation I's 80% adoption criterion pattern, which includes the cooking stove. Out of these twelve patterns, only six met the sustainability check used in Simulation II (this sustainability check included replacement costs, which were not included in the sustainability check for the first simulation).

Comparative analysis was then conducted on these six patterns, using the prioritization of three demographic groups to determine the optimal system: elderly men, women, and the wealthy. This comparative analysis found two optimal patterns. One pattern coincides well with the priorities of elderly men and the wealthy, while the other coincides more with the priorities of women. While it has been shown that empowering women, something that can be done by giving them access to their desired priorities, is beneficial to communities at large, the pattern that coincided with elderly men and the wealthy (those currently holding the power in the village) allowed more varied use of the community center, and appealed to two as opposed to one demographic group, and was thus tentatively determined to be the optimal activity schedule for Mbanayili. However, more research is needed to ensure that this is the best choice.

Implementation Plan (Chapter 9)

Management of a multifunctional community center, where many individuals are free to use the facilities at their digression, poses many challenges. The potential for opportunistic behavior is high, as patrons will pay flat rates for service and deterrents to limit usage are absent. Maintaining energy consumption within the constraints of the community center's power generation system is critical for long-term project success. Mbanayili is governed by local community leaders who have indicated that they wield authority sufficient for regulating patron usage effectively, as well as for deterring opportunism.

Having a trained technician to conduct operation and maintenance is integral to the project's success. However, trained professionals in Ghana have a tendency to depart rural communities for urban areas where their skills return higher wages. To compensate for this, a sufficient wage will be offered to an individual with strong community ties, that is, someone who will value contributing to the community's prosperity while receiving this wage. This person will be required to complete a technical training program, which is available in the urban centers of Ghana. Once trained, the responsibilities of this individual will include routine daily maintenance of the energy system, security, management of patron usage, and dispute resolution.

In order to counter the difficulties in payment that have led to the demise of many other rural electrification projects, this project suggests the implementation of monthly fixed prices that correspond to the income levels of the villagers. The villagers are divided into three groups, based on their income level and WTP, and prices are tiered accordingly. To allow flexibility to the patrons and to guarantee the continuation of the community center's amenities, a group payment plan, similar to a micro-finance scheme, may be applied. These informal payment groups have proved successful in many rural areas of developing countries (Nagarajan and Meyer, 2006).

While the optimal electricity generation system for Mbanayili, that is, one that can accommodate all of their appliance priorities, uses PV arrays, batteries, and a diesel generator, this system does not meet the sustainability check. It is not below the villagers' WTP. The system that best accommodates their needs while remaining within their financial abilities uses only PV arrays and batteries. A graduated implementation strategy is needed to successfully reach the villagers' ideal electricity system (see Table E.1). This has been planned as a four-stage effort, which employs Jatropha cultivation as a means of revenue generation, a plan that has been successfully implemented by another project (Henning, 2004).

Table E.1: Implementation Plan Overview

		Stages 1 and 2	Stages 3 and 4
System Architecture		**Solar Power System (PV array)**	**Hybrid System (PV array and generator)**
	System components	0.4 kW PV	0.5 kW PV
		-	1.5 kW Diesel (or Jatropha)
		5 Hoppecke 4 OPzS 200	5 Hoppecke 4 OPzS 200
		0.5 kW Inverter	1.5 kW Inverter
		0.4 kW Rectifier	1.2 kW Rectifier
	Total net present cost	$12,391	$27,429
	Levelized cost of electricity	$ 2.499/kWh	$ 1.088/kWh
Cost (USD)			
	Initial capital cost	4,922	7,747
	Annualized capital cost	461	726
	Annualized replacement cost	104	326
	Annual O&M cost	596	939
	Annual Fuel Cost	-	579
Electricity consumption			
	Total consumption per year	476.2 kWh	2,506 kWh
	Average consumption per day	1.30 kWh	6.87 kWh
	Peak load	264 W	2,657 W
Activity Schedule		see Table A.4.1 in the Appendix	see Table A.2.3 in the Appendix
Permitted Electrical Appliances			
	Parties	Light(CFL)	Television, Stereo, Speaker, Fan, Light(CFL), Refrigerator
	Watching Television	Television, Light(CFL)	Television, Fan, Light(CFL)
	Weddings	Light(CFL)	Television, Stereo, Speaker, Fan, Light(CFL), Refrigerator
	Funerals	Light(CFL)	Stereo, Speaker, Fan, Light(CFL)
	Newborn celebration parties	Light(CFL), Stereo	Stereo, Speaker, Fan, Light(CFL)
	New Year parties	Light(CFL)	Stereo, Speaker, Fan, Light(CFL)
	Studying (Class)	Light(CFL)	Light(CFL)
	Using computer	Computer, Light(CFL)	Computer, Light(CFL)
	Market	Light(CFL)	Stereo, Light(CFL)
	Cell phone charging	Cellular phone charger	Cellular phone charger
	Free space	Light(CFL)	Television, Light(CFL)
	Cooking	-Banned-	Light(CFL), Cooking stove
	Healthcare	Fan, Light(CFL), Refrigerator	Fan, Light(CFL), Refrigerator
Financial Resources			
	Annual costs	Villagers' income (Willingness to pay, 720USD)	Villagers' income (Willingness to pay), increase with revenue generation scheme
	Initial costs	Foreign governments, international development organizations	
Revenue Generation from Jatropha			
	Processes	Seed collection	Seed collection
		Oil extraction	Oil extraction
			Electricity generation
			Soap production
	Jatropha seed production	2,848kg (2007 - 2008) 4,450kg (2009 - 2011)	5,340kg (2012-) 6,675kg (future goal)
	Land requirement for Jatropha plantation	1.19 - 1.78ha (2007-2008) 1.48 - 2.23 ha (2009 - 2011)	1.78 - 2.67ha (2012 -) 2.23 - 3.34ha (future goal)
	Expected revenues	157 USD (2007 - 2008) 437 USD (2009 - 2011)	1,180 USD (2012 -) 1,833 USD (future goal)
	Workers needed	6 individuals (2007 - 2008) 13 individuals (2009 - 2011)	16 individuals (2007-2008) 22 individuals (future goal)
Electricity Price (per month by income level)			
	less than 100,000cedis	1,800 cedis (0.20 USD)	(Further research is needed based on future income level)
	less than 150,000cedis	4,595 cedis (0.51 USD)	
	more than 150,000cedis	11,892 cedis (1.32 USD)	
Reference		Chapter 8	Chapter 7 (benchmark configuration)

The first stage of this plan focuses on harvesting Jatropha seeds and selling them in an unprocessed form for revenue generation. The second stage expands these activities to include oil extraction, which is then sold for increased revenue. At this point, the power generation system is comprised of only a PV array. In the third stage, using the revenue from selling Jatropha seeds and oil, as well as soap made from Jatropha, the village should be capable of financially supporting a hybrid electricity generation system consisting of PV arrays and a generator.[4] From this stage onward, a fraction of the fuel costs for the generator will be offset by the use of Jatropha fuel oil. The fourth stage will occur when Jatropha production and usage leads to the villagers' electricity goals being fully met. If achieved, this strategy will culminate in the villagers' attainment of their desired energy consumption, without surpassing their WTP at any phase of the project's implementation. Furthermore, this plan would spur economic development and improve the villagers' overall quality of life by eventually providing annual revenue of 1,832 USD and twenty-two job opportunities.

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[4] Significant evidence exists that supports the use of Jatropha biodiesel as a proxy for diesel. However, initial attempts to model unesterified Jatropha oil in a Lister-style engine were not successful because of the difficulty in determining an appropriate fuel efficiency curve for this obscure biofuel and engine. For this reason, and due to the fact that diesel can be procured more easily in Mbanayili, initial benchmark modeling parameters assume that the generator is fueled by diesel. (see Chapter 6 and 7 for details)

Chapter 1 Introduction: The Need for Rural Electrification in Ghana

1.1 Geographic Information and Main Socioeconomic Issues of Ghana

Republic of Ghana is located on the West African Coast with Cote d'Ivoire on the west, Burkina Faso on the north, Togo on the east, and Gulf of Ghana (Atlantic Ocean) on the south[5] as shown in Figure 1.1.

Figure 1. 1: Map of Republic of Ghana (CIA the World Factbook, 2007)

Ghana encompasses an area of 92,100 sq miles (239,460 sq km) (CIA the World Factbook, 2007). The population in 2006 was 22,409,572 (CIA the World Factbook, 2007). The country is divided into ten administrative regions – Ashanti, Greater Accra, Eastern, Northern, Western, Brong Ahafo, Volta, Central, Upper East, and Upper West. The capital city of Ghana is Accra, which is located in the Greater Accra region, and has an approximate population of 2,000,000 inhabitants.[6] Each region has its own capital city, which can be seen in Figure 1.2. Other information is shown in Table 1.1.

[5] Data from http://www.info-ghana.com/general_info.htm.
[6] Data from http://www.info-ghana.com/general_info.htm.

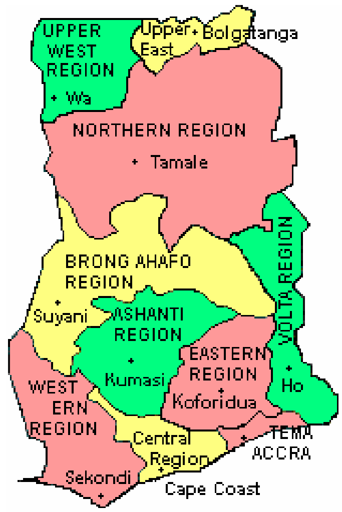

Figure 1. 2: Map Showing Regions and Cities in Ghana (Ghanaweb.biz, 2007)

Table 1.1: Facts about Ghana (CIA the World Factbook, 2007)

Government type	constitutional democracy
Languages	English (official)
	African languages (including Akan, Moshi-Dagomba, Ewe, and Ga)
Religions	Christian 63%
	Muslim 16%
	indigenous beliefs 21%
Population growth rate	2.07%
Median age	19.9 years old
Sex ratio	1 male: 1 female
Currency	cedi (9000 cedi = $1.00)

During the past 30 years, Ghana has encountered high inflation rates, high interest rates, and a lack of economic development (IMF, 2003) However, its development is quite significant during the past five years. The inflation rate has decreased from around 40% to 10%. The interest rate has been lower from 30% to 15%. The annual economic growth increases from 4% during the past twenty years to 6.2% in 2006 (World Bank, 2007). Ghana's GDP per capita in 2006 is 2,600 USD, which is approximately one fourth of the world's average GDP.[7] 31.4% of the population has income below the poverty line.[8] When considering only rural areas, 50% of the population in rural Ghana is below the poverty line. The problem is more acute in three northern regions: Upper East, Upper West, and Northern regions, with fractions of the population below the poverty line in 1999 of 88%, 84%, and 69%, respectively (IMF, 2003).

[7] World's GDP as of 2006 is $10,000.
[8] Poverty line is the minimum level of income required for achieving adequate standard of living.

As a consequence of being poor, several health problems are prevalent in Ghana. For example, malnutrition among Ghanaian children is high, 26% nationally and 35% - 40% in the northern area of the country (IMF, 2003). The infant mortality rate in 2006 was 5.52%. Inadequate medical service is also one of the problems (CIA the World Factbook, 2007). In 1998, a quarter of baby deliveries were neither supervised by technical practitioners or Traditional Birth Attendants. The figure for rural northern regions is approximately 30% (IMF, 2003). The reasons for not using medical services are due to high transportation costs. 20% of people in urban areas and 61% of people in rural areas are more than thirty minutes away from the nearest health facility (IMF, 2003).

Education problems also relate to poverty. In 2003, only 74.8% of Ghanaians who are 15 years of age or older can read and write (CIA the World Factbook, 2007). According to the fourth Ghana Living Standard Survey (GLSS4) conducted in 1998, 32% of Ghanaians did not attend school, and only 10% have completed secondary school or attained higher education. The main reasons for not attending school are that 1) the schools are too far from their residence; 2) they have insufficient funds to pay for the tuition; 3) they have to work at home instead; 4) they have a perception that schools cannot provide them with skills they need (IMF, 2003).

In addition, pervasive poverty contributes to lack of access to developed energy sources. Electricity accessibility is 60% nationwide, 60% - 77%[9] in urban area, and 17% in rural area (Ackom, 2003; JICA, 2006). Situations in the three northern regions are more problematic. On average, 20% of the population in these regions has access to electricity. Furthermore, rural areas in these regions experience a higher incidence of these problems. The electricity access is as low as 10%. Due to lack of access to electricity, major sources of energy consumed are traditional biomass (97%).[10] The remaining 3% is from other energy sources, which include crop residue, kerosene, liquidified petroleum gas (LPG), and electricity. The use of traditional fuel, such as fuel wood and charcoal, also produces in-door air pollution, which leads to health problems, namely, acute respiratory diseases (World Bank, 2000).

[9] According to Ackom, 77% of population in urban area has access to electricity, while JICA's data shows 60%.
[10] Traditional biomass includes firewood (84%) and charcoal (13%).

1.2 Impacts of Rural Electrification on Poverty

Electrification has been identified of as a measure to improve standards of living and the eradication of poverty (World Bank, 2000). According to the World Bank (2000), providing electricity to rural communities can positively impact the region in numerous ways;

- Living standard:
  - Electric lighting allows studying in late evening and at night.
  - Electric lighting increases safety.
  - Electrical appliances can facilitate routine works.
- Health:
  - Electricity can replace traditional energy sources, which reduces adverse health effects such as asthma.
- Local economy
  - Electric lighting allows working in late evening and at night.
  - Employment can be increased on both supply side and demand side.
    - Supply side: electricity generation system provides job opportunities to rural villages.
    - Demand side: it can create new local businesses by enabling the village to adopt industries requiring electricity.

1.3 Research Objectives and Methods

As discussed above, modern energy services are vital to solve Ghana's poverty issues, particularly in rural areas. Electrification can improve living standards, facilitate education, relieve health problems, and promote the development of local economies. Therefore, energy modernization is recognized by the government as having a central role in the alleviation of poverty. Realizing the benefits of electrification, the Government of Ghana has established a plan for nationwide electrification. However, despite the governmental emphasis on electrification, large portion of Ghanaians, mainly in rural areas, are still without electricity. Thus, this project began by studying the problems of the stagnated electrification plan. The causes of the problems were then analyzed. From the analysis, the project concluded that the electrification policy of the Government of Ghana should be modified to promote and accelerate electrification.

Therefore, to support rural electrification in Ghana, this project has attempted to develop new concepts and approaches that are feasible and effective for promoting rural electrification. To meet the project's goal, field research conducted in summer 2006, interviews with professionals in rural electrification, lessons learned from other rural electrification projects in Ghana, and academic journal research have been utilized. Chapters 3 through 9 will explain the logic, the processes, the findings, and the recommendations for rural electrification in Ghana.

Chapter 2: Background and Policy Analysis

2.1 Preface

In the spring of 2006, the authors conducted preliminary research on power sector reform in Ghana to become familiar with the institutional players, the challenges facing the power industry and the current reform initiatives. The following is that report in its entirety:

2.2 Introduction

Despite Ghana's endemic electricity supply shortages and low quality service, no significant infrastructure redevelopment has been initiated. Because it is a state-owned monopoly, the sector has neither substantial incentive nor sufficient funding to improve operations. Consequently, power sector reform has been proposed as a means of increasing competition, improving the sector's operational efficiency and effectiveness, and acquiring investment from the private sector. (Edjekumhene, 2001)

The purpose of this chapter is to review the history and current status of Ghana's power sector and its reform initiatives as per the Government of Ghana's (GOG) 1997 reform plan. The study will then analyze how Ghana's economic and political landscape will affect the success of the proposed initiatives. This study will critique the relative merits and weaknesses of the reform plan and its ability to satisfy its objectives. Finally, recommendations for effectively initiating energy sector reforms will be proposed.

2.3 Pre-Reform History

Ghana's power sector is a vertically integrated state monopoly governed by the Ministry of Energy, which is responsible for policy development and coordination of the power sector (Edjekumhene, 2001). The institutions involved are 1) Volta River Authority (VRA), which is responsible for generation, transmission, and construction of the transmission system. The VRA dominates generation as well as controls transmission and distribution activities; 2) Electricity Corporation of Ghana (ECG), which is responsible for distribution of electricity in southern Ghana; 3) Northern Electricity Department (NED), which is responsible for distribution of electricity in northern Ghana; and 4) State Enterprise Commission (SEC), which acts as a regulatory body. The SEC inspects state-owned corporations and companies. Also, to measure the management performance of those organizations, the SEC sets benchmarks for every organization's annual performance contracts.

Due to the heavy dependence on hydropower for Ghana's electricity energy supply (99% before 1992) (Edjekumhene, 2001), the prolonged droughts in 1983-84 and 1993-94, coupled with growing demand, caused severe power shortages. Consequently, more generation, transmission, and distribution infrastructure was required, as well as improvement of the existing facilities to meet the increasing electricity demand and to upgrade the service quality. Therefore, in 1993, the GOG planned to construct a 330 MW thermal combined cycle power plant and sought funding from the World Bank. That same year, the World Bank, which had been a major source of funding for Ghana's power sector, announced they would not provide any further funding unless recipient countries committed to reforming their power sectors. To achieve this, the GOG is in dire need of private sector investment to maintain and improve the current infrastructure. With few alternatives, the GOG agreed to satisfy the World Bank's conditions to create an economic environment that attracts private investors. The GOG demonstrated its commitment for reform by establishing the Power Sector Reform Committee (PSRC) in 1994.

2.4 Current Situation

2.4.1 Generation Sector

Ghana's installed capacity as of 2003 is approximately 1,652 MW. Although three thermal plants have been installed, 65% of generating capacity (1,072 MW) remains from hydro-electricity (hereafter hydro) (Ministry of Energy, Government of Ghana, 2003). Hydro generation has posed significant problems as a reliable source of electricity due to periodic drought and unsustainable water consumption practices. The primary turbines at Akosombo produce 52% of the country's total generating capacity. In 2000 this facility had a shortfall of 380 GWh, which was offset by imports from neighbouring Cote D'Ivoire. This facility is currently under renovation to increase water reserves, a project that was slated for completion in late 2006. The added generating capacity anticipated after the renovations are completed will be 108 MW. However, generation shortfalls are likely to continue as demand (5% growth per annum) is expected to outpace the availability of water and/or newly installed capacity (Edjekumhene, 2001). Due to anticipated sustained energy shortfalls, the GOG is attempting to transition their fuel mix from one that is heavily reliant on hydro to one that is primarily thermal based, reliant on natural gas. This transition will be facilitated by the construction of the West

African Gas Pipeline (WAGP), which will transport natural gas from the plentiful reserves in Nigeria to Ghana.

The VRA is effectively a state run monopoly and solely owns all the generating capacity, except for a joint thermal plant venture between the VRA and the privately owned firm CMS (CMS Energy Co.). As a government run and vertically integrated organization in a non-competitive market, it has little incentive to improve efficiency. The 1997 reform plans call for the GOG to divest from the VRA, and for all other generating operations to open up the market to independent power producers (IPP). The current market is not attractive to investors for myriad reasons. The VRA is the main generation, transmission, and distribution company—previous market entrants faced opportunistic behavior perpetrated by the VRA, such as restricted access to transmission lines, high transmission prices, and restricted customer access, which causes new entrants to be wary and reluctant to invest. One of the previously cancelled projects is a power plant in Ashanti Goldfields. The VRA served as a significant barrier to the project's completion because it restricted access to transmission lines and did not allow the new plant to sell electricity to the VRA's existing customers (ECA, 2003). Thus, the reform plan calls for the unbundling of the VRA's activities and divestment from thermal generation in the short-term, with a long-term goal of having the GOG completely divested from all power sector operations. The immediate unbundling of the VRA's upstream activities will prevent the opportunistic behaviours that are a major impediment to private sector investment. The unbundling and divestiture of the VRA from the upstream operations would also make cost and tariff structuring activities transparent.

To make the markets competitive, the VRA is looking to divest from all thermal generating plants, while remaining the country's sole hydro producer. New entrants are reluctant to come forth, knowing their costly thermal generation will be competing with the government's inexpensive hydro operations. This will continue to be a significant barrier to the formation of a competitive market until it is resolved. Also, current generating tariffs are revised infrequently and do not reflect long run marginal costs, which has caused the VRA to place significant financial burdens on the GOG in order to sustain operations (ECA, 2003). Furthermore, persistently high levels of inflation continue to erode the real value of the tariffs. The GOG keeps tariff prices artificially low, in part due to the political ramifications of passing the actual costs of generation on to the public. A common mantra voiced by the public is "no electricity, no vote"

(Ahiataku-Togobo, 2003). This places political pressure on representatives seeking election to provide the public with electricity, even if it is not economically viable.

Another aspiration of the reform plan is to initiate competition for long-term bilateral contracts in the wholesale market. This will give more opportunity for new private generators to enter the market. However, there are not a sufficient number of power producers and large volume consumers to create a competitive market for these contracts. Potential IPPs would be discouraged by the lack of available contracts, because all the large consumers have already locked in to long-term agreements.

This problem is further exacerbated by the fact that even if credible investors were identified for participation in existing generating facilities, there would only be five generating plants in operation. However, in the short-term the GOG is only looking to privatize two thermal plants. This is hardly fertile ground for a competitive market. With so few generating facilities, there is a strong likelihood that a dominant firm would surface and potentially monopolize the market, or collusive practices would transpire amongst the few existing firms. Despite growing electricity demand in Ghana, it might take a number of years before enough demand and installed capacity exist to allow for a competitive market.

2.4.2 Transmission Sector

Currently, the VRA is vertically integrated into the transmission network, which serves as a major obstacle to the formation of a competitive market. Third party access (TPA) to transmission must be assured to entice private sector investment in the wholesale market. Strict regulations will be required to ensure both the transparency of the VRA's operations and the absence of the discriminatory and collusive practices that have transpired in the past. Stringent accounting rules could be devised to achieve this, but currently no strong regulatory body has the jurisdiction to oversee compliance (ECA, 2003). An even better option is to have the VRA divest from its transmission assets altogether, assuring that it has no vested interest in these operations. Though an independent transmission systems operator (TSO) would be best, a non-discriminatory TPA agreement would be ideal in the short term, because of the substantial amount of time and coordination it would take to successfully create a TSO. In the short-term, clearly delineating regulatory roles amongst current government institutions and, as well as the government's unconditional support for TPA rights, is critical if progress towards a competitive market is to be achieved.

Previously, transmission charges were set at 0.09 USD/kWh, which was prohibitively high to attract IPPs. There has been difficulty in accessing the true cost of transmission, but recently the PURC has cut these charges by 50% (0.045 USD/kWh) to try to encourage interest in market investment. However, the PURC will continue to have difficulty in assessing the actual cost of transmission as long as the VRA is vertically integrated and maintains its lax accounting rules.

2.4.3 Distribution Sector

Currently, there are two main electricity distributors in Ghana: the ECG and the NED. The ECG distributes energy to the densely populated southern region of Ghana, where 80% of electricity consumption exists, while the NED is responsible for supplying energy to the sparsely populated north. The ECG and the NED are entirely owned by the GOG, despite attempts to make these companies available to private investment. In 1997, the ECG was transformed into a limited liability corporation, but due to poor financial health the GOG was unable to attract investors and remains the sole shareholder. Both of these distribution companies have incurred massive financial losses over the past decade, placing considerable economic strain on the government (ECA, 2003).

The ECG customer base has increased steadily over the past five years at approximately 8%-10% per annum (ECA, 2003). The company’s financial losses have been growing over the same period, with annual losses of approximately 27% during the period from 1999 to 2001 (Ministry of Energy, Government of Ghana, 2003). This can be attributed to a number of factors (as per ECA 2003):

- an archaic and inefficient transmission network
- inaccurate billing and meter reading services (collection service is only 80% efficient) (Ministry of Energy, Government of Ghana, 2003)
- unlawful connections and unmetered customers, who account for 3.5% of the total customer base, and
- inaccurate and outdated metering system

Similar to the ECG, the NED has exhibited major operation losses over the past five years, ranging from 25% to 30% annually. Its customer base has been growing by more than 14% per annum (Ministry of Energy, Government of Ghana, 2003), in large part due to the mandate of a government program, the National Electrification Scheme (NES). This program contributes to the NED's financial instability because of various mandates, in particular the "life line" subsidy, which requires the NED to provide electricity to customers who pay flat uneconomic rates that are inadequate to recapture generation and transmission costs. This government electrification scheme was not intended to be economically viable, but rather devised as a tool to garner political favour by improving the standard of living.

Despite the NES, there is still a low quality of distribution services—technical and non-technical losses, and low access to electricity, particularly in rural areas. After it was implemented, there were only minor improvements in network expansion and rural electrification, due to both financial difficulties from operational inefficiencies, and a lack of funds for increasing reliability and overall performance. Thus, for higher operational performance and the acquisition of additional funding for capital improvements, private sector participation has been proposed. The reform plan aims to attract private sector investment in five individual distribution business units, with exclusive market territories, by separating the ECG into four distribution areas and making the NED the other business unit under an ECG holding company. The long-term goal is to have the business units fully privatized by investors (ECA, 2003).

However, dividing distribution service into five companies may result in market territories insufficient for each business unit to remain solvent. This would undermine the distribution companies' credibility as off takers of electricity with emerging IPPs.

2.5 Electrification Programs: On-Grid and Off-Grid

In 1995 the GOG conceived of a strategy that "will have achieved a balanced economy and a middle-income country status and standard of living" by 2020. If successfully implemented, the Ghana: Vision 2020 plan (also known as Ghana 2020) will increase access to healthcare, employment, shelter, and leisure. The distribution of benefits derived from this progress will be allocated in an equitable manner with the intent of eliminating "gross deprivation and hard-core poverty". In broad terms, this will be achieved by "deriving maximum productivity from the use of [Ghana's] human and natural resources", while simultaneously observing "due regard [for] the protection of the environment" (Ministry of Finance, Government of Ghana, 2000).

In advance of the Ghana 2020 initiative, the government was cognizant that promoting electrification would be a priority if progress is to be achieved. In 1989, the NES was instated to facilitate the expansion of the electricity supply to predominately rural inhabitants with the intent to satisfy the achievements envisioned by 2020. Under the NES master plan, 4,221 communities with populations exceeding 500 were determined to be ideal candidates for future electrification, to be administered at some point over the project's duration. The Self Help Electrification Program (SHEP), initiated in 1990, was created with the expressed intent of fostering the aims of the NES master plan. The SHEP functions by providing low voltage grid connection and in-house wiring for 5,000 cedi per household if the community purchases the utility distribution poles, and is situated no farther that 20km from the nearest grid connection. This initiative was generally heralded as a success, because from the period from 1989 to 2000, national household electrification in Ghana increased from 15% to 43%. Accolades aside, this program is not without criticism: Payment default, especially by rural inhabitants, places considerable burden on the project's fiscal stability, which impedes investment in future network expansion (JICA, 2006). A lack of cohesive planning causes inefficient allocation of the distribution network. The government obligation to provide grid connections to whomever purchases distribution poles permits haphazard network connectivity, which in turn increases the overall cost of electrifying particular communities (JICA member, Pers. Comm., 2006).

Where on-grid electrification solutions under the SHEP program are uneconomical or technologically infeasible, distributed off-grid rural electrification schemes are also being implemented in remote communities. Over the past decade, many of these projects have been fraught with substantial technical and financial hardships, in part due to a lack of long-term strategic planning. In the mid 1990's the World Bank financially backed a program to assist in the installation of battery recharge stations powered by photovoltaic arrays. Approximately 2,000 Solar Home Systems were installed, but unfortunately, at present a non-negligible fraction of these systems have been rendered obsolete because many of these communities have since received grid electricity (JICA member, Pers. Comm., 2006).

The Renewable Energy Service Project (RESPRO) was initiated in 1999, with financial backing from the Global Environmental Facility (GEF), the Ghanaian Government, and the US Department of Energy's National Renewable Energy Laboratory. From its inception to the present, the RESPRO has been accumulating budget shortfalls, despite implementing a fee-for-service approach. The financial instability of the program is attributable to a number of factors, namely, the high transaction costs associated with collecting payment, and the maintenance and installation of PV systems in the sparsely populated northern regions of Ghana. The RESPRO was initiated without adequate financial and strategic planning from the government, and without the cooperation of existing utility companies. Insufficient operational funds available for maintenance, coupled with a reactionary maintenance regime, culminated in many installed systems becoming defunct. This further contributes to the lackluster perception Ghanaians have of off-grid energy systems, which are often believed to be inferior to grid electricity. In 2002, GEF funding for the project ceased, and now it is currently being restructured as an NGO corporation (JICA, 2006).

In 1999, the Danish National International Development Agency initiated a program to construct 14 battery charge stations, operational from 2000 to 2002. The EC conducted operations beginning in 2003 and promptly transferred operational responsibilities to regional assemblies in 2004. Regional assemblies were required to provide the EC with annual statements outlining financial activities. These local agencies were expected to collect the payments owed to the rural banks which subsidized operations, because excessive transaction costs prohibited the banks from directly overseeing repayment schedules themselves. Recipients of these loans (local agencies) provided creditors with deposits and made almost entirely no effort to repay the principal. This culminated in the demise of the project, which is largely attributable to the following factors: mismanagement and opportunistic behavior by local agencies caused the funding apparatus to disintegrate, in part because the sum of the loans overwhelmed local farmers with financial burdens they could not realistically repay; apparent dissatisfaction in the quality of service enabled service recipients to harbor grievances against collection authorities and justify defaulting on payments; rural communities in Ghana are dictated by blood relationships, further compounding the ability of these agencies to recapture payment from individuals (JICA, 2006).

The difficulties exhibited by the projects above further underscore the necessity for comprehensive field research and long-term contingency strategizing for successful project deployment. The Japan International Cooperation Agency (2006) has provided in-depth analysis on these issues.

2.6 Regulatory and Pricing Structure

The GOG established two regulatory bodies in 1997: the PURC and the EC. This has been the only progress made to date regarding the recommendations posited by the 1997 reform plan (ECA, 2003):

- The PURC regulates tariffs for all public utilities and the monitoring of performance standards, enforces customer service obligations, and promotes competition.
- The EC grants licenses to qualified operators in the energy sector and sets standards of performance.

The assignment of the roles of the two regulatory bodies could be considered deficient. No regulators have been assigned to oversee the development of the market and competition. There is also overlapping and inconsistency in their respective roles; separating licensing and setting standards of performance for tariff regulation lowers the electricity companies' ability to improve efficiency. Although the PURC is responsible for the tariff regulation, it lacks the power to impose the regulation, because it cannot adjust licenses. Moreover, the PURC can only monitor standards, which are set by the EC, and recommend that the EC suspend or cancel licenses to enforce standards. Finally, it is not clear who is responsible for setting the performance standards for service quality.

2.7 Policy Analysis

As outlined above, the problems in the energy sector are myriad and interrelated. The government has tried to solve them, but their solutions have not had significant impact. To understand the lackluster results, the attributes of Ghana's energy market must be detailed. The current electricity market in Ghana is bifurcated into two distinct sectors: on-grid and off-grid. This study analyzes the two markets separately because they differ in the scale of investment and the numbers of players involved. Similarly, to develop and enact effective policies, the GOG should not treat these as a single market, but rather analyze and strategize for them independently. Thailand has a similarly bifurcated market and provides a potential paradigm of policy and action. The Thai government has established two organizations for managing the electricity market and industry; one is for the urban electricity market and the other is for the rural market. As a result, responsibilities are more clearly assigned to each organization, thereby allowing them to achieve their goals effectively (Ministry of Energy, Government of Ghana, 2003).

2.7.1 On-Grid Market: Problems

To cope with on-grid market problems, the GOG has instated a plan that focuses on creating market competition by attracting private investors through organizational reforms, such as the divestiture of the VRA and the dividing of distribution system responsibilities amongst five independent companies. However, even if competition emerges, these problems will persist, because the tariff structure (price) does not reflect the actual costs of generation, distribution, and transmission. Consequently, emerging businesses cannot acquire sufficient funds for improving the management or infrastructure necessary for a thriving and stable on-grid market. This is because electricity price is determined not by market mechanisms but rather by government regulation. Therefore, the reform plan would not lead to any significant improvements, which conforms to the World Bank's criticism that an artificially low price is the primary obstacle for the on-grid market to overcome (ECA, 2003).

The current energy price set by the PURC is less than the competitive market price. Therefore, the producer’s surplus has been decreased by the price control, which deteriorates the performance of the power companies. The price control at the lower level transfers the surplus from the producers to the consumers. If the consumers do not have enough disposable income for purchasing electricity, this policy is useful. However, judging from the increase of electricity consumption in the on-grid area, one can presume that some consumers do in fact have the ability to purchase electricity at the higher price. One can discern this by noting that if the current price were too high for consumers, there would not be an increase in consumption. Therefore, the surplus may be currently disproportionately distributed to the consumers. That is, the current price might be lower than the price that consumers have the willingness-to-pay.

To set the price appropriately, Economic Consulting Associates (Ministry of Energy, Government of Ghana, 2003) insists that the market should be competitive. For the successful implementation of a competitive market, the following criteria must be met:

- Infrastructure must be well established: trying to introduce a competitive market in advance of revamping the existing archaic power sector infrastructure is likely to prevent the emergence of new entrants. The long-term investment and uncertainty required by private investors to improve the infrastructure will likely present excessive risk to entice such entities. Thus, a competitive market does not necessarily improve the current infrastructure. Government supported improvement to the infrastructure is vital prior to the promotion of a competitive market.
- Each company must have the capabilities and resources to compete with competitors: if this is not the case, a competitive market may bankrupt some companies, especially the smaller ones, culminating in a monopoly or oligopoly.
- Political acceptance: increasing the number of suppliers may exacerbate the utility company's ability to achieve profitable margins. Since available generation capacities would be dispersed amongst many suppliers, their fixed cost would increase, because of the reduced generation capacity remaining for each supplier, thereby diminishing achievable scales of economy. Consequently, electricity prices would soar in the short-term to cover the increased electricity generation costs. Despite the potential long-term benefits of a competitive market (i.e., inducing more effective management), policies that increase consumer prices in the short-term would garner little favor amongst politicians because of the consequent unfavorable public perception.

If Ghana can effectively introduce a competitive market by meeting these criteria, the overall health and stability of the energy sector institutions will improve. As of yet, these criteria have not been satisfied. For instance, the current infrastructure, especially the transmission network, remains substandard and a competitive market may discourage the power companies from making the large-scale investments required for improvement. The existing power companies are not in a situation conducive to instigating a competitive market, due to their large debt that restricts necessary efficiency improvements. It is also not known if the price will rise adequately after market deregulation to cover the actual cost of generation. If consumer price concessions continue in consort with capital improvements, the performance of these companies will worsen.

Altogether, considering the current market conditions, a competitive market would not provide enough benefits: As discussed above, the government needs to take actions to solve these issues before a competitive market is introduced.

2.7.2 On-Grid Market: Solutions

The low performance of the power companies is the chief problem of the energy market. The companies' large debts prevent improvement of electricity transmission quality and network expansion. In economic terms, the producer surplus should be increased so that they have enough financial resources to improve their own performance. There are two main methods to increase producer surplus. One method is resetting the electricity price based on current supply and demand, which would lead to a price increase. The other method is providing government subsidies to energy producers in order to alleviate their production cost. Unfortunately, government subsidies are unfeasible given their current financial condition. Alternatively, resetting the electricity price is feasible and effective, because the enhanced price gives a portion of the customer surplus to the producers without government expenditure. In addition, changing the price based on current demand and supply levels leads to the maximization of social surplus. Through increased producer surplus, power companies can improve their performance and the infrastructure. However, this method should receive attention in terms of the price stability. Electricity production in Ghana is unstable, owing to its dependence on hydropower, which is greatly contingent on weather conditions. Thus, in cases of severe drought, electricity shortages make prices soar. In this particular case, if the price is determined only by the demand and supply, the consumers' surplus could decrease dramatically, causing serious political concerns, because of widespread electricity outages. Therefore, even if the price is determined by the demand and supply, a price cap mechanism is still needed to control the price.

The government may feel that this policy is unfeasible, because a strong citizen opposition to a higher price is expected. Thus, the government must convincingly explain the current conditions to the public. High quality electricity and expanded transmission systems are vital for improving the economy. To achieve countrywide economic development, the power companies must be healthy. However, the current low prices are deteriorating the companies' performance. As long as the citizens insist on low prices, the economy will not improve.

2.7.3 Off-Grid Market: Problems

Rural areas have the potential to be a future market, because the energy consumption in rural areas has increased 14% per year in recent years (JICA, 2005). After the implementation of the NES' mandates, there is an expected electricity market of 12,530 GWh (JICA, 2005). Despite this, partly due to future uncertainties and the lack of government support, potential companies are hesitant to enter the market. Their main concerns are the long-term economic potential of the rural market, the uncertainty of future governmental policy/support (tax, subsidy, etc), and the ability of customers to pay the actual cost of electricity production (ECA, 2003). To complicate the situation, the government focuses solely on on-grid solutions for rural electrification. Though the on-grid expansion is a powerful solution for electrification, because it can maximize economy of scale, this is not feasible, due to the large investments required and the current inefficacy of the myriad of small, fragmented markets. In particular, focusing solely on on-grid solutions is not a cost-effective solution to achieve electrification in low-density areas. Due to this, the current government policy creates market barriers for potential producers and limits the expansion of the off-grid market.

2.7.4 Off-Grid Market: Solutions

To promote rural electrification, the government should change their policy from an on-grid centered solution to an off-grid system. The small amount of initial investment necessary for the off-grid system would remove market barriers for potential producers; the cost of satisfying the electricity needs of rural inhabitants with off-grid systems is less than utilizing on-grid generation systems (Geller, 2002). If the government makes clear policies, such as giving subsidies to off-grid energy producers, this would foster market expansion.

Specifically, the government should remove two major uncertainties in the rural electricity market, namely, the future market scale and profitability of off-grid business, because these are the two most influential factors for new producers considering entering the market (World Bank, 2006). First, in order to remove the uncertainty with regard to future market scale, the government should show commitment to rural electrification. Even though the government has established the NES, which promotes rural electrification, the achievement of the plan is somewhat doubtful. If the government commits to its goal, the market barriers will diminish, because potential producers can develop business plans based on an anticipated future market scale, thereby reducing risk, but if the achievement of these goals in not realistic, risk and uncertainty will remain. The government should also find a mechanism for guaranteeing the minimum profitability of emerging businesses. There are two major risks regarding profitability: the risk of future solvency for rural villages, and the uncertainty of future policies regarding cost-covering subsidies. First, the solvency of villages has to be assured. Since both the local governments and the consumers do not have enough financial capacity and purchasing power, potential producers may face the risk of irrecoverable debt. Thus, a scheme to minimize the risk needs to be developed. Second, the GOG should demonstrate long-term commitment regarding subsidies for electricity generation. The effectiveness of subsidies for electrification has been proven (JICA, 2002). If the subsidies were ensured in the long term, the market would attract new entrants.

2.7.5 Reform Suggestions

To implement the policy measures stated above, the government has to prioritize them, due to its limited resources. Firstly, on-grid market problems—companies' huge debts, deadweight loss, and uneven distribution of the social surplus—should be addressed as soon as possible. This is because price measures based on demand and supply do not require any further government expenditure. In addition, this measure would have a large impact in comparison to other measures, because the size of the existing on-grid market is far larger than that of the off-grid. Thus, an on-grid market reform would bring a large surplus to both the government and the companies. A surplus increased by this measure would contribute not only to the improvement of the companies' profits, but also to the government's revenues, due to increased tax earnings. Using financial resources from this tax, the government could remove the market barriers to the off-grid market through the measures stated above. Using these means, the current power companies could improve their performance, and potential producers would be encouraged to enter the market.

Chapter 3: The Purpose and Scope of the Research

3.1 Overview

As mentioned in the previous chapter, electricity scarcity is more evident in rural areas of Ghana, especially in the north. In addition, achieving the goal of the government's electrification plan (National Electrification Scheme (NES)) is doubtful because of an ineffective electrification strategy, which focuses mainly on on-grid electrification. This can be costly in sparsely populated areas, which is a common characteristic of rural Ghana. Successful implementation of the NES is further compounded by insufficient governmental funds and the reliance on donor assistance (JICA, 2006).

Renewable resources are considered to be a cost-effective alternative for providing energy to remote and rural areas in developing countries, according to IEA (International Energy Agency) (Ackom, 2005). Moreover, utilizing local and distributed renewable energy, as opposed to hydropower which is insufficient for the entire Ghana's electricity demand, strengthens energy security of Ghana. Additionally, utilizing renewable energy minimizes adverse impact on the environment. However, some past renewable off-grid electrification projects were not successful because of their inability to cover electricity generation costs.

Therefore, to promote the NES, the government's electrification strategy needs to be altered. This project proposes a new approach for rural electrification, that is, sustainable rural electrification strategy. The term "sustainable" is used in reference to two factors: 1) financial sustainability, which maintains electrification costs within the local communities' ability to afford it, and 2) environmental sustainability, which aims to minimize environmental degradation through the use of renewable energies. For the long-term success of rural electrification, attainment of these two aspects of sustainability is paramount. In the study, the new approach is introduced and analyzed using a case study.

Field research was conducted in a rural village in northern Ghana for three reasons: to thoroughly understand the needs for electricity in rural areas, to collect specific data for precise analyses, and to posit pragmatic solutions. Through the case study, financially and environmentally sustainable electrification solutions were developed. In addition, the lesson could be adapted for rural electrification projects in other localities to suit their energy sources availability and social characteristics.

3.2 Project Approach

As discussed above, lessons from past projects show that the main cause of previous projects' failures is lack of financial sustainability. Taking into account insufficient government fund for rural electrification projects and villagers' inability to cover all requite costs, it is evident that cost minimization is integral to successful project deployment. Given this realization, the study focuses on cost minimizing measures from both a demand and supply perspectives. For example, in some situations, benefit lost from reducing end-use consumption would be lower than the cost to generate additional electricity to meet the need. Thus, by understanding sensitivities of both demand and supply, an optimum generation system can be designed (Redford (1994) supports this idea). The overview of the project approach is shown in Figure 3.1.

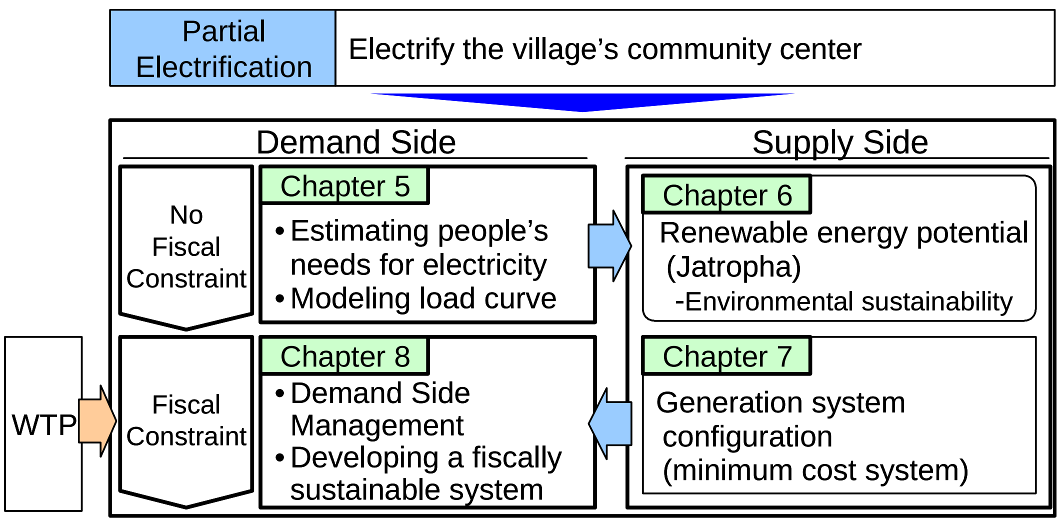

Figure 3.1: Project Approach – Framework

3.2.1 Partial Electrification

First, the study focuses on the roles and functions of a community center in rural areas. The center plays an important role in rural villages, by providing a community space for cultural activities. Electrifying the community center would be able to provide many benefits to villagers. In addition, considering insufficient financial resources of the Ghanaian Government and local individuals, the electrification of all households is not feasible. Thus, to provide electricity access to many villagers under current financial constraints, this project proposes a partial electrification strategy, which initially only electrifies the community center. The partial electrification can significantly decrease electrification costs. Also, providing electricity contributes to improve people's standard of living and develop the local economy (Reiche et al., 2000). Through this strategy, there is potential for increasing villagers' income, affluence and quality of life. After improving income levels, if villages aim at electrifying all households, they can do so with their own funds. In general, electrification is expected to increase people's income levels. This is the primary reasons that the government of Ghana promotes electrification. However, successful implementation often requires a certain level of the villagers' own income. A paradox exists because the funds necessary for electrification are not available in advance of the economic development it intends to spur. To solve this issue, the study suggests electrification should take two steps; 1) partial electrification, to provide minimum access to electricity at present, and 2) the electrification of all households in the future once the community is capable of covering these costs (see Figure A.5.1 in the Appendix.).

Working with graduate students from the University of Michigan's School of Arts and Architecture (Mechtenberg, Buaku, 2006) (see Figure 3.2), the community center was designed, consisting of four zones: multifunctional open area, a health clinic, a storage room for ancillary equipment, and a rainwater cistern. The open area is capable of accommodating 100 people. All activities except health-related ones will be in the open area. The storage room is for storing an electricity generator, batteries, and other equipments and supplies. The enclosed room would be utilized as the health clinic, which has equipment necessary for minor treatments and vaccination. The water tank is for storing and purifying rainwater, which can be used by villagers for drinking, washing clothes and cooking. The health clinic and the open area are the zones that will be electrified to power various appliances. Consequently, the project focuses on people's needs and an electricity generation system only for these two facets of the community center.

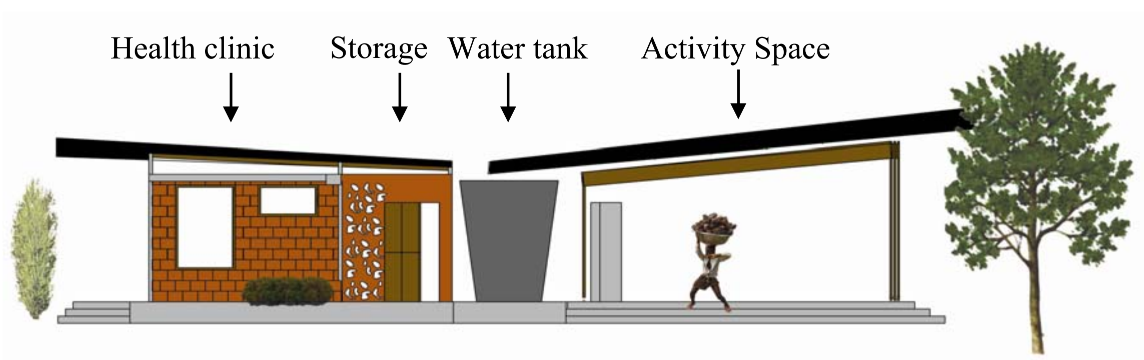

Figure 3.2: Schematic Drawing of the Community Center

This project focuses on electrifying the health clinic and the open space of the community center to find measures for cost-effective rural electrification measures.

3.2.2 Demand Side Analysis (Chapters 5 and 8)

The demand side analysis takes two steps. First, the study focuses on people's potential needs for electricity and estimation of electricity consumption to satisfy these needs. According to our field research, the needs expected from electrification are health service development, education facilities improvement, cultural enhancement, greater entertainment options, and increased job opportunities and revenue generation. In the research, people's needs for electricity are quantified based on data elicited from interviews. This helps in estimating potential needs for electricity. Next, for each of the activities that consume electricity, their time preference and electric appliances needs are analyzed. After that, a demand model is developed and people's potential demand for electricity is calculated using this preference data. From the developed demand model, their consumption patterns are analyzed and the points to control the demand are identified.

Second, people's electricity consumption is controlled by demand side management for an electricity generation system that is affordable for villagers. To maximize villagers' benefits from electricity use under the financial constraint, their benefits are analyzed using people's preference data for electricity use. Then, the study proposes a financially sustainable system for the village.

3.2.3 Supply Side Analysis (Chapters 6 and 7)

The supply side analysis aims at designing renewable electricity generation systems that provide electricity to fulfill demand derived from the demand side analysis with minimum cost. To lower investment for electrification, the project proposes an electrified community center for the village. The community center is designed such that it provides space, basic electrical amenities, and electricity in order to satisfy the villagers' basic needs.

To fulfill the villagers' basic needs, the community center described above would be a lower cost alternative for electrification, compared to having every household electrified and equipped with fundamental amenities. Firstly, the former option can avoid the cost of a power distribution system. Secondly, total requirement for electrical appliances of the community center is less than that of the latter option because people can share them thus reduce purchasing cost. Thirdly, as all villagers use the community center as a common space, they can share costs such as electricity generation cost and repair cost, resulting in less cost per person. Likewise, electricity generating capacity and electrical appliances are utilized more effectively. Therefore, in a poor rural area, electrifying the community center would be more financially feasible than electrifying all households in a village. Another rationale for electrifying the community center is a shorter completion time than electrifying the entire village. Since improving people's standard of living by electrification is an imminent issue to be solved, this benefit is not negligible. Lastly, potential electricity demand of the community center can be easier to estimate than that of every household because the research scope is limited, reducing the research cost and uncertainties.

3.2.4 A Case Study

Detailed data on rural Ghanaians' demand for electricity is crucial for our project because it contributes to better realization of people's needs, thus more realistic solution. However, there is currently no such data available. Consequently, the field research is vital to collect the needed data. A rural village in northern Ghana is selected as the case study for the project. A case study enables us to conduct field research to collect detailed and specific data on the village, which is essential for a thorough understanding of people's potential electricity demand and consumption pattern. Moreover, we can specifically select renewable resources based on their abundance in the area. As a result, we can customize the system such that it best satisfies the villagers' need for electricity and, thus increase benefits of electricity. In addition, detailed data allows us to perform precise analysis. Consequently, the project can deliver a more informed recommendation for the case study. Eventually, the project as a whole could serve as a model for Ghana's rural electrification plan.

From the next chapter, our new approach, shown in Figure 3.1, is discussed and analyzed.

Chapter 4: Field Research Overview

4.1 Overview of the Village and Its Energy Sources

Understanding the potential demand for electricity, electricity consumption patterns and the size of investment needed for electrification are critical elements to develop an electrification plan for rural Ghana. Available data regarding electricity consumption for rural Ghana, however, is very limited (Constantine et al., 1999; Al-Alawi et al., 2002). To explore the potential demand for rural Ghana and to make our models more realistic, field research was conducted in June and July of 2006. A village, Mbanayili (Figure A.1.1 in the Appendix), which is not yet electrified, was chosen from the northern part of Ghana because the electrification rate of the northern area is quite low compared to other regions (JICA, 2004) (Figure 4.1). In addition, electrification of this region has been determined as a site of critical importance by the Ghana government (JICA, 2005).

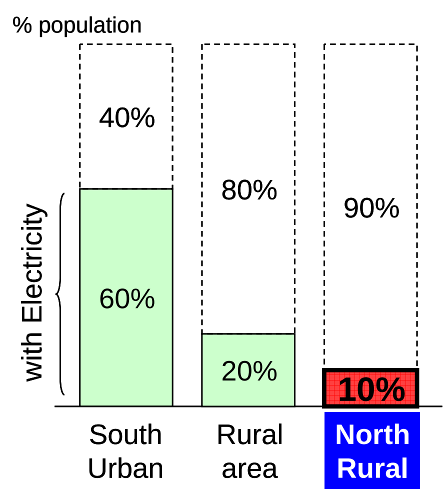

Figure 4. 1: Electrification Rate of Ghana in 2005

Mbanayili is located about 15km northwest from Tamale, the largest city in the northern Ghana, and approximately 7 km from the nearest electricity grid. The local language is Dagbani. Despite Ghana's national language being English, only a few villagers spoke it. According to one of the village leaders, Mbanayili has 1,000 households and 4,050 residents. Annual birth rate is approximately 1.5%, which is lower than the Ghana's average: 3%[11]. There are two seasons: the rainy season, from May to September, and the dry season, from October to April. The average

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[11] Data from Geographic.org: http://www.theodora.com/wfbcurrent/ghana/ghana_people.html.

monthly income is 147,661 cedis (16.4 USD[12]) for men and 57,453 cedis (6.4 USD) for women, according to the field research (national monthly average income: 24.2 USD (2002)[13]).

The energy sources in the village were fuelwood, charcoal and kerosene, which are used mainly for lighting or cooking (see Figure 4.2). These energy sources consume 85% of the income of people living in Mbanayili (Figure 4.3). The remaining 15% of people's income is allocated to other purposes, such as clothing. Note that since many workers are farmers, they do not need to pay for food.

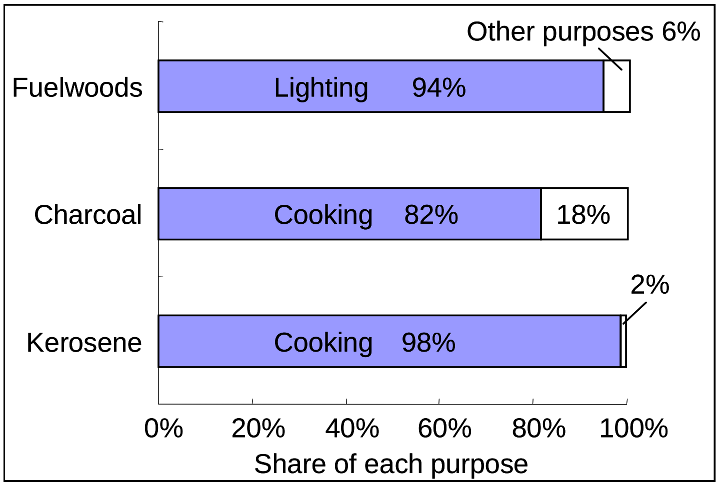

Figure 4. 2: Purpose of Energy Consumption by Energy Source

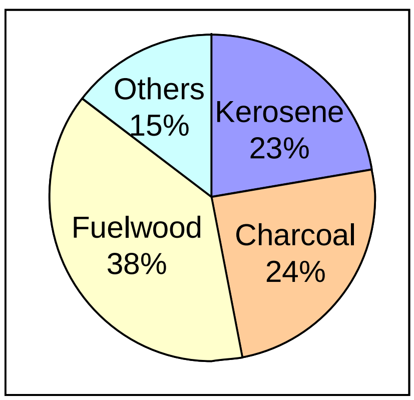

Figure 4. 3: Share of Each Energy Cost in Income

Mbanayili villagers may pay for energy more than the people in neighboring villages, because they do not need to pay rental fee to land owners owing to the policy of Mbanayili's chief (Alhassan, Pers. Comm., 2006).

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[12] The exchange rate is 9,000 cedis / USD (July, 2007). This exchange rate is used through all chapters.

[13] Data from Ghana Homepage: http://www.ghanaweb.com/GhanaHomePage/economy/statistics.php

4.2 Interests and Problems of Mbanayili

Through the interviews and observations, two salient problems were observed. According to one of the leaders of Mbanayili, a prominent problem for the village is a lack of staffed healthcare and educational facilities. He said, “Although they have one building for a hospital, neither a nurse nor a doctor is there on any regular basis.” A nurse comes by the village mainly for pediatric care only a few times a month. In addition, he said, “there are not enough classrooms for students.” When the research was conducted, the students of a class had studied outside. There was a general lack of educational infrastructure.

Villagers’ desire for electricity was great because they anticipate that it will solve many of their problems. For example, a resident said, “if we have electricity and lighting, we can have another class at night in the school.” They think electrification will improve their standard of living and facilitate job creation (Alhassan, Pers. Comm., 2006).

4.3 Introduction of the Field Research

To understand the potential needs for electricity, a questionnaire was designed to elicit information from the villagers in a consistent manner. It is comprised of two parts: 1) basic information, such as gender, occupation and income, and 2) preference for electricity use, including a) activity preference – which activities, such as watching television, having a party and cooking, are preferred, b) time preference – what time these activities are desired to occur, and c) electrical appliance preference – what kind of electrical appliances are preferred for these activities (Table A.1.1 in the Appendix). In order to elicit the much needed information, interviewing was determined to be the ideal method because most people could not read and write English. The questions were asked in the local language through interpreters. By random sampling, 133 residents (men: 94, women 39), who all were above 15 years old, were selected and interviewed. (Note: At the time the interview was conducted, a funeral required the help of many women. Thus, the number of female interviewees is substantially less than the number of male interviewees. As seen in Chapter 5, since women’s preferences for electricity are different from men, the results might be somewhat skewed).

The share of the people who were interviewed, out of all people of 15 years old or above, is 5.4%. Basic data of the respondents is as follows.

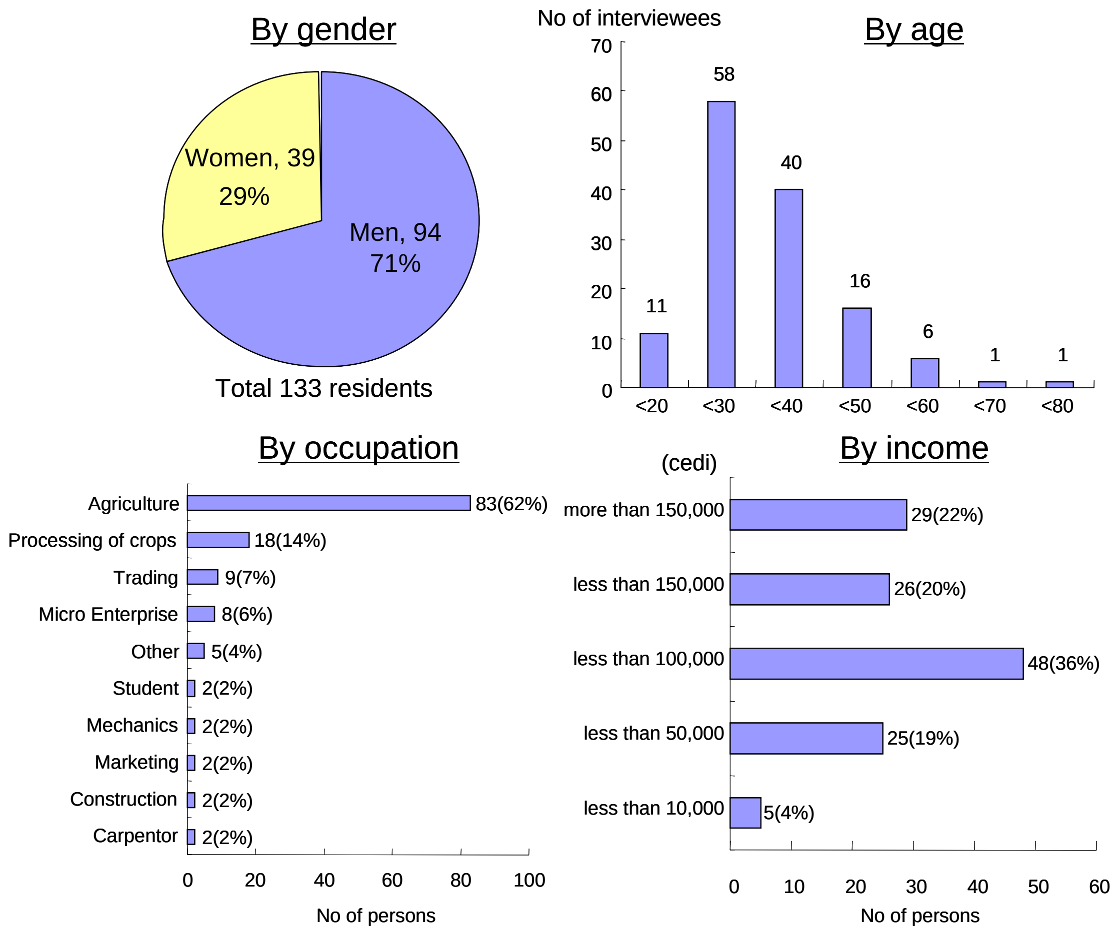

Figure 4. 4: Basic Information of the Respondents

4.4 The Steps of the Case Analysis

In Chapters 5 to 8, this case is analyzed to explore the efficient electrification method. To begin with, the preferences of electricity consumption and potential demand for electricity in Mbanayili are analyzed and determined using the interview data. Then, the consumption patterns are modeled based on the preferences and the resulting demand patterns (Chapter 5). Using the model, an optimum generation system is designed to provide both cost effective and reliable electricity production utilizing HOMER, software developed by National Renewable Energy Laboratory (NREL, USA) (Chapters 6 and 7). After that, the potential for Mbanayili residents to purchase electricity is measured by their willingness-to-pay. Through comparing the required cost for the optimum generation system with the residents' willingness-to-pay, disparities between their ideal electricity demand and the ability for them to pay for it, are identified. Lastly, measures to control electricity consumption to meet Mbanayili's financial constraint are developed with the intent to maximize the people's benefit of electricity usage (Chapter 8).

Chapter 5: Potential Demand Analysis

5.1 Overview of Potential Demand Analysis

In general, electrification plans mainly focus on the supply side, including generation technology, capacity and investment. This is because: 1) cost is the main concern for the institutions, and 2) the outcome is usually measured by electrification rate in a village/region (e.g., National Electrification Scheme of Ghana). The electrification plans are designed with an emphasis on cost-effectiveness due to limited financial resources. Therefore, the governments' primary concerns are price and durability of the generation system, including generators, batteries and solar panels. In addition, governments place importance only on providing electricity, because increasing the electrification rate is their primary goal.

The supply-side-centered electrification plan, however, has problems. For example, past rural electrification projects in Ghana (e.g., World Bank's project (SHS)) could not contribute well to the rural development. One of the reasons would be that the project did little to consider people's affordability to pay for electricity and their technical capability of maintaining the generation system, thus the households' use of electricity were very limited or electricity provider cannot cover all costs (a member of JICA, Pers. Comm., 2006). As a result, the electrification cost was not recovered and the generation systems were deserted. If the people's needs, affordability and capability were well realized, the appropriate size generation system could be designed for them.

Thus, to provide an optimal generation system to Mbanayili, this study focused on the demand side before designing an optimal generation system. In this chapter, to begin with, villagers' potential need for electricity is estimated. Then, based on the results of potential demand analysis, electricity consumption patterns and load curves are modeled. Using the load curve models, in the next chapter, an optimum generation system for the village will be configured.

5.2 Knowledge of Electrical Appliances

Before electricity demand in Mbanayili is explored, the study analyzed people's exposure of electrical appliances. Since Mbanayili is only 15 km from Tamale, the largest city in northern Ghana, many people in the village had seen many electrical appliances (Figure 5.1-A). However, Mbanayili people had rarely ever used them (Figure 5.1-B), partly because most electrical appliances did not exist in Mbanayili with the exception of radios powered by battery.

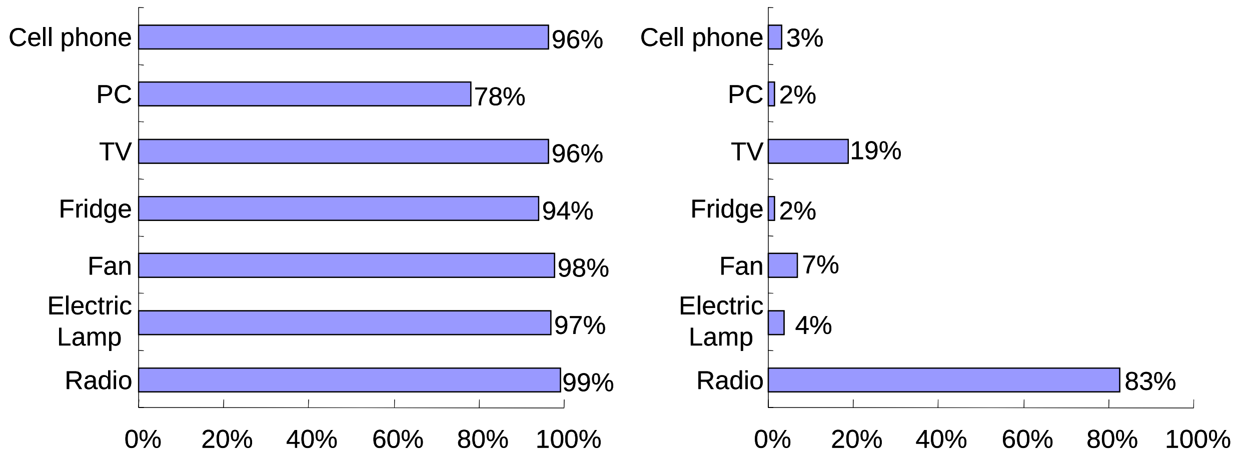

Figure 5. 1: A) Respondents' Exposure (left) and B) Experience (right) for the Appliances

As shown in Figure 5.1, more than 90 percent of the people had seen all electrical appliances except for computers. Most of the people probably had seen these appliances in Tamale. Since these appliances were displayed outside of the stores in the city, pedestrians had opportunities to see them. This result suggests that the interviewees can realize benefits from using these appliances. In contrast, only less than 20 percent of the people in Mbanayili had used the appliances other than radios. Interestingly, though several radios were found in the village, 17 percent of the residents, mainly women, had no experience using them.

Furthermore, two correlations were observed. One is a correlation between income and experience using the appliances and the other between income and the exposure to the appliances. As seen in Figures 5.2 and 5.3, average incomes of people who have seen computer or have used television are higher than those of the people who have never seen or used them. The income difference by computer exposure is statistically significant (Television experience: $p=0.287$, Computer exposure: $p=0.019$[14]). The probable reason is that the people with higher income visit Tamale more often where they can see and use a variety of electrical appliances.

[14] The means of two groups were compared by t-test.

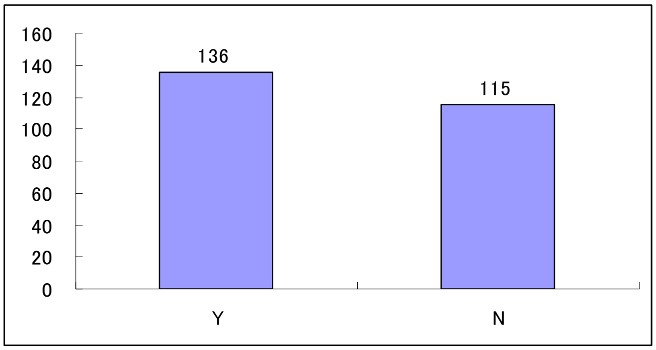

Figure 5. 2: Average Monthly Income of People with (Y) and without (N) TV Experience (unit: 1,000 cedis)

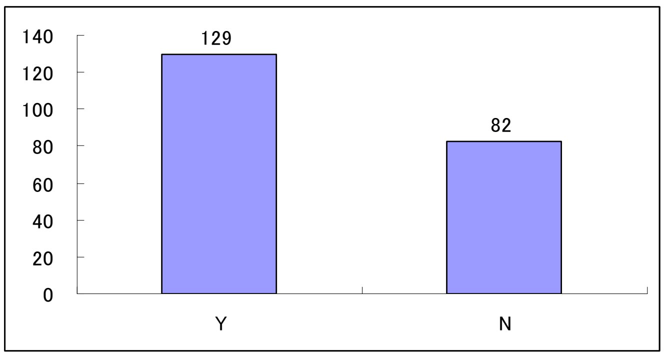

Figure 5. 3: Average Monthly Income of People with (Y) and without (N) PC Exposure (unit: 1,000 cedis)

5.3 Preference Analysis

5.3.1 Research Method

In general, government planners focus mainly on consumption behavior with electrical appliances to estimate potential electricity consumption (e.g., Al-Alawi et al., 2002). To explore potential demand more precisely, this study, however, focuses primarily on people's preference for activities that consume electricity in the community center. Since people in Mbanayili have not used many kinds of electrical appliances (Figure 5.1-B), their preferences for appliances may not well represent their potential demand for electricity. In other words, people may not be able to judge their own preferences for each appliance correctly. Surveying people's preferences for activities, however, would help them to know their potential electricity demand. For example, if people are asked how long they want to use a stereo, they may not accurately estimate their own needs for it. However, if they are asked these two questions: 1) how long would you like to have a party, 2) which electrical appliances do you want, such as refrigerator, stereo and fan for the party, they can answer their preference more precisely. This is because people already know what a party is like, thus can easily imagine how much a stereo makes the party more fun. Therefore, in this chapter, people's activity preferences are analyzed first.

Activities in the community center were listed through a discussion with a local volunteer before interviews (Table 5.1). As seen in the figure, the listed activities were categorized into six areas: entertainment, culture, education, healthcare, business and communication and others. Using this list, two types of surveys: 1) category preference survey and 2) activity preference survey, clarified people's preferences for electricity use.

Table 5. 1: Category - Activity List

Category	Entertainment	Healthcare	Culture
Activity	Watching television (TV activity)	Treatment for minor injuries	Funerals
	Parties	Vaccination	Wedding ceremonies
			Newborn celebrations
			Islamic New Year parties
Category	**Education**	**Business & Communication**	**Others**
Activity	Studying (Classes)	Markets	Cooking
	Using personal computer (PC activity)	Cellular phone charging	Free space

1) Category Preference Survey

First, preference for each category was asked. People in Mbanayili allocated ten points to preferred categories to show their category preferences. To know their priority and importance of these categories, this question was addressed in three steps. At the first step, people were asked to allocate three points to preferred categories to show their highest priority. Second, they allocated another two points to the next prioritized categories. Finally, the remaining five points could be allocated to any preferred categories. People were allowed to allocate more than one point to a category at each step. Based on this rule, for example, five people gave two points for the entertainment category at the first step. The allocated points of each respondent were scored at each step.

This category preference survey consisting of three steps could reveal the transition of people's preferences. For example, the result of the first step showed the most important categories for electricity use. In other words, these categories need to be prioritized for people's electricity use. In contrast, categories that people chose at the third step represent the preferred categories in case that they have plenty of electricity. As discussed below, people chose different categories at each step, showing the transition of the preferences.

2) Activity Preference Survey

Second, eight questions were used to understand people's preference for each activity (see Table 5.2). For example, respondents answered which activity, watching television or having a party, is preferred in the entertainment category (Question1). To accurately measure the activity preference, two pieces of information were provided: 1) pictures of activities to aid their identification and 2) the amount of time that each activity can be maintained using the same amount of electricity (See Table A.5.1 in the appendix). For example, people were asked to choose 60 minutes of attending a party or 100 minutes of using a computer (Question 7 in Table 5.2). Thus, both interests for the activities and the activities' durations influenced the people's choice.

Table 5. 2: Questions for Activity Preference Survey

	Option A		Option B	
Question 1	Watching TV	60 min	Parties	60 min
Question 2	Studying (Class)	60 min	Using PC	70 min
Question 3	Markets	60 min	Cellphone charging	Anytime
Question 4	Free space	60 min	Cooking	10 min
Question 5	Watching TV	60 min	Using PC	20 min
Question 6	Studying (Class)	60 min	Free space	60 min
Question 7	Parties	60 min	Using PC	100 min
Question 8	Markets	60 min	Free space	40 min

5.3.2 Research Results

5.3.2.1 Category Preference Survey – Overview of the Results

Through the three steps of the category preference survey, 126 allocation patterns were found from 133 respondents. In other words, only seven persons' allocation patterns were the same as others (five villagers' allocation patterns were exactly same). Table 5.3 shows the allocation pattern of the five respondents. At the first step, they allocated points to healthcare, culture and education categories. Then, another two points were allocated to business & communication and others categories at the second step. Finally, all categories except entertainment category received one point each at the third step.

Table 5. 3: Allocation Pattern – Sample

Step	Entertainment	Healthcare	Culture	Education	Business & Communication	Others
First	0	1	1	1	0	0
First + Second	0	1	1	1	1	1
First + Second + Third	0	2	2	2	2	2

The fact that many allocation patterns were found represents a variety of people's category preferences. Category preference analysis, however, could find people's tendencies among the diversified preferences. In this part, after interpreting these results, category preference was analyzed by attributes, such as gender and age.

5.3.2.2 Category Preference Survey – First Step

Figure 5.4 shows the results of the first step's point allocation. As seen in the figure, healthcare and education categories were the highest prioritized categories. 42% of the interviewees chose both categories at this step. According to a local volunteer, local radio programs might be influencing people's preference for these categories, because the radio programs had often emphasized the importance of improving healthcare and education (Alhassan, Pers. Comm., 2006).

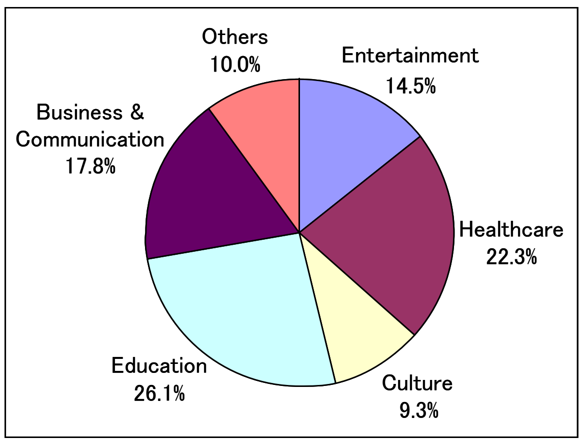

Figure 5. 4: First Step: Three-Point Allocation – the Share of the Allocated Points (%)

5.3.2.3 Category Preference Survey – Second Step

As seen in Figure 5.5, culture and others categories received more than 20% of the points as second priorities. Interestingly, 80% of the people selected at least one category from these three, namely, culture, business and others. In addition, 32% of them chose two from those categories. This finding suggests that the people's second priorities were different from the first ones. In other words, they prefer to use electricity for more variety of activities, if more electricity is provided.

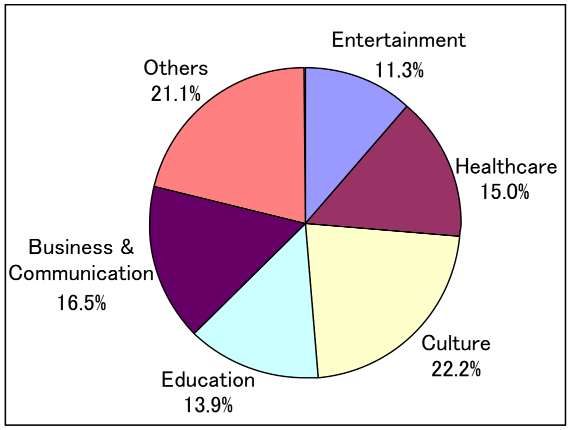

Figure 5. 5: Second Step: Two-Point Allocation – the Share of the Allocated Points (%)

5.3.2.4 Category Preference Survey – Third Step

The third step's result revealed the category preferences given the least constraint in electricity availability. As observed in Figure 5.6, people allocated the points more equally to each category than the first and second steps. This result suggests that people's preferences are more diversified as more points are given to the interviewees.

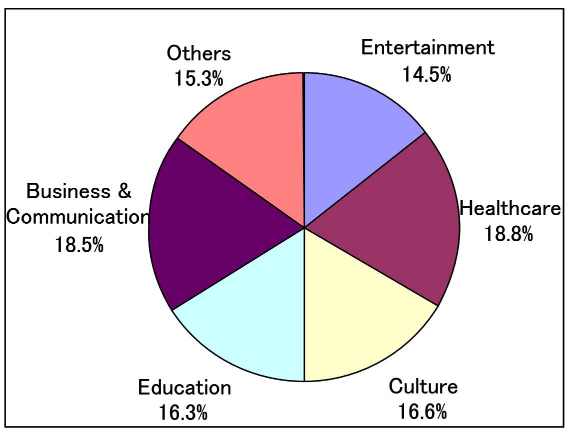

Figure 5. 6: Third Step: Five-Point Allocation – the Share of the Allocated Points (%)

Figure 5.7 shows the allocation of accumulated points across three steps. The tendency between three steps and diversity of people's preference is clearly observed in this figure. For example, points were disproportionately allocated to each category at the first step. Education, the most popular category, received approximately three times more points than culture, the least preferred category (Education: 26%, Culture: 9.3%). This difference between the most and the least popular categories becomes smaller at the second step (Education: 21.2%, Entertainment: 13.3%) and more at the third step (Healthcare: 19.1%, Entertainment: 13.9%).

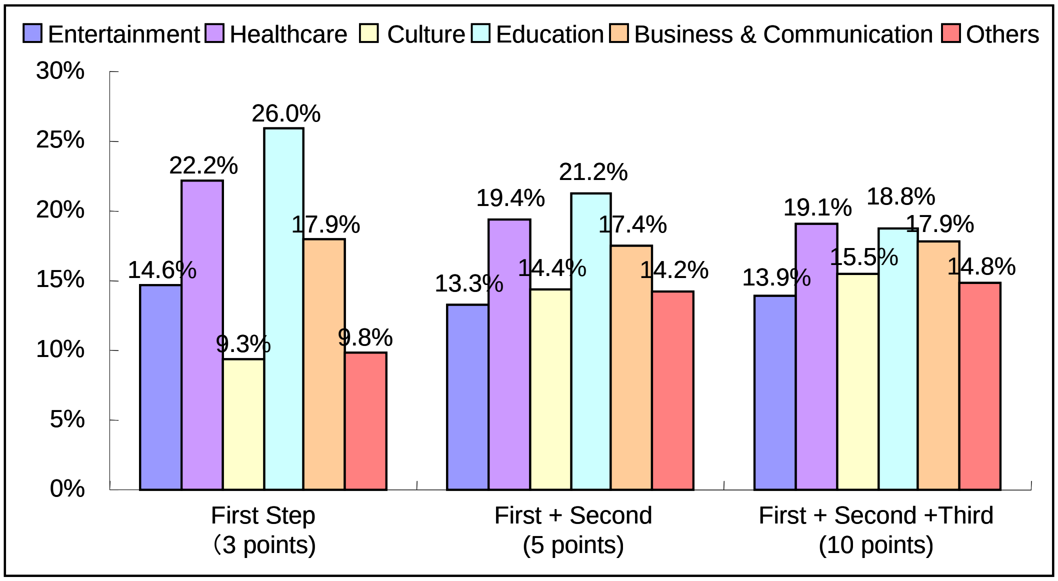

Figure 5. 7: Category Preference Across Three Steps

In addition, Figure 5.7 revealed other two interesting results. First, across the three steps, the health and education categories were always either the first or the second important categories. Second, business was the third most popular category at every step. Two comments from the volunteer help to understand the finding: "*People expect electrification not only to improve people's standard of living but also to create new jobs*". "*Currently, Mbanayili has only one small shop with limited variety of products. Thus, people's needs are not well satisfied in the village.*" From these comments, the people might expect that the economic development by electrification will provide a larger store for the people to meet their needs.

5.3.3 Category Preference – by Attributes

To better understand the category preference for electricity, the preference data were analyzed according to four attributes: 1) gender, 2) age, 3) income, and 4) distance. Tendencies of the people's preferences were found from this analysis. Category preference data from the first step was used for this analysis as clearly representing people's preferences. The results from this analysis are inputs for the financial sustainable system modeling (Chapter 8). This section discusses the tendencies of the people's preferences by attributes.

1) Gender

As seen in Figure 5.8, women have relatively stronger preferences for the education category than men do, though it was not the significant difference (p=0.789[15]). Given their role in taking care of children, women might perceive the importance of education for their children's future. In contrast, men were more likely to allocate their points to healthcare category than women (p=0.197[16]). As a possible reason, farmers -88% of men's occupation- often require treatment for injuries resulting from their work.

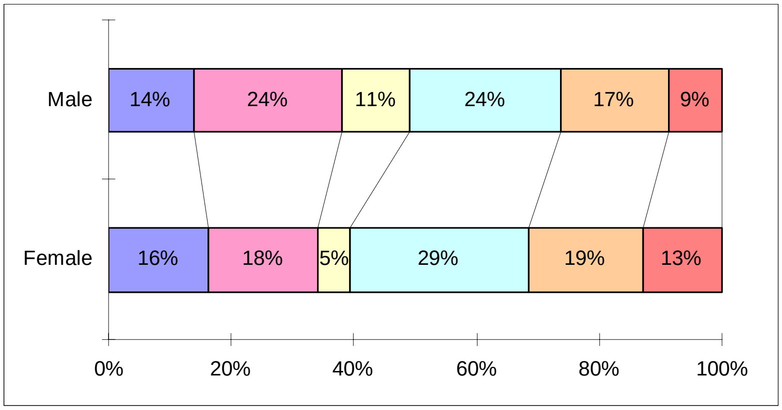

Figure 5. 8: Category Preference by Gender

2) Age

Four correlations between age and category preferences were found (Figure 5.9). First, younger people were more interested in the education category than older people (p=0.234[17]). The percentage of the points allocated to the education category increases from 19% to 33% as people's age decreases. Second, younger people are more likely to choose the business category (p=0.196[18]); they appear more interested in economic activities.

[15] The means of two groups ("male" and "female") were compared by t-test.
[16] The means of two groups ("male" and "female") were compared by t-test.
[17] The means of four groups by age were compared by one-way ANOVA.
[18] The means of four groups by age were compared by one-way ANOVA.

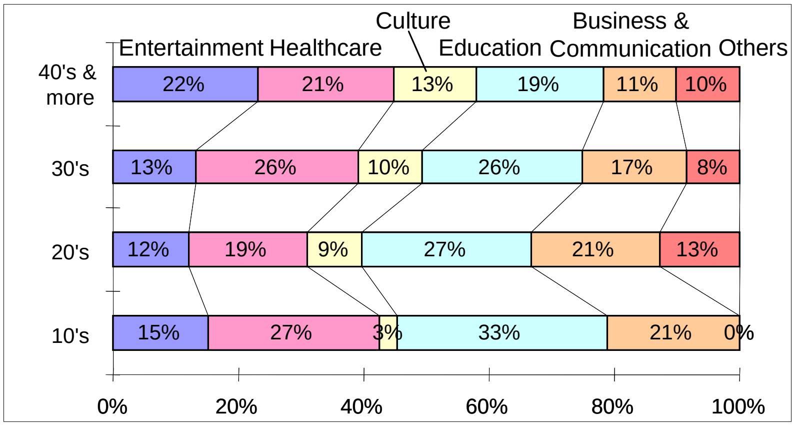

Figure 5. 9: Category Preference by Age

Third, older people were more attracted by the culture category (p=0.317[19]). It is probable that they thought cultural ceremonies are important for their society. Lastly, though the entertainment category was not popular for the people of three generations, only the people who were forty years old or above were interested in using electricity for entertainment activities (p=0.022[20]).

These analyses of the category preference by age showed contrasting results. Older people placed the importance on entertaining and their current life, while younger people focused on improving future life. As seen in Figure 5.9, the entertainment category was the most popular for the generation of 40's and more (22%), while the education category was the most popular for teenagers (33%). These results reflect the people's life expectancy. In other words, older people are likely to demand short-term benefits, while the younger have long-term point of view.

3) Income

Figure 5.10 reveals three tendencies. First, lower-income people were more likely to focus on the education category. People with an annual income of 50,000 cedis or less allocated 30% of their points to this category, while people with the income of more than 150,000 cedis allocated only 22% of their points. In contrast, higher-income people were more likely to prefer the culture and entertainment categories. The results suggest that the people realized the importance of education for the improvement of their economic status and incomes. Thus, people with lower income preferred this category to want to improve their living standards. In contrast,

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[19] The means of four groups by age were compared by one-way ANOVA.
[20] The means of two groups ("10's – 30's" and "40's and more") were compared by t-test.

high-income people preferred using electricity for entertaining. Therefore, the entertainment and culture categories were more important for people with higher income. In addition, people's knowledge of electrical appliances might influence their preferences. In other words, high-income people could more perceive the benefit provided by entertaining activities. As seen in Figure 5.11, since higher-income people have more experience of using television, they could realize the benefit from the entertainment activity.

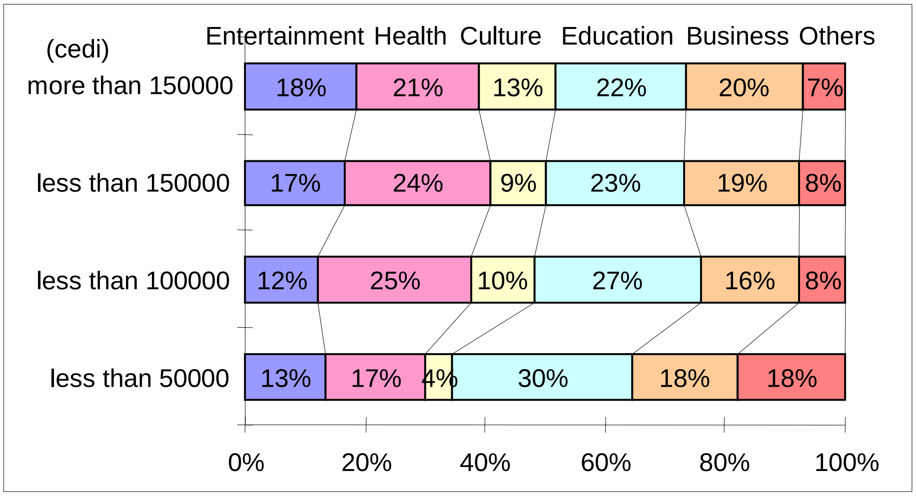

Figure 5. 10: Category Preference by Monthly Income

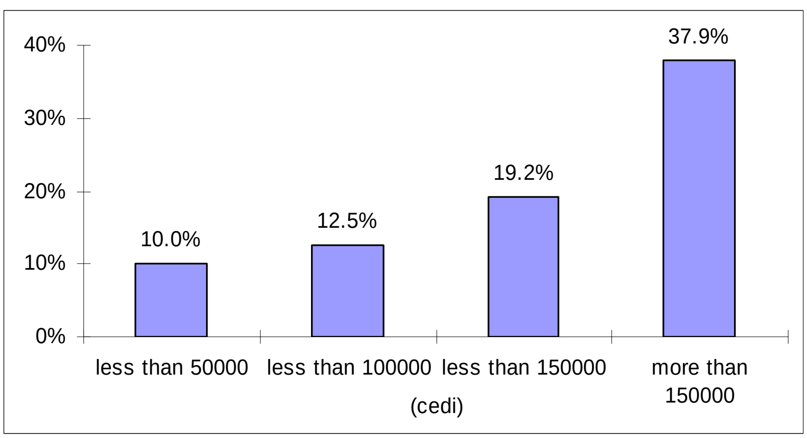

Figure 5. 11: Experience of Watching TV by Monthly Income

4) Distance from the Community Center

Distance between people's houses and the community center influenced their preferences. For example, as shown in Figure 5.12, people who live far from the community center preferred the education category (p=0.201[21]). Since their houses were also far from the

21 The means of four groups by distance were compared by one-way ANOVA.

school of Mbanayili, they expected electricity to improve the current educational environment. On the other hand, people living close to the center preferred using electricity for entertainment (p=0.110[22]). They have more opportunities to get information regarding electrical appliances such as television and TV programs through only one main road connecting Mbanayili to Tamale and other villages. Such information, brought to the center of the village, could potentially generate the interest for television in people living near the center. As illustrated in Figure 5.13, people who live near the community center have more knowledge about computer than those who live far from the center (p=0.088[23]).

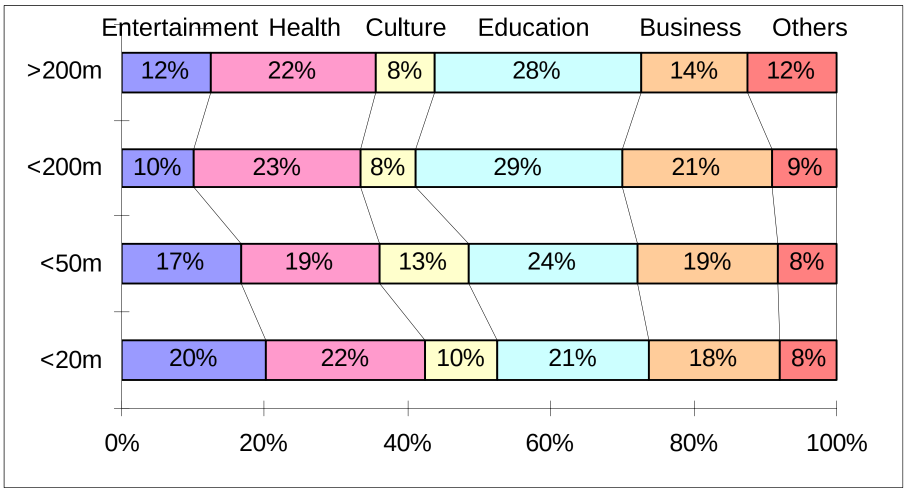

Figure 5. 12: Category Preference by Distance to the Community Center

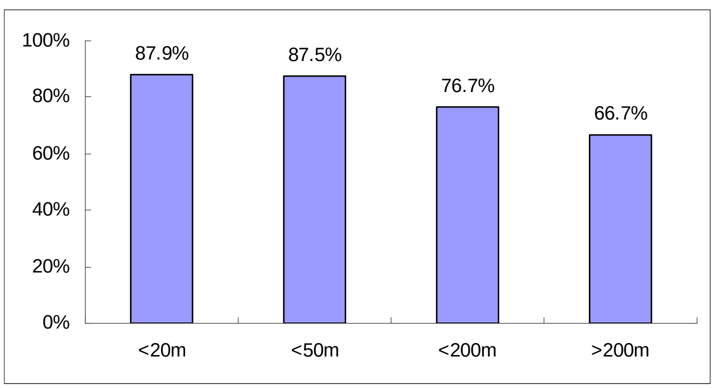

Figure 5. 13: Knowledge about PC by Distance to the Community Center

5.3.4 Activity Preference Survey – Overview of the Results

To measure people's activity preference, respondents were asked to choose one preferred activity from each pair of activities (Table 5.2). First, as Figure 5.14 shows, in five questions,

[22] The means of four groups by distance were compared by one-way ANOVA.
[23] The means of four groups by distance were compared by one-way ANOVA.

more than 80% of the people chose one activity. These preferred activities, namely cooking, markets and studying (class) activities are related to people's fundamental needs such as eating, buying/selling (economic activity) and studying, while less popular activities are related to entertaining or making their lives more comfortable. The results indicate that people preferred using electricity primarily for the fundamental needs. This finding is consistent with the result of the first step's point allocation in the category preference survey. Specifically, people primarily chose the categories of healthcare, education and business as satisfying their fundamental needs.

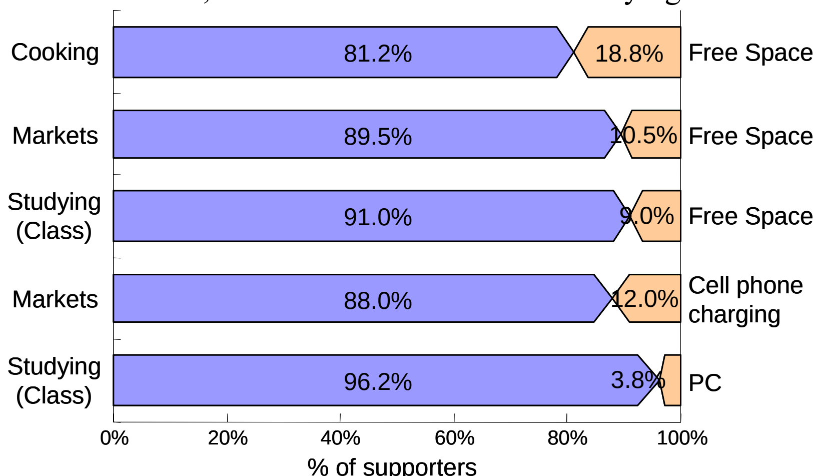

Figure 5. 14: Activity Preference between Pairs of Activities (1/2)

On the other hand, when comparing two activities for entertaining people's life, the study indicated the divergence of people's opinion. For example, as shown in Figure 5.15, about 40% of people preferred using personal computer, while 60% chose the party activity. This result suggests that people do not always have same preferences in the village, when activities with similar characteristics are compared.

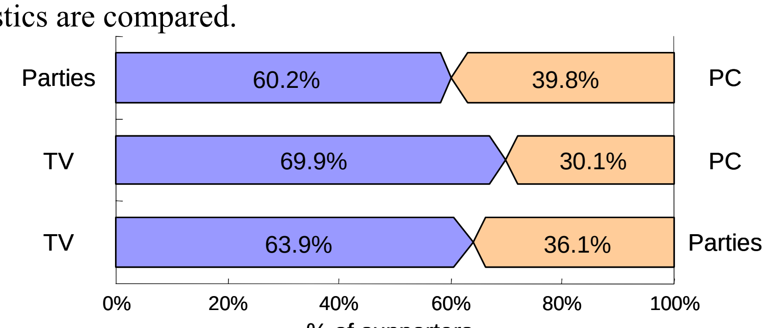

Figure 5. 15: Activity Preference between Pairs of Activities (2/2)

In the following section, the study further explores these divergences to better understand people's preferences.

(a) Party (60.2%) vs. Personal Computer (39.8%)

The preferences by age show an interesting finding. As seen in Figure 5.16, only teenagers strongly preferred using a computer to having a party (though it was not proved statistically because of the sample number of teenagers is very small (p=0.561[24])), since they were probably more interested in new technology and up-to-date electrical appliances. Figure 5.17 explains teenagers' strong interest about using computer. More than 90% of the teenagers, which is the highest among all generations, already have seen computer.

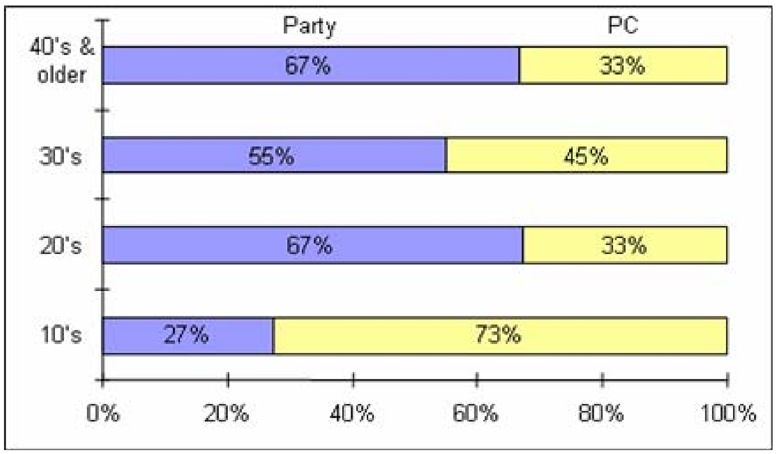

Figure 5. 16: Comparison between Party and Personal Computer by Age

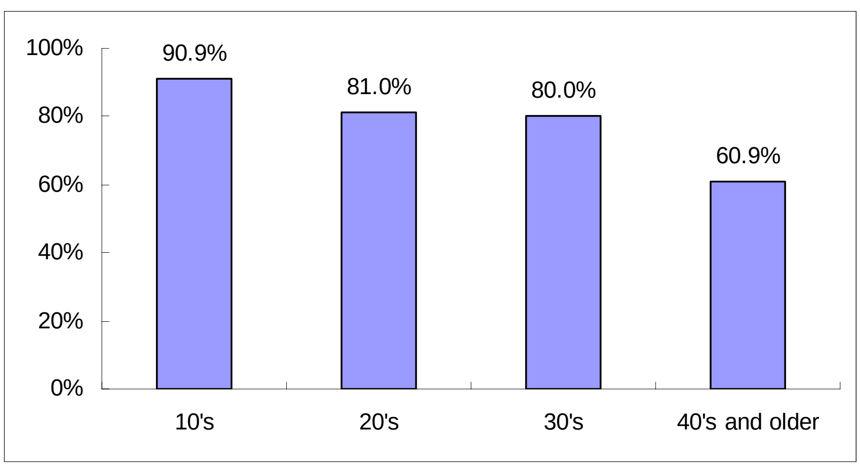

Figure 5. 17: Exposure of Personal Computer by Age

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[24] The means of two groups ("10's" and "30's-40's and more") were compared by t-test.

In addition, income is another factor that influences people's choice. The higher-income people were more likely to choose the computer activity (Figure 5.18, $p=0.064$[25]), since they could somewhat afford to use computer or internet service. (For example, the internet services in internet cafés of Tamale cost between 6,000 cedis (0.66 USD) and 8,000 cedis (0.89 USD) per hour.)

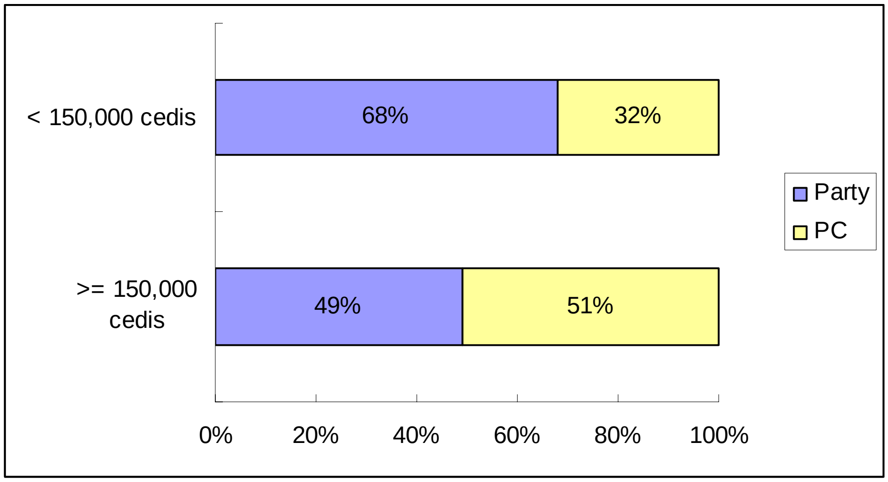

Figure 5. 18: Comparison between Party and Personal Computer by Monthly Income

These results suggest that only teenagers or high-income people were attracted by the computer activity.

(b) Television (69.9%) vs. Personal Computer (30.1%)

The comparison between the television and computer activities provides the same tendency as the comparison between having a party and using a computer (a). Teenagers and high-income people more preferred using a computer to watching television (Figure 5.19: $p=0.142$[26], Figure 5.20: $p<0.001$[27]). In addition to them, Figure 5.21 revealed that women did not choose using personal computer like men ($p<0.001$[28]). This result was different from the comparison between the party and computer activities (a). In this comparison (a), women's

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25 The means of two groups ("income < 150,000 cedis/month" and "income >= 150,000 cedis/month") were compared by t-test.
26 The means of two groups ("10's" and "30's-40's and more") were compared by t-test.
27 The means of two groups ("income < 150,000 cedis/month" and "income >= 150,000 cedis/month") were compared by t-test.
28 The means of two groups ("male" and "female") were compared by t-test.

preferences for a computer use were the same as men's preferences (women: 38%, men: 40%). Thus, this result suggests that the television activity influenced women's choice.

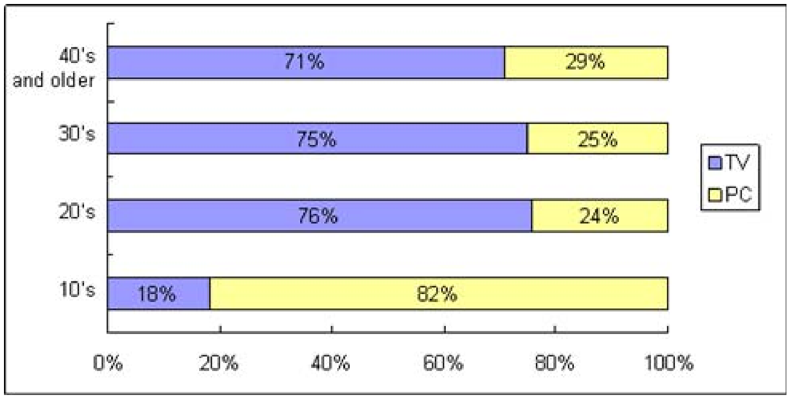

Figure 5. 19: Comparison between Party and Personal Computer by Age

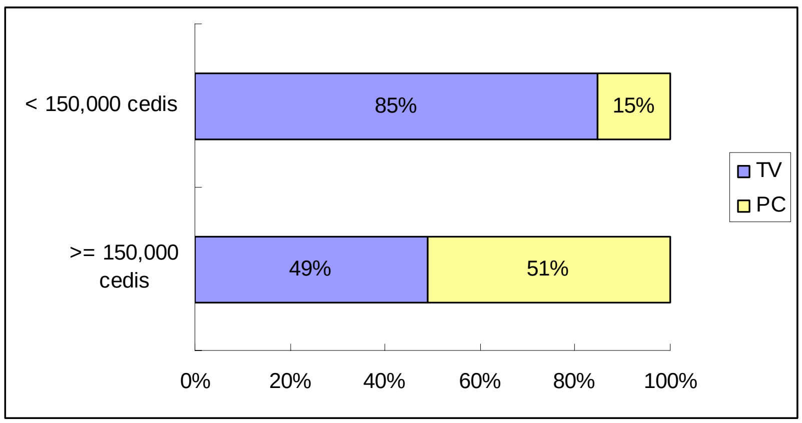

Figure 5. 20: Comparison between Television and Personal Computer by Monthly Income

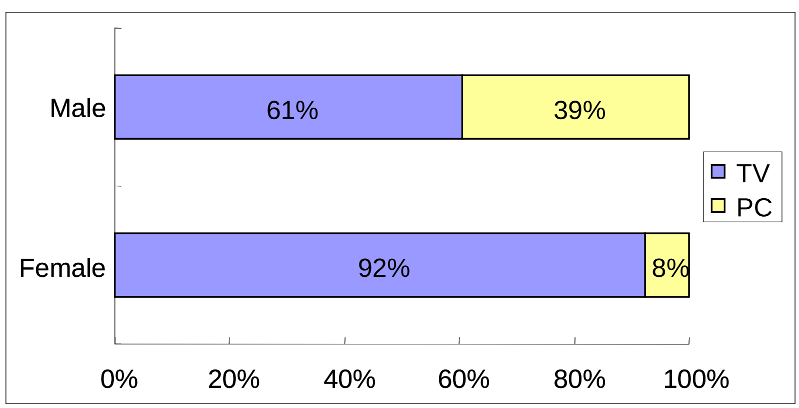

Figure 5. 21: Comparison between Television and Personal Computer by Gender

(c) Television (63.9%) vs. Party (36.1%)

As seen in Figure 5.22, women strongly preferred watching television to having a party, while men had no preference between the two ($p<0.001$[29]). This result is consistent with those in the previous two comparisons: (a) party vs. computer, and (b) television vs. computer. That is, while men had no preference among three activities (television, party and computer), women showed strong preference for the television activity. In this regard, people's knowledge for computer and television had not influenced their preferences (the exposure to computer: Male: 78.5%, Female: 76.9%, exposure to television: Male: 96.8%, Female 94.9%). Therefore, it can be concluded that this gender's difference of the preferences resulted from women's strong interest for watching television.

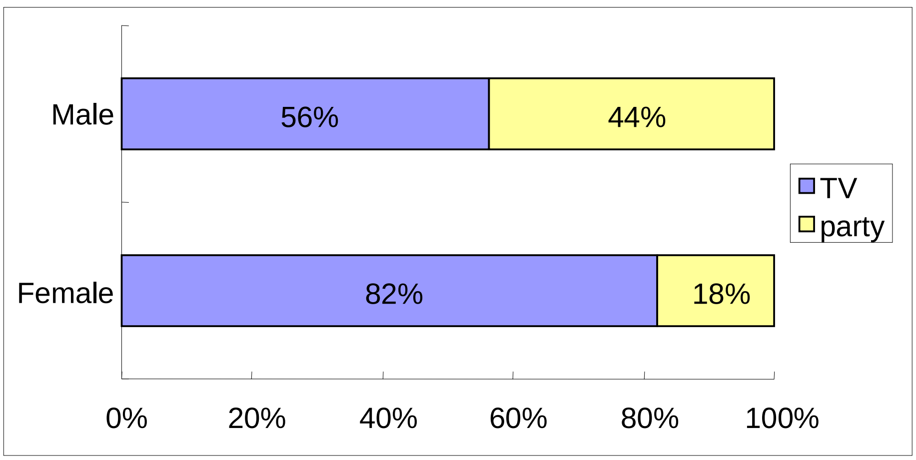

Figure 5. 22: Comparison between Television and Party by Gender

Based on the category preference survey and activity preference survey, people's potential electricity demand is estimated in the next section.

5.4 Load Curve Generation

5.4.1 Overview of producing the Load Curve from the Field Research Data

An electricity load curve for the community center has been generated based on the villagers' preference for activities. The steps can be described as 1) an activity schedule for the center was created; 2) electrical appliances were selected for each activity and electricity consumption for each activity was calculated; 3) the activity schedule and the corresponding

[29] The means of two groups ("male" and "female") were compared by t-test.

electricity consumption of each appliance were combined to produce the load curve. The procedure for generating load curve is described below in Figure 5.23.

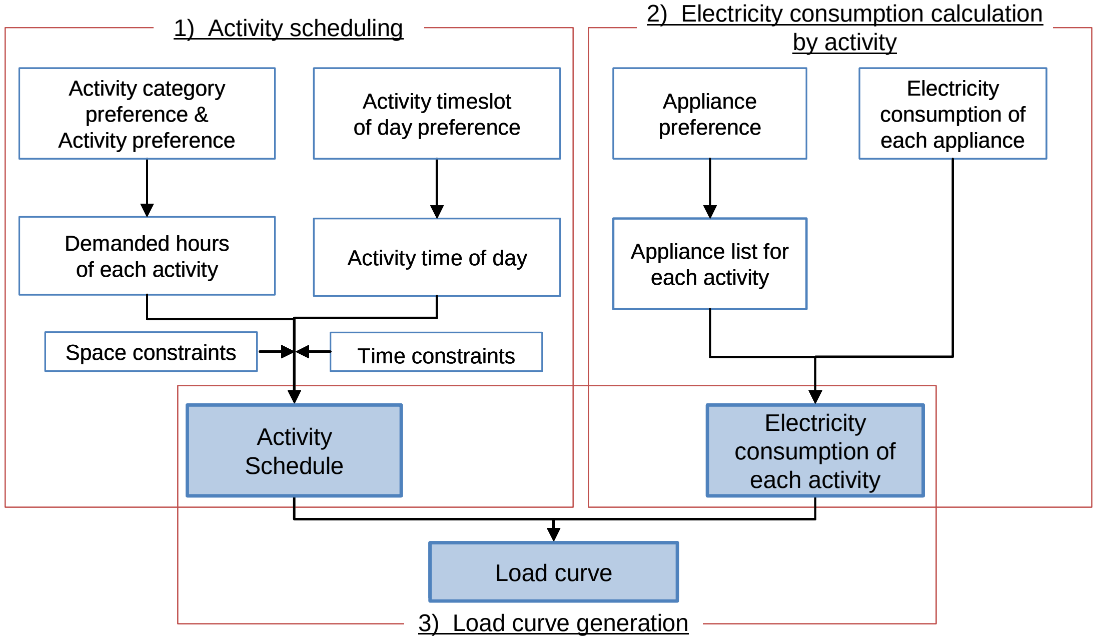

Figure 5. 23: Process for Generating Potential Load Curve

5.4.2 Activity Scheduling

To aid the calculation, activity scheduling was conducted on a monthly basis. Prior to scheduling activities, the length of time demanded for each activity was to be determined based on people's preference. The time was allocated across activity categories using category preference data first and then distributed to activities within the same category using activity preference data. Additionally, timeslots of day – before breakfast, after breakfast, after lunch, after dinner, and bedtime - for each activity were also selected using time preference data. After that, activities were arranged into a monthly schedule subject to time constraints and space limitations of the community center.

5.4.2.1 Time Allocation

a) Time Allocation among Activity Categories

First, the study decided how long people can enjoy each activity category a month based on the preference data. To accommodate the majority of villagers' electricity needs, interviewees were given 10 points in total, which represents having adequate electricity for all activities. Here we assumed that points given to each category represented the relative length of time the interviewees would expect for the activity.[30] Using this assumption, we proportionately allocated time to each activity category based on the points the category received.[31]

The allocation result across categories is shown in Table 5.4.

Table 5. 4: Time Allocation across Activity Categories

Activity categories	Hours/month		
	30 days/month	31 days/month	28 days/month
Entertainment	95	98	89
Healthcare	106	109	99
Culture	107	110	99
Education	129	133	121
Business & Communitation	123	126	115
Others	102	105	95

b) Time Allocation for Activities within the Same Category

Time allocation for activities within a category was based on the results from the activity preference survey, where the interviewees were given two activities within the same category, and asked to select the preferred one. Within an activity pair, the time in hours was allocated in proportion with the activity preference data. However, for activities in the culture category, the lengths of time were distributed according to the village's population data.

The number of newborn celebrations is determined from the number of births. Forecasted from the village's birth records in 2000 to May 2006, births in 2007 will be 54. However, there are no such records for marriage and funerals. Therefore, the number of marriages and funerals are estimated using Ghana's past population data.

Data from the International Database of US Census Bureau (2006) for the year 2005 were used for estimating the number of weddings. Ghanaians usually get married around 20 years old (Alhassan, Pers. Comm., 2006). The corresponding age range to this information is 15 – 19 and

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[30] Time available for each month was calculated from multiplying number of days in a month by daily available time. Hours typically spent sleeping, which are approximately 5.5 hours per day, from 11pm to 4.30am (Alhassan, Pers. Comm., 2006), were excluded from daily available time. Therefore, the time that the community center will have activities per day is 24 hours deducted by 5.5 hours, which is 18.5 hours. As a result, available time for each month is 18.5 hrs*(days per month).

[31] As health activities occur in a separated space from other activities, these activities can occur simultaneously with others; points given to health category were omitted from calculating the time available for other activities. Nonetheless, to compute hours demanded for health activities, the points given to this activity were included when allocating time to the health category.

20 - 24 years old. According to the data, 10.6% of males[32] and 10.4% of females[33] are between 15 and 24 years old. Using this national population distribution and the fact that the population in Mbayanili at the time of field research was 4,050, there are an estimate 429 men and 421 women between 15-24 years old in the village. In Ghanaian society, individuals with no children are strongly disliked and disrespected (Ampofo, 2001). Therefore, this study assumes that all villagers get married. This study also assumed equal frequency of weddings over time as the villagers do not have seasonal preference for this ceremony. Therefore, there are an estimate 43 men and 42 women get married each year.[34] According to the local volunteer (Alhassan, Pers. Comm., 2007), rural Ghanaian women are responsible for getting water for their villages. If the water supplies are far away from the villages, they have to travel far from their villages, and thus might meet men outside and eventually get married with them. However, Mbanayili has pipe born water. Therefore, Mbanayili women usually do not go outside the village. So it is unlikely for them to get married with men from other villages. In addition, a study on marriages in northern Ghana shows that approximately 30% of the villagers get married with people from other villages (Goody, 1966). Therefore, this study assumes 70% - 100% of them get married with people in the village. Using 70%, in each year, there will be 30 marriages among Mbanayili's villagers,[35] 13 men marrying to outside women,[36] and 12 women marrying outside men[37]. Among these 12 + 13 = 25 marriages with outside people, as Mbanayili is Muslim community, where men are dominant, the weddings might usually be held in husbands' villages. Consequently, 13 out of 25 weddings are expected to be held in Mbanayili. As a result, possible weddings held in Mbanayili are 30 + 13 = 43 weddings per year. And if 100% internal marriage is assumed, there are still 43 possible weddings per year. Therefore, the possible number of weddings per year is 43.

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[32] Percentage of men between 15 and 24 = (1,274 + 1,057) thousand/22,026 thousand = 10.6%.
[33] Percentage of women between 15 and 24 = (1,255 + 1,033) thousand/22,026 thousand = 10.4%
[34] As the age range is 10 years, one tenth of the 429 men and 421 women will get married each year.
[35] To simplify the calculation for weddings between people in the village, the number of such weddings was based on number of men. That is, 70% of the 429 men, which are 300 men, get married to 300 women out of the 421 women. Therefore, the number of such marriages is 300 within 10 years, thus 300/10 = 30 marriages per year.
[36] The number of Mbanayili men marrying women from other villages per year = (429 men * 30%)/10 years = 13 marriages/year.
[37] The number of Mbanayili women marrying men from other villages per year = (421 women – 300 women)/10years = 12 marriages/year.

To estimate the number of funerals in 2007, 2006 Ghana's mortality rate[38] was used. Assuming equal mortality rates in 2006 and 2007, estimated deaths in the village are 40 per year.

However, if all of these cultural events were held in the community center, assuming equal frequency across the year, 13 hours[39] x 54 = 702 hours would be newborn celebrations, 24 hours[40] x 43 = 1,032 hours would be weddings, and 24 hours[41] x 40 = 960 hours would be funerals. That is 2,694 hours per year or 224.5 hours per month would have to be allocated for cultural activities in each month, which is greater than the results of time allocation for culture category. Therefore, the available time that the category received was allocated to each category based on each activity's demand (newborn celebrations: 26%, weddings: 38%, funerals: 36%). The result of hours distributed to each of the activities is as shown in Table 5.5.

[38] Data from http://www.theodora.com/wfbcurrent/ghana/ghana_people.html
[39] Duration of a newborn celebration is 13 hours. This will be discussed in 5.4.2.2 Time of Day Selection, section b-2.
[40] Duration of a wedding is 24 hours. See 5.4.2.2 section b-2.
[41] Duration of a funeral is 24 hours. See 5.4.2.2 section b-2.

Table 5. 5: Available Time by Each Activity in the Community Center

Activity category	Activities	Hours/month		
		30 days/month	31 days/month	28 days/month
Entertainment	Watching television	61	63	57
	Parties	34	35	32
Health		106	109	99
Culture	Wedding ceremonies	41	42	38
	Funerals	38	39	35
	Newborn celebrations & Islamic New Year parties (only in January and March)	28	29	26
Education	Classes	124	128	116
	Using personal computer	5	5	5
Business	Markets	108	111	101
	Cellular phone charging	15	15	14
Others	Free space	19	20	18
	Cooking	83	85	77

5.4.2.2 Time of Day Selection

Timeslots for each activity were assigned based on the interviewees' time preference data and local practices. Since the lifestyle of the villagers does not require strict punctuality, they typically identify time of day by their daily routines – getting up, having breakfast, having lunch, having dinner, and going to bed. Normal daily schedule of a villager is as follows (Alhassan, Pers. Comm., 2006)

4.30 am	get up
7.00 am	have breakfast
1.00 pm	have lunch
8.00 pm	have dinner
11.00 pm	go to bed

Using these routine events and standard times, timeslots of day, which this study identifies, were created. Time periods listed above represent time intervals as shown in Table 5.6.

Table 5. 6: Time Periods and Corresponding Time Intervals

Time Periods	To	From	Duration
Before Breakfast	4.30 am	7.00 am	2 hours 30 mins
After Breakfast	7.00 am	1.00 pm	6 hours
After Lunch	1.00 pm	8.00 pm	7 hours
After Dinner	8.00 pm	11.00 pm	3 hours
Bedtime	11.00 pm	4.30 am	5 hours 30 mins

The questionnaire asked the interviewees to select the time periods in accordance with this routine.[42]

a) Time Preference Analysis

Interviewees were asked in which time slots they would like to have each activity.[43] Among nine activities included in the survey, three patterns of time preference were identified.

a-1) Type 1: Whole day activities

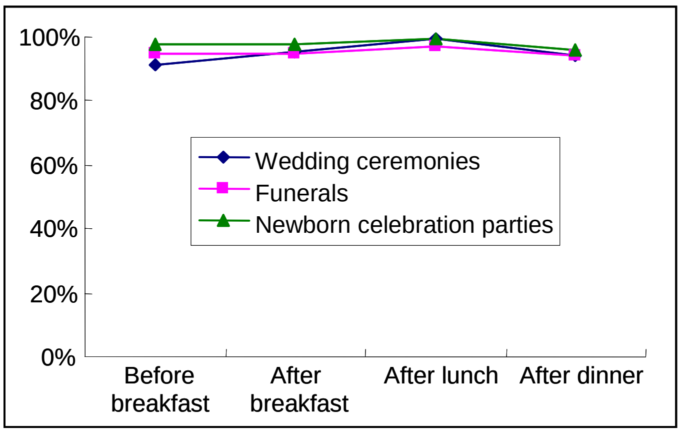

Figure 5. 24: Activity Time Preference Type 1: Whole Day Activities

As can be seen from Figure 5.24, all activities in this type are cultural activities. The villagers' desire to use electricity is always significantly high from before breakfast to after dinner. This is because, according to their culture, the villagers would like the cultural activities to last at least an entire day.

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[42] Bedtime was not included in the questionnaire as the villagers are sleeping thus not having any activities at the community center. However, there is an exception for having cultural activities during bedtime, which is described in the time selection assumptions.
[43] They could select more than one timeslot.

a-2) Type 2: Daytime Activity

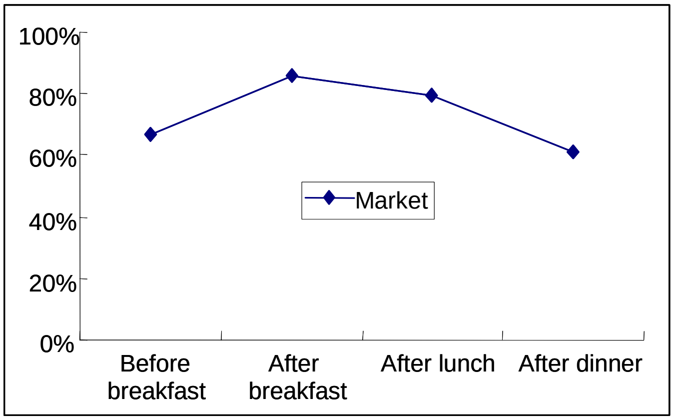

Figure 5. 25: Activity Time Preference Type 2: Daytime Activity

Figure 5.25 shows that the villagers would like to have markets during daytime – after breakfast and after lunch, which are the periods they normally work. As shown in the graph, all time slots are preferred by more than 50% of the villagers, but they particularly prefer the after breakfast period.

The time preference between men and women are very different.

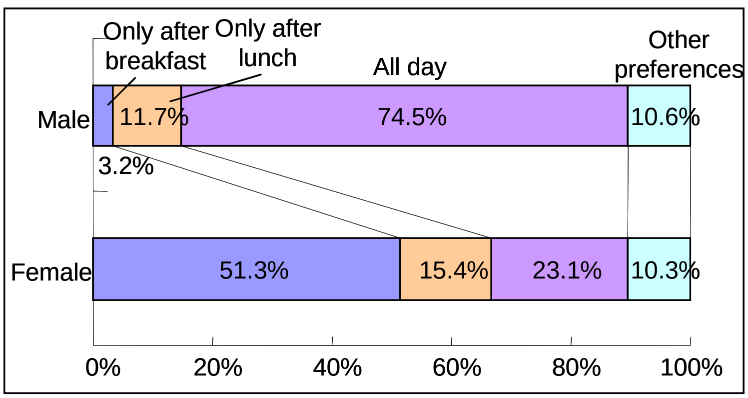

Figure 5. 26: Time Preference for Markets by Gender

Figure 5.26 shows the villagers' preference toward markets. As seen in the graph, men want to have this activity all day long while women only would like this activity to happen mainly after breakfast. The reason might be that women see markets as a place to buy foods so they want to go to market in the morning before starting their work. On the other hand, men may think of markets as a place for selling products. That is men consider the markets as a workplace. Therefore, men want to have markets open for an entire day.

a-3) Type 3: Night Time Activities

Entertainment, education, and other activities, which include watching television, parties, classes, using personal computer, cellular phone charging, and free space, are preferred during the after dinner period (Figure 5.27). It shows that the villagers would like to use electricity after dinner mainly for education and entertainment.

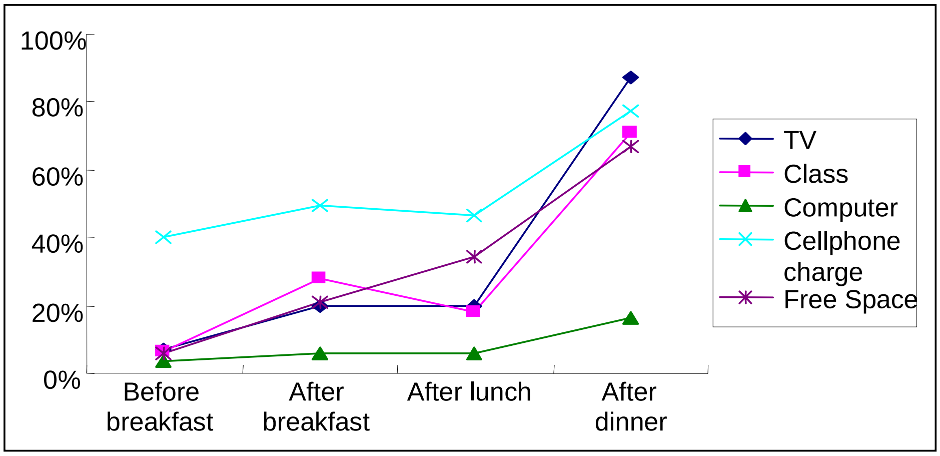

Figure 5. 27: Activity Time Preference Type 3: Night Time Activities

b) Time Selection Assumptions and Rules

b-1) Time Selection Rules

For each of the activities, time periods are classified into two groups based on the time preference data from the survey. Therefore, rules are set accordingly as follows.

1) If 80 or higher percent of the respondents wish to have the activity at a specific time period, the activity must be at that period.
2) If less than 80% of the respondents prefer to have the activity at a time period, the activity can either occur or not occur at the time slot.

b-2) Time Selection Assumptions

- All activities except cultural activities can be completed within one time slot. For example, a class starting after lunchtime can finish before dinner time, which is when the next time slot starts.
- Assumptions for cultural activities

Time periods of the cultural activities were arranged in accordance with local practices. Cultural activities in the village include wedding ceremonies, funerals, newborn celebrations and Islamic New Year parties. As stated by a local volunteer (Alhassan, Pers. Comm., 2006), a wedding and a funeral begin after breakfast and last for 24 hours. A newborn celebration starts after breakfast and ends before dinner time of the same day. That is, a newborn celebration lasts for 13 hours.

In addition to those ceremonies, the village has two Islamic New Year parties each year. The first one is on the day of the Islamic New Year, which changes every year according to tradition; and the second is two months later. This study assumes Islamic New Year parties are between breakfast and dinner of the same day. This data is arranged into time periods and illustrated in Table 5.7.

Table 5. 7: Time Periods of Cultural Activities

Day 1					Day 2
Before Breakfast	After Breakfast	After Lunch	After Dinner	Bedtime	Before Breakfast
	Wedding ceremony				
	Funeral				
	Newborn celebration				
	Islamic New Year party				

- Assumption for health activities

Time period selection for health activities was based on the regular hours that the nurse from another town visits the village, which is in the after lunch time slot.

From the rule and assumptions described above, the result of the time preference data is shown in Figure 5.28.

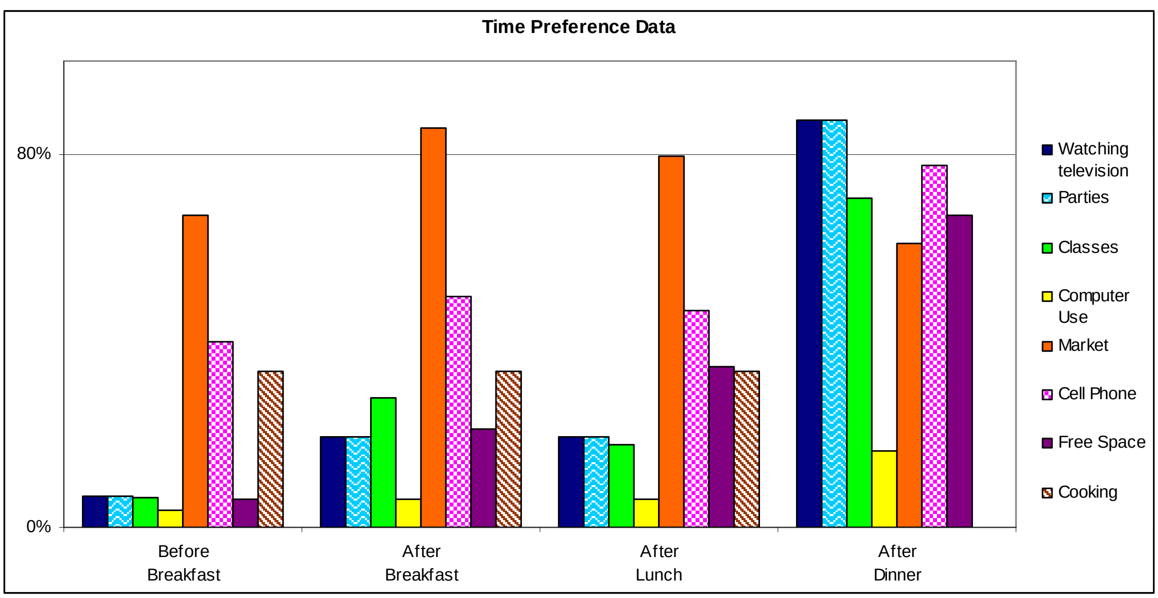

Figure 5. 28: Time Preference Data

Table 5.8 shows the result of time period classification using the criteria described.

Table 5. 8: Activity Time Selection Result

Activities	Before Breakfast	After Breakfast	After Lunch	After Dinner	Bedtime
Watching Television	2	2	2	1	3
Parties	2	2	2	1	3
Vaccination	3	3	1	3	3
Treatment for Minor Injuries	3	3	1	3	3
Wedding Ceremonies	1	1	1	1	1
Funerals	1	1	1	1	1
Newborn Celebrations	3	1	1	3	3
Islamic New Year Parties	3	1	1	3	3
Studying (Classes)	2	2	2	2	3
Using personal computer	2	2	2	2	3
Markets	2	1	2	2	3
Cell Phone Charging	2	2	2	2	3
Free Space	2	2	2	2	3
Cooking	2	2	2	2	3

1	The timeslots are primarily assinged to the activities
2	The timeslots can be assinged to the activities
3	The timeslots are not assigned to the acitivites

c) Space Requirement Assumptions

- The community center has two separate areas, the health clinic and the open space. Therefore, activities in each of these areas can happen concurrently.
- Space requirements of activities in the open space are specified as follows
  1. Activities that occupy the entire open space: parties, wedding ceremonies, funerals, newborn celebrations, Islamic New Year parties, and markets.
  2. Activities that use more than half of the entire open space: watching television, classes, using personal computer, free space, and cooking.
  3. Activity that requires minimal space: cellular phone charging. This activity uses the open space but is not influenced by any other activities.

Consequently, due to space constraints, when one of the activities in the first category is occurring, no other activities can happen at that time. Also, activities in the second group cannot occur concurrently. Moreover, the activities in the second and third categories can happen concurrently because these activities only occupy a fraction of the available space. For example, watching television and cellular phone charging can happen concurrently.

5.4.2.3 Activity Scheduling

After the activities' hours per month and preferred time of day are identified, all activities can be arranged into a monthly schedule. Limiting factors are time availability for each timeslot of day, and space restrictions. Therefore, when arranging activities into the schedule, we had to ensure that not only hours demanded are fulfilled but also the community center's space are utilized such that the space requirements described above is satisfied.

We have set two assumptions.

a) The villagers have no preference on which day they wish to have the activities.
b) They want each of the activities to occur equally frequent throughout a given month.

To begin with, for each month, the activity with the highest time period preference was scheduled with uniform frequency across the month regardless of the date. Then activities with lesser preferences were scheduled. When hours per month required by the villagers for an activity could not be fulfilled by its most preferred time period due to either time conflicts or insufficient space availability, the activity was arranged into the next preferred period(s). These processes were continued until hours required by all activities were fulfilled.

However, there is a specific requirement for Islamic New Year parties. The Islamic New Year has to be on a specific date according to the Islamic Calendar. In 2007, the Islamic New Year parties are held on January 20^{th}.[44] Therefore, the second party of the Islamic New Year is on March 20^{th}. We have assumed that the villagers prefer to have the New Year parties at the same time period as newborn celebrations. Consequently, after breakfast and after lunch periods on January 20^{th} and March 20^{th}, of 2007 are for Islamic New Year parties.

By the procedure described above, the monthly schedule for the community center was produced. Example of the activity schedule is as shown in Figure 5.29.

Date	Before Breakfast	After Breakfast	After Lunch	After Dinner	Bedtime
	4.30 am – 7 am	7 am – 1 pm	1 pm – 8 pm	8 pm – 11 pm	11 pm – 4.30 am
Jan 1st	Market	Studying (Class)	Cooking	Watching television Cellular phone charging	
Jan 2nd	Market	Market	Party	Watching television	

Figure 5. 29:Activity Schedule – Example

[44] Data from http://islam.about.com/cs/calendar/a/hijrah_calendar_3.htm.

Note that since the same procedure was used with every month, we streamlined the process by using the same schedule for months with identical number of days in the months, and adjusting a few activities in months with different numbers of days. Consequently, the schedules of all months are similar. Months with 30 days have the exact same schedule. Months with 31 days have the exact same schedule except January and March, which have Islamic New Year parties. The activity schedule for the year 2007 can be seen in Table A.5.3 in the appendix.

5.4.3 Electrical Appliance Selection

a) Appliance Selection Criteria

First, principal appliances were identified for each activity. This includes a television for watching television, a computer for computer use, a cooking stove for cooking, cellular phone chargers for cellular phone charging, and a vaccine refrigerator for health activities. Second, supporting appliances were selected for an activity only if 50% of the interviewees wanted to use it for the activity (Figure 5.30).

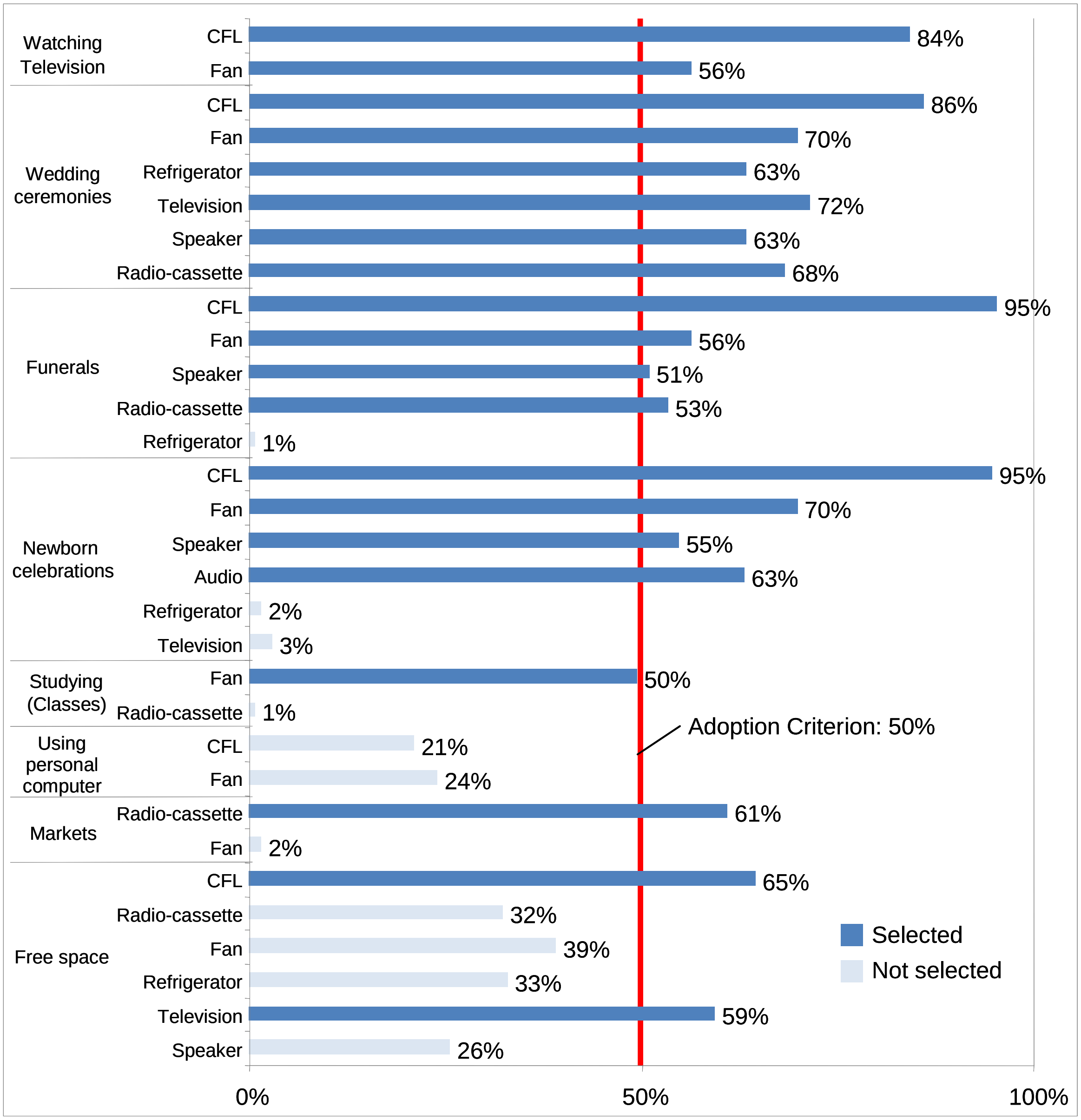

Figure 5. 30: Appliance Preference Selection Criterion and Result

b) Assumptions for Appliance Uses

In addition to appliance acceptance rule, there are assumptions for some appliances.

b-1) CFL

CFL use is different between daytime and nighttime because of sunlight availability. Normal sunrise and sunset in Tamale, a city near Mbanayili, are at 6am and 6pm, respectively[45]

[45] The sunrise and sunset times vary within 30 minutes.

across a year.[46] For most of the activities, no CFLs are used during the daytime. However, for activities that demand enhanced visibility, which are having classes and using computer, we have assumed that 5 and 1 CFLs are used during the day, respectively.

b-2) Fan

Weather conditions affect fan usage. In the dry season, which starts from November to March, the weather is relatively hot compared to the rainy season, which is April to October. Though fans are obviously used in the dry season for cooling, its primary utility in the rainy season is for deterring mosquitoes. However, from the villager's responses, less than half (45%) of the respondents would like to use fans in the rainy season. In accordance with their prioritization, we have assumed that the villagers use fans only in the dry season.

b-3) Cooking stove

In the after lunch time slot, which is 7 hours long, the villagers would not cook for 7 hours before dinner. Therefore, if cooking occurs during the after lunch period, the hours that the stove is being used would be reduced to 3.5 hours prior to dinner time.

Table 5.9 shows electrical appliances used in each of the activities.

Table 5. 9: Electrical Appliances Used in Each of the Activities

	Quantity of Appliance										
	CFL										
Activity	After sunrise	After sunset	Fan*	Refrigerator	Television	Speaker	Radio Cassette	Computer	Cellular Phone Charger	Cooking Stove	Vaccine Refrigerator
Watching television		11	4		1						
Parties		11	4	1	1	1	1				
Wedding ceremonies		11	4	1	1	1	1				
Funerals		11	4			1	1				
Newborn celebrations		11	4			1	1				
Islamic New Year parties		11	4			1	1				
Studying (classes)	5	11									
Using personal computer	1	11						1			
Markets		11					1				
Free Space		11			1						
Cooking		11								1	
Cellular Phone									1		
Vaccination		3	1								1
Treatment for minor Injuries		3	1								1

*: Dry season only

[46] Data from www.gaisma.com.

Greater than 50% of villagers want lighting for all activities except for computer. This is because most of the interviewees have little knowledge about using computer and therefore do not know that it requires enhanced visibility. So we have set 1 CFL for this activity.

Cultural activities usually incur playing music at high volume. Therefore, the villagers desire to have speakers and radio-cassette for these activities. In addition, they prefer to have a television and a refrigerator for weddings and parties in addition to those two appliances.

Appliance information, specifically power consumption and sizes, was drawn mainly from the JICA technical report (JICA, 2007) and from various other sources. For instance, the report selected ceiling fans with 55 Watts power consumption. Appliances not listed in the JICA report were selected based on availability in Ghana, the size of the activities, and their prices to minimize the cost. For example, the television chosen for this project is Sony BZ-21M50, which is a 21” screen television, because Sony is available in Ghana and the price of a 21” television is relatively low compared to larger televisions. Quantities of the appliances were identified based on the size of the community center. For example, eleven light bulbs are required to provide sufficient light for the open space during the night. (See the details in the appendix, Table A.2.2)

5.4.4 Load Curve Generation

Before a load curve was produced, the activity schedule was converted into an hourly schedule based on the time periods described in section 5.4.2.2. And the load curves for the entire year 2007 were constructed. There are two versions of load curves generated, the averaged monthly load curve and 8,760 hours[47] load curve. Utilizing both approaches allows us to compare how HOMER, the optimization software for designing the electricity generation system, would respond. To calculate electricity consumption for the averaged monthly load curve, we assumed that electricity consumption of each period of a day is the same for every day in a month. Therefore, for each time slot, the consumptions of every day in the month were averaged and used as consumption for the time slot. For example, the consumption during 9am to 10am of everyday in January was derived from averaging electricity consumptions from 9am to 10am of January 1 to 31. The alternative hourly model was derived using hourly consumption patterns for an entire year, 8,760 hours.

[47] 24 hours/day x 365 days/year = 8,760 hours/year.

Using the method above, the bedtime period ends (that is, the before breakfast period starts) at 4.30am. Therefore, for the 8,760 hours load curve, electricity consumption between 4.00am to 5.00am is derived from averaging power consumption of both periods. Lastly, since there are both AC and DC appliances selected for the community center, separate load curves for AC appliances and DC appliances are generated (further detail is provided in Chapter 7).

Table 5.10 provides a summary of the load curve generated.

Table 5. 10: Summary of Electricity Consumption in the Year 2007

	Unit	AC	DC	Total
Total	kWh	2,112	395	2,507
Consumption	kWh/day	5.79	1.08	6.87
Peak Load	kW	2.60	0.12	2.65

The load curves are similar across months with slightly higher consumption during the dry season, when fans are used. This is because the schedules of each of the months are similar. Shown below is the load curve generated for April 2007.

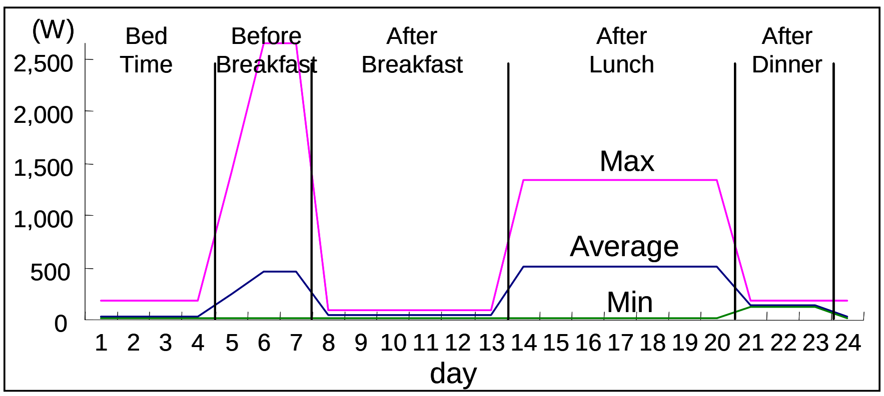

Figure 5. 31: Load Curve of April 2007

In the load curve above, the red line is the highest daily consumption of the month. In contrast, the green line is the lowest consumption of the month. The blue line is the average consumption, which is the load curve in the average scenario. As can be seen from the load curve above, there are two peaks, one before breakfast and one after lunch. The main activity responsible for the peaks is cooking, which uses cooking stove. In addition to cooking, activities contributing to the after dinner peak are as shown in Table 5.11.

Table 5. 11: Electricity Consumption Share of Activities in After Lunch Period[48] of April[49] 2007

Activity	Share	Quantity of appliance used in the activities							
		CFLs		Computer	Television	Refrigerator	Speaker	Radio-Cassette	Cooking Stove
		Before sunset	After sunset						
Cooking	86.50%		11						1
Parties	4.20%		11		1				
Health activities	3.10%		3						
Markets	1.60%		11						
Wedding ceremonies	1.40%		11		1	1	1	1	
Free space	1.10%		11		1				
Using personal computer	1.00%	1	1	1					
Newborn celebrations	0.70%		11				1	1	
Funerals	0.40%		11				1	1	

Another observation from the load curve (Figure 5.31) is that the electricity consumption fluctuates. To study the variation in detail, the activities are grouped by their power consumption as listed in Table 5.12.

Table 5. 12: Activities in After Lunch Period in April 2007

Electricity consumption (Wh)	Activities
1) Under 100	Healthcare
2) 100 – under 200	Healthcare
3) 200 – under 500	Markets, free space
4) 500 – under 1000	Funerals, wedding ceremonies, newborn celebrations, Islamic New Year parties
5) 1000 – under 3000	Parties, using personal computer
6) 3000 and above	Cooking

As can be seen from Figure 5.32, activities using power between 200 and 500 Wh occur most frequently within a month as well as activities consuming electricity over 9,000 Wh. The bar chart also shows high variation in electricity consumption regardless of cooking activity. For example, there are three days that the consumption is between 1,000 and 3,000 Wh while the consumption is less than 200 Wh on another three days. The difference is more than 10 times. In short, their consumption greatly fluctuates, and such fluctuation might impact electricity generation cost.

48 Sunset is in after lunch period. Numbers of CFLs used are different before and after sunset.
49 April is in rainy season. Therefore, fans are not used in this month.

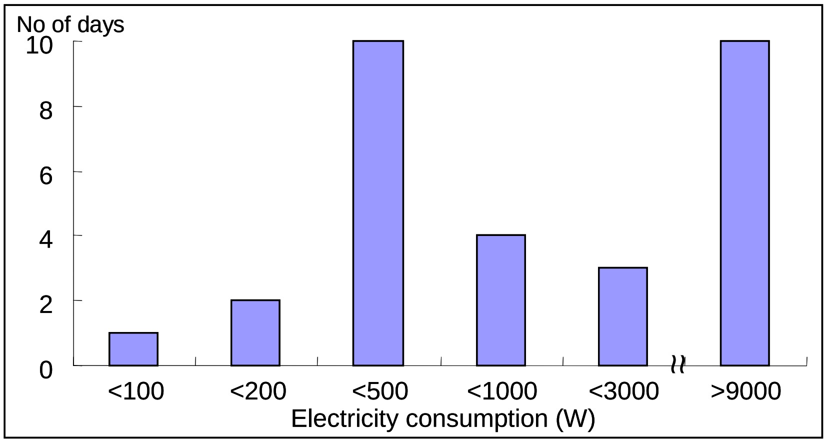

Figure 5. 32: Distribution of the Electricity Consumption for the After Lunch Time Period (1pm – 8pm)

Despite being the most popular activity period, dinner time slot does not have the highest electricity consumption. This is because high energy consuming activities, such as cooking, are not scheduled in this time slot.

However, if we consider only DC appliances, which are the refrigerator and the CFLs, the peak occurs at a different time slot- after dinner. This is shown in Figure 5.33.

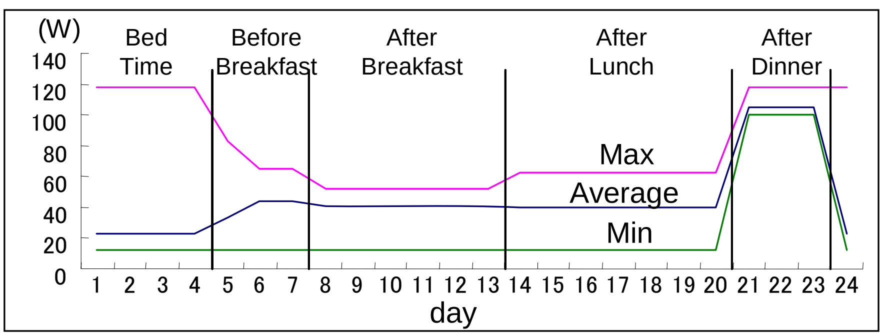

Figure 5. 33: DC Load Curve

Considering total monthly electricity consumption in each of the time slots, we will see that 60% of electricity is consumed during the after lunch period (Figure 5.34). The second most energy consuming period is before breakfast. This is largely due to the fact that cooking occurs in these two time slots.

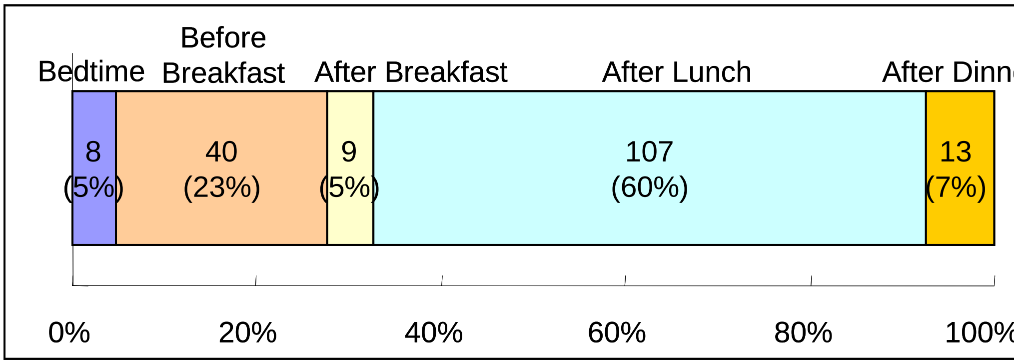

Figure 5. 34: Share of Electricity Consumption by Time Slot (kWh, %)

Regarding total monthly consumption by appliance as shown in Table 5.13, the cooking stove consumes the greatest amount of energy. The reason is that it requires the highest power. CFLs are the next because they are turned on in all activities at night and also during daytime in activities requiring enhanced visibility – classes and using personal computer. Cellular phone chargers use the least electricity because they require minimal power. Also, cellular phone charging occurs only approximately once a week.

Table 5. 13: Aggregate Electricity Consumption by Appliance of April 2007

Electrical Appliance	Consumption (Wh)
Cooking stove	130,000
CFLs	22,362
Refrigerator	10,835
Television	4,980
Audio	3,795
Fan	3,080
Speaker	2,115
Personal computer	1,050
Cellular phone charger	198

In this chapter, the survey results of villagers' preference toward activities and potential demand for electricity have been analyzed and translated into numerical data for generating the load curve. The load curve was then used by the supply analysis to determine the optimized electrification system for the community center.

Chapter 6: Biofuel Potential from Jatropha Curcas Linn. [50]

6.1 Multifunctional Platform[51]

The Ghanaian government has identified localized biofuel production, particularly from Jatropha Curcas L. (hereafter Jatropha), as a potential method for alleviating poverty. The plant can be utilized not only as a fuel source, but also for a number of highly adaptive revenue generating schemes. Unlike fossil fuels that the GOG primarily procures through foreign imports, added value derived from Jatropha production can remain within the country. Instead of importing petroleum and exporting funds in return, biofuels have the potential for spurring economic development by creating local markets for production, refining, and distribution of Jatropha products and byproducts. Professor Fred Akuffo from the Kwame Nkrumah University of Science and Technology (KNUST) made a 2004 keynote address to the GOG's Energy Commission highlighting the benefits of Jatropha based biodiesel. In this address Prof. Akuffo asserted that biodiesel is a mature, commercially viable technology that can provide the country with "immense benefits" (Akuffo, 2004). The most notable benefits from establishing biofuel markets would be: the displacement of oil imports that are a major contributor to the county's astounding debt (oil imports comprise 28% of the total energy supply and 10% of GDP) (UN Energy, 2006); the emergence of new markets to supplement existing agricultural industries; increases in the country's Gross National Product and employment opportunities, especially in the rural northern regions (Akuffo, 2004). Furthermore, it is apparent the GOG is pursuing modernity, and this approach may help minimize energy scarcity and price volatility. There is also mounting evidence suggesting that biofuels derived from Jatropha can be cost competitive with fossil fuels, once greater experience is attained with cultivation, refining, and distribution practices.

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[50] The following text was instrumental in this research and was heavily cited in many other works on the subject: Heller, Joachim. (1996) "Physic Nut. Jatropha curcas L. Promoting the conservation and use of underutilized and neglected crops." Institute of Plant Genetics and Crop Plant Research, Gatersleben/Internation Plant Genetic Resource Institute, Rome, Italy.

[51] The biofuel potential of Jatropha was given special attention here, partly because of the Ghanaian Government's expressed interest in expanding local biofuel production for energy security and poverty alleviation, but also due to the authors' unfamiliarity with this obscure biofuel. Furthermore, Jatropha presented the opportunity to examine the feasibility of providing both renewable energy production and economic development simultaneously. The rationale for the suite of energy sources (PV and a generator) used for modeling purposes is outlined in Chapter 7. Other potential sources for renewable energy production that were examined, but not considered within the scope of analysis, can be found in Appendix 3.

6.2 Origins & Nomenclature

There is considerable controversy regarding the origins of Jatropha, but most research indicates that the center of origin was likely in Mexico or other regions of Central America. Although some sourced contend Jatropha is indigenous to Africa, there is a sufficient body of evidence to discredit this. Jatropha was probably introduced to the continents of Africa and Asia by Portuguese merchants prior to 1810 (Heller, 1996). Since Jatropha introduction into Ghana, it has acquired many different names regionally and is rarely referred to as Jatropha: in the Akan region, Jatropha is known as Nkaneadua, in Ewe it is referred to as Kpotikpoti, and inhabitants in Ga/Adangme call it Kutugbletso (Akuffo, 2004). English speakers have also ascribed numerous nomenclatures to Jatropha: it is alternatively referred to as the physic nut, purge nut, pig nut, and fig nut.

6.3 Botanical Description (see Figure 6.1)

Jatropha belongs to the euphorbia family and has an average lifespan of 50 years. The plant is described as a small tree or large shrub, having a maximum height of 5 to 6 m (Benge, 2006; Heller, 1996). The root structure of the plant consists of five roots, one tap root and four peripheral roots. However, tap root formation is absent with vegetative plant propagation (cuttings), with the exception of occasional pseudo-tap roots that mature abnormally, not attaining the full size of tap roots cultivated from seedlings (Heller, 1996; Kobilke, 1998; Benge, 2006). Jatropha's unisexual flowers (inflorescences) are clustered in a dichasial cyme configuration, which means flower clusters emerge and bloom first at the terminal end of a branch. Newer flower clusters then emerge and bloom further down the branch, leaving the earliest blooming flower cluster at the terminal ends. Beneath the flower clusters are 5 to 7 leaves that have significant variation in length and width, both of which can span 6 to 15 cm. Jatropha is not a self-propagating plant and requires insects for pollination. Once pollination occurs, ellipsoidal fruits emerge containing three seed cavities (trilocular). The outer husk (exocarp) remains firm and plump until the seeds are mature. The seeds are black in color, weighing approximately half a gram, and have an average length and width of 18mm and 10mm (Heller, 1996; Henning, unknown).

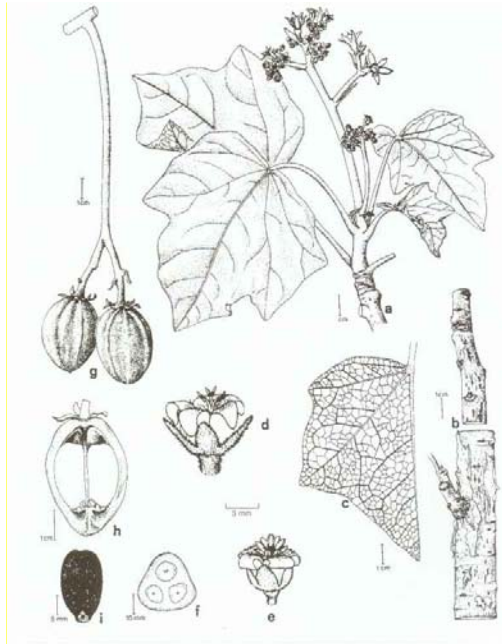

Fig. 2. Important parts of the physic nut: a - flowering branch, b - bark, c - leaf veinature, d - pistillate flower, e - staminate flower, f - cross-cut of immature fruit, g - fruits, h - longitudinal cut of fruits; a - c and f - h from Aponte 1978; d and e from Dehgan 1984 (reprinted with permission).

Figure 6. 1: Botanical Illustration of Jartropha Curcas L. (Heller 1996)

6.4 Seed Properties

The composition of the Jatropha seed is provided in Table 6.1, acquired from Joachim Heller's seminal text on Jatropha, entitled "Physic nut: Jatropha curcas L" (1996). The data were compiled from J.E. Mendes Ferrao's previous studies on Jatropha seed composition samples in Cape Verde (Santiago and Fogo), Sao Tome, and Principe, islands off the west coast of Africa. Unfortunately, only the crude fat content of the seeds were evaluated; more detailed analysis was conducted on the kernel. Analysis on seeds from these three locations indicate: relative shell and kernel compositions and crude fat content of seeds, as well as the moisture, ash, crude protein, crude fat, and crude fiber content of the kernels. (see Table 6.1) Results from this analysis show potential for deriving significant quantities of crude fat from Jatropha seeds, concentrated in the kernel. As fats are the primary constituent of oil, prospects for achieving high oil yields from this plant seem promising.

Table 6. 1: Jatropha Seed and Kernel Composition

Location	Seed Composition (%)		Kernel Constituent (%)					Seed Constituents (%)
	Shell	Kernel	Moisture	Ash	Crude Protein	Crude Fat	Crude Fiber	Crude Fat
Fogo	35.5	64.5	4.7	4.5	20.3	52.8	0.9	32.1
Santiago	44.9	55.1	3.8	3.8	23.5	59.8	1.9	32.9
Sao Tome'	47.7	50	7.8	6.4	28.4	46.7	4.2	23.7
Mean	42.7	56.5	5.4	4.9	24.1	53.1	2.4	30.2

Source: Heller 1996 citing Ferao et al. 1981;1984;1982

Heller (1996) compiled data on the fatty acid composition of Jatropha oil from numerous localities and sources. Only four significant fatty acids were evaluated: palmitic, stearic, oleic, and linoleic. These findings were determined using gas chromatography after the oil had undergone the methylesterification process. Jatropha oil is characteristic of most vegetable oils in that the unsaturated fatty acids, oleic and linoleic, are the primary constituent.

6.5 Toxicity

Jatropha leaves and nuts contain phorbol esters and curcin, a highly toxic protein that has similar properties to ricin, which is found in the castor bean. The only known nontoxic varieties are indigenous to Mexico and can be consumed after roasting; however, consumption in this manner is not totally devoid of risk (Benge, 2006). Despite the toxic nature of most varieties, risk of illness or death is minimal unless ingested. The plants found in Ghana are of the highly toxic variety and are not consumed as food, though small quantities have been ingested as a purgative (Benge, 2006). According to Duke (1983) "Two seeds are [a] strong purgative. Four to five seeds are said to have caused death," although which particular seed variety this refers to remains unclear. Further analysis of Jatropha's toxicity is warranted to determine the risk associated with handling the leaves and nuts, though anecdotal evidence indicates harvesting and oil extraction can be conducted safely (Heller, 1996).

6.6 Ecology

Jatropha is particularly well adapted to grow in arid or semi-arid, low altitude (0-500 m) environments and can flourish on marginal soils lacking high nutrient content. It has grown with particular success in drier tropic areas with annual precipitation between 300 and 1000 mm (Heller, 1996). Reportedly, it has survived prolonged drought in Cape Verde where annual rainfall is merely 250mm, but successful growth is largely attributable to the intense regional humidity (Henning, unknown). The majority of Africa south of the Sahara Desert is suitable for growing Jatropha, including the entirety of Ghana. These regions are depicted in green on Figure 6.2.

Figure 6. 2: African Regions Hospitable for Growing Jatropha (Green)
(Source: Bio King 2007, http://www.bioking-deutschland.com/img/AF-Map.jpg)

Ideal meteorological conditions require between 600 and 1000mm of precipitation and annual average temperatures between 20°C and 28°C (Heller, 1996; Benge, 2006). For comparison, the mean temperature in Ghana ranges from 29°C on the southern coast, to 34°C in the extreme north and average precipitation in the north is approximately 1,100 mm annually (Ghana Web, 2007; Ghana Meteorological Service Department, 2006). Table 6.2 provides further detail as to climatic conditions observed at locations of seed collection. Jatropha is not particularly resilient to cold weather. Though it can survive light frosts, all of its leaves will be shed, likely diminishing fruit and seed yields. Jatropha has some characteristics that are indicative of invasive species. This makes it unsuitable for agroforestry management techniques, because it competes heavily for resources; the easy disbursement of toxic seeds and the ability to thrive in marginal soils allow for Jatropha to maintain a competitive advantage over many species in close proximity, although there seems to be conflicting evidence from various sources as to Jatropha's actual invasive tendencies (Heller, 1996; Benge, 2006). According to a Washington State University (2002) report, once planted, Jatropha has a tendency "to grow where is has been planted", without encroaching on adjacent lands. However, Benge's (2006) description of Jatropha's invasiveness claims it "has a potential to be weedy", potentially creating "dense stands on uncultivated lands". He continues on, enumerating countries where it is considered a weed, although the distinction should be made that weeds are not necessarily synonymous with invasive species. Ackom (2005 citing Gubitz et al., 1999) clearly states that "the Jatropha plant is not an invasive species".

Table 6. 2: Climatic Data of Seed Provenances

Origins of Provenances	Altitude (m)	Average Temp (°C)	Average Annual Precipitation (mm)
Cape Verde, Fogo	150-1600	19-25	200-1000
Senegal, Santhie Ram	15	28	700
Ghana, Nyankpala	183	28	1080
Benin, Cotonou	7	25	1330
Burkina Faso, Kongoussi	300	-	520
Kenya, Kitui	1020	28	790
Tanzania, Mombo	430	20	670
Burma, Sink Gaing, Mandalay	80	27	825
India, Kangra	580	-	-
India, Kangra	434	11-38	-
India, Poona	556	25	672
Costa Rica, Rio Crande	10	28	2000
Mexico, Veracruz	16	25	1623

Source: Heller 1996

6.7 Agricultural Propagation Methods

Jatropha can grow from either vegetative (cuttings) or generative (seeding) propagation methods. However, plants propagated from cuttings tend to be less resilient against disease and tolerant of drought conditions because tap root formation is either partial or nonexistent. The lack of deep penetrating tap roots inhibits the plants' ability to uptake water and nutrients (Heller, 1996). Furthermore, crops propagated from cuttings tend to have less genetic diversity, thereby rendering them more susceptible to disease and pest incursions (Benge, 2006). Seed yields from vegetative propagation methods are contingent on a number of factors, the most influential being the age of the donor plant and the portion from which the donor plant cuttings were taken. The soil's nutrient content, drainage, precipitation, the season in which plantation occurred, and soil aeration are other elements which influence the viability of plant establishment with either method (Benge, 2006; Heller, 1996). Vegetative propagation is ideal if immediate seed yields or mitigation of soil erosion is desired, otherwise generative propagation methods are preferable for plant longevity and prolonged seed yields. Myriad factors contribute to actual seed yields of Jatropha, including: genetic variation, propagation methods, hedge configuration, and ecological conditions, which may account for contradicting reports on observed yields (Heller, 1996; Henning, unknown; WSU, 2002). For example, Heller (1996) compiled nineteen sources reporting data between the years 1934 and 1987 on the seed yields of Jatropha. These findings indicate a massive disparity in seed yields, from 100 to 8000 kg per hectare (see Table 6.3).

From this, Heller concludes that "at least 2-3 t [presumably metric tons] of seeds/ha can be achieved in semi-arid areas". Heller does not adequately substantiate this conclusion; no calculations are provided. But performing a simple mean (2,490 kg/ha) using the data below indicates that his conclusions are correct, though it would be more appropriate to discount anomalous data points. It appears, however, that the standard deviation is significant, and ascertaining which data points are in fact anomalous would prove daunting. The authors have yet to discover comprehensive or contemporary analysis on the prevailing factors influencing anticipated seed yields; further research and analysis is warranted.

Table 6. 3: Jatropha Seed Yields

Location	Yields (kg/ha)	Age (years)	Reference
Cape Verde	-	-	Avila (1949)
India	1733	3	Bhag Mal (pers. comm.)
Nicaragua	5000	-	Foidl (pers. comm.)
Mali	2640	-	Henning (pers. Comm.)
Thailand	2146	-	Ishii and Takeuchi (1987)
Mali	8000	-	Larochas (1948)
Madagascar	-	-	Martin and Mayeux (1984)
Paraguay	100	3	Matsuno et al. (1985)
Paraguay	700	4	Matsuno et al. (1985)
Paraguay	1000	5	Matsuno et al. (1985)
Paraguay	2000	6	Matsuno et al. (1985)
Paraguay	3000	7	Matsuno et al. (1985)
Paraguay	4000	8	Matsuno et al. (1985)
Paraguay	4000	9	Matsuno et al. (1985)
Cape Verde	1750	-	Naigeon (1987)
Cape Verde	200-800	-	Silveira (1934)
Thailand	794	1	Stienswat et al. (1986)
Thailand	-	1	Sukarin et al. (1987)
Bukina Faso	-	-	Zan (1985)
Conclusion	2000-3000	-	Heller (1996)

Source Heller (1996)

6.8 Uses

6.8.1 Living Fence

Traditionally, thick Jatropha hedgerows are used as a living fence to protect crops or to delineate property boundaries, because it is easily established with vegetative propagation and its toxic seeds deter livestock grazing (WSU, 2002).

6.8.2 Mitigating Desertification & Crop Stabilization

The extensive root structure formations that occur from cuttings, in consort with hedgerows functioning as windbreaks, can help combat desertification by stabilizing soils against wind and water erosion (Heller, 1996; WSU, 2002). Furthermore, its ability to flourish in marginal soils likely provides understory shade, enhanced surface water percolation, and groundwater recharge. Jatropha has been utilized to promote the growth of other crops, namely for climbing plants such as vanilla and pepper, that adhere to Jatropha stalks for stabilization (Heller, 1996; Benge, 2006; Henning, unknown date). Jatropha's potential invasiveness may limit its cohabitation with other species, though conflicting reports make it difficult to ascertain its actual invasive tendencies, as mentioned earlier.

6.8.3 Food Source and Medicinal Properties

Seeds from the Mexican variety have been boiled or roasted for consumption due to the absence of phorbol esters. All other varieties are considered toxic and are not consumed as a food source. Nonetheless, Jatropha has been utilized for a number of medicinal purposes. Extraction of oils from seeds, stems, and leaves by pressing or boiling (decoction) are used in traditional medicine, either to be ingested or applied as a topical solution: the oils are a strong purgative and effectively induce diarrhea or vomiting and offer pain relief against rheumatism and certain types of skin disease; decocted leaves have antiseptic properties and are a proven cough suppressant; teas derived from leaves are used as a malaria treatment; and sap is administered to wounds to promote healing (Heller, 1996; Benge, 2006; Henning, date unknown). Also, recent analysis on the recumbent protein of curcin (found in Jatropha curcas seeds) conducted at Sichuan University in Chengdu, China, suggests this cell-killing agent may restrict the growth of tumor cells (Meng-Jun LUO et al., 2006). Their conclusions are promising, prompting continued research to determine if curcin can be utilized as an anti-cancer or anti-viral agent.

6.8.4 Pesticide

Various extracts from the Jatropha plant have been identified as an effective insecticide and/or molluscicide. Myriad concoctions from seed oil and seed oil extracts, as well as the phorbol ester derivatives from this oil, have minimized the successful establishment of pests associated with cotton, potato, pulse, mungbean, corn, and sorghum crops (Heller, 1996). Pressed seed oil is the most common preparation, although aqueous, acetone and phorbol ester extracts from the oil have also been deemed effective (Heller, 1996). A detailed listing of pest species, corresponding crops, and pesticide preparation methods are provided in Table 6.4. Unfortunately, research on the use of Jatropha extracts as a pesticide is limited. Consequently, the active properties of the oil that enable it to function as a pesticide have not been isolated. Preliminary evidence suggests the presence of phorbol esters are likely responsible for the ability of these extracts to function as a plant protectant (Heller, 1996).

Table 6. 4: Effective Jatropha Pesticide Preparations

Pest	Crop	Preperation	Reference
Helicoverpa armigera	Cotton	seed oil;acetone seed extracts; aqueous oil extracts	Solsoloy et al. (1987); Solsoloy (1993) *ibid* (1995)
Aphis gossypii	Cotton	seed oil; aqueous oil extracts	Solsoloy (1993) *ibid* (1995)
Pectinophora gossypiella	Cotton	aqueous seed oil extracts	Solsoloy (1993)
Empoasca biguttula	Cotton	seed oil	Solsoloy (1995)
Phthorimaea opercullela	Potato	seed oil	Shelke et al. (1985)
Callosobruchus maculatus	Pulse	seed oil	Jadhav and Jadhav (1984)
Callosobruchus chinensis	Mungbean	seed oil	Solsoloy (1995)
Sitophilus zeamays	Corn	seed oil	Solsoloy (1995)
Manduca sexta	-	phorbol esters	Sauerwein et al. (1993)
Sesamia calamistis	Sorghum	oil and phorbol esters	Henning (1994)

Source: Heller 1996

6.8.5 Fertilizer

Residual press cake, otherwise known as seed cake, derived from the vegetable matter after seeds have undergone pressing to expel the oils, can often be used as animal feed. The toxicity of Jatropha press cake prohibits its use in this application, though this co-product to oil expulsion is sought after in many markets as fertilizer, having similar nitrogen content to that of chicken manure and castor bean press cake (WSU, 2002; Heller, 1996). Field trials in Mali examined the effects of various fertilizers (5t/ha of manure, 5t/ha of Jatropha press cake and 150kg/ha of mineral fertilizer) on pearl millet yields. Substantially higher yields were realized from Jatropha press cake (1366 kg) versus manure (815 kg) and mineral fertilizer (1135 kg). Furthermore, Jatropha press cake was considerably less costly than the next best alternative, mineral fertilizer (Heller, 1996 citing Henning et al., 1995). Because of Jatropha's phytotoxicity, which appears to affect crop yields, there may be limitations regarding how much Jatropha seed cake can be used as fertilizer without causing unintended adverse impacts (Heller 1996). Instances of reduced seed germination have been observed in applications where Jatropha fertilizer is used in excess of 5 tons per hectare.

6.8.6 Soap Production

Saponification from Jatropha oil can be achieved in two ways: unadulterated Jatropha oil can be combined and boiled with a base solution to release glycerol, the primary ingredient in soap manufacturing. Alternatively, once the oil has undergone transesterification (see section 6.8.9 for detail) the resultant glyceride byproducts of biodiesel production can be used for soap production as well. The Tata Oil Mills Co., LTD in Mumbai, India has successfully produced high quality soap combining hydrogenated Jatropha oil (75%) and refined, bleached Jatropha oil (15%), with coconut oil (10%) (Heller, 1996).

6.8.7 Jatropha Oil

Jatropha seeds contain between 35 to 40% oil, while seed kernels have higher oil concentrations, between 55 to 60% (WSU, 2002). Oil products derived from Jatropha seeds and kernels have recently prompted significant interest to determine whether or not these products can foster rural economic development. Jatropha oil can be utilized for an array of products that do not require prohibitively intensive capital investments, predominately for biofuel production (non-transesterified) and soap manufacturing; this is promising for the creation of highly adaptive, small-scale industries. The majority of recent analysis on Jatropha has been undertaken to elucidate its feasibility for instigating economic growth in developing countries (Akuffo, 2004; Henning, 2004; Henning, unknown).

6.8.8 Lighting and Cooking Fuel

Interest in Jatropha oil as a fuel for lighting and cooking apparatuses has been instigated because it reportedly has similar characteristics to that of kerosene. Unfortunately, Jatropha's higher ignition temperature and viscosity present a challenge for its use in standard kerosene lanterns and stoves. The high viscosity of Jatropha oil tends to make it congeal, occluding hoses and apertures, and its significantly higher ignition temperature requires the use of kerosene or other supplemental fuels to facilitate ignition. Alternatively designed equipment has attempted to compensate for these complications: lanterns fabricated with short wicks that maintain the flame in proximity to the fuel source, thus providing greater heat for ignition; and stoves specially designed to allow the flow of higher viscosity fuels (WSU, 2002).

6.8.9 Biofuel

The use of vegetable and/or animal oils as a fuel source for internal combustions engines is not a novel concept. In 1900, Rudolf Diesel unveiled an engine that combusted peanut oil at the world exhibition in Paris. Recently, there has been considerable interest in determining whether or not Jatropha biofuel is a suitable alternative to diesel fuel. A number of studies have examined Jatropha's potential for this application, because of its drought resistance and ability to grow in arid climates on marginal soils. Furthermore, unlike palm oil, which is commonly used in Ghana for cooking, the toxicity of Jatropha renders it unfit for human consumption, precluding market competition with other oil used as fodder.

Jatropha oil can be combusted in two ways: either as unadulterated oil or as biodiesel after the oil has undergone transesterification. Once extracted and filtered, unadulterated oil can be combusted in direct injection combustion engines. The most commonly cited with regard to the use of Jatropha oil are Lister-style engines; duplicates of the original British 1930's design are known as Listeroids, and are currently mass-produced in India and China. These engines have proven ideal for the combustion of viscous oils that have not undergone transesterification. However, the viscous nature of the oil necessitates higher operational temperatures because of its propensity to solidify, "which causes inadequate atomization and incomplete combustion" (Forson et al., 2003). The simplicity of Lister engines has prompted extensive promotion of this technology in rural applications, as they require minimal technical expertise to service and replacement parts are fairly easily procured, compared to other, more complex engines. Lister engines tend to operate at relatively low speeds, typically between 500-700 RPM and have been successfully used to drive small mills, water pumps and electric generators (WSU, 2002).

Alternatively, Jatropha oil can be transesterified and combusted in any indirect injection diesel engine. There are various methods for converting oils into biodiesel. Most current biodiesel production combines oils or fats with an alcohol, such as methanol or ethanol. Transesterification occurs once this mixture is in the presence of a base catalyst, typically potassium or sodium hydroxide, which is often premixed with the alcohol solution. Methyl/ethyl esters or pure biodiesel (B100) are produced, along with the glyceride co-products that separate out during the reaction. Base catalyzed transesterification is considered superior to alternative biodiesel production methods for a number of reasons: no intermediary processes are required to achieve methyl/ethyl ester conversions; the reaction occurs at low temperatures (150°F) and pressure (20 psi); and it is a comparatively stable and controllable process capable of attaining 98% conversion efficiency with minimal reaction time (National Biodiesel Board, 2007). In Ghana there is great potential for conducting the transesterification process with ethanol derived from locally grown sugar cane or corn crops, as opposed to methanol, which is a petroleum based product and must be imported. The feasibility of producing ethanol from surpluses in either corn or sugar cane production should be investigated. Without ample surpluses, ethanol production may prove a risky proposition, especially if it directly competes with food production.

In developed countries, requisite raw materials and the equipment needed to conduct the transesterification process are fairly easy to procure; however, acquisition of these materials by rural inhabitants in developing counties may be unrealistic, particularly with methanol. Methanol is a highly flammable and toxic material that requires handling and storage by trained individuals. Direct human exposure to methanol or methanol vapors, via inhalation, skin absorption or oral ingestion can have detrimental health impacts. Consumption of as little as one ounce of methanol has been known to cause irreversible damage to the nervous system, blindness, or even death (Methanol Institute, 2007). Although flammable, the toxicity of ethanol is minimal in comparison to methanol or gasoline. Nonetheless, the level of technical expertise, specialized equipment, and the handling of hazardous chemicals needed for the transesterification of Jatropha oil into biodiesel may exceed what is practical under real world conditions in Northern Ghana.

6.9 Oil Expellers

The oil can be expelled manually with rudimental hand (ram) presses, engine powered screw and spindle presses, or hydraulic presses. Chemical expulsion can also be achieved with hexane solvents (Heller, 1996). Significant variants in the relative efficiency between these extraction methods have been observed. This is of importance with regard to economic development, as oils are far more valuable on the open market than the residual seed-cake that remains after pressing. With inefficient expulsion methods, oil content of the residual seed-cake may exceed 25% - 50% of the total extractable oil residing within the seed, which translates into huge economic losses (Benge, 2006). Khaodhiar et al. (date unknown) suggest that oil extraction using chemical solvents is the most effective means of attaining high extraction efficiencies, recovering 2.5 times more oil than with a "mechanical crusher". Unfortunately, this method may not be viable in rural applications, because of its requirements: a higher level of technical expertise than mechanical extraction methods; the use of potentially volatile solvents that may not be easily procured by rural inhabitants; and capital intensive, large-scale production needed to make it economical.

6.10 Oil Yields

It is evident that oil yields from Jatropha are contingent on many factors; therefore, the reliability with which data can be extrapolated and generalized is very limited. The most salient factors determining oil yields are: genetic variation; ecological conditions; and propagation, cultivation, harvesting, and oil expulsion methods. Few sources have gone so far as to actually assert oil yields, but the variability in available reports is large and the calculations may be contingent on extremely optimistic seed yields and other unrealistic assumptions (Benge, 2006). The complexity underlying actual oil yields, coupled with inconsistent research methodologies, further compounds the issue. It is unclear if yields can be predicted with any certainty without *in situ* field trials. At this juncture, determining potential oil yields for Mbanayili would be sheer conjecture without further field research. However, a few seemingly reputable sources indicated oil yields and are provided in Table 6.5.

Table 6. 5: Jatropha Oil Yields

Reference (year)	Yield	Oil Type
Fulton et al (2006)	2,000 L/ha	"feedstock"
Benge (2006 citing Gaydou 1982)	2,100-2,800 L/ha	"fuel oil"
Ackom (2005 citing Henning 1994)	0.17 L/m	"seed oil"
Henning (2004)	5kg/L	"raw oil"

The Worldwatch Institute (citing Fulton et al., 2006) and Benge (2006) both posit yields in liters per hectare ranging between 2,000 and 2,100-2,800 liters, respectively. Fulton et al. report their findings in terms of a biofuel "feedstock" while Benge's values are apparently "fuel oil" yields. Presumably, "feedstock" implies that the oil has not undergone the transesterification process and "fuel oil," as reported by Benge, insinuates that yields are in biodiesel equivalents. It is disconcerting that one report indicates that fuel grade oil yields are substantially higher than feedstock yields (considering conversion losses—although minimal). However, given the inherent variability in actual biofuel yields, which are contingent on the many factors mentioned earlier, this may be justifiable. Ackom posits an oil yield of 0.17 liters "per meter of hedge per year", but he does not indicate if this is in square or linear meters. Henning (2004) cites a project in Tanzania (KAKUTE) that required 5 kg of seeds to expel a liter of "raw oil".

6.11 Fuel Characteristics: Jatropha Biodiesel vs. Conventional Diesel

The viscosity and the abundance of glycerides in untransesterified Jatropha oil make it unsuitable for combustion in standard diesel engines, although transesterified Jatropha oil has similar characteristics to those of conventional diesel. According to Ackom (2005, citing Schrimpff, 2002), Jatropha biodiesel has similar properties to conventional diesel with regard to its energy content and specific weight, although notable dissimilarities between the fuels exist: Jatropha biodiesel is superior to conventional diesel with respects to cetane value, flash point, sulfur content, and overall emissions, although there are limitations and tradeoffs worth mentioning. (see Table 6.6)

Table 6. 6: Jatropha Biodiesel vs. Conventional Diesel

Parameter	Diesel	Jatropha oil
Energy Content (MJ/kg)	42.6-45.0	39.6-41.8
Specific weight (15/40^{0}C)	0.84-0.85	0.91-0.92
Solidifying point (^{0}C)	-14.0	2.0
Flash point (^{0}C)	80	110-240
Cetane value	47.8	51.0
Sulphur (%)	1.0-1.2	0.13

(Source: Schrimpff, 2002).

Cetane values indicate a fuel's propensity to ignite: it is the time delay between the fuel's injection in the cylinder and the initiation of combustion. Typical cetane values for conventional diesel range between 40 and 50 with higher values indicating premium grade fuels. This improves engine performance, longevity, and starting ability in cooler ambient temperatures. Jatropha achieves a cetane value of 51 without using the cetane enhancing additives required for some conventional diesel fuels to meet original equipment manufacturers (OEM) specifications (The Department of Environment and Heritage, 2004).

Jatropha's flash point, or the temperature at which fuel vapor ignites when exposed to an open flame, is significantly higher (110-240°C) than conventional diesel (80°C). Higher flash points allow for safer transportation and storage of the fuel and have negligible effects on engine performance (Exxon, 2007).

There are a few potential limitations to combusting Jatropha biofuel in some diesel cycle engines. Biodiesel mixtures, especially with concentrations exceeding 5% (also known as B5, comprised of 5% pure biodiesel and 95% conventional diesel), have a tendency to corrode natural rubber gaskets and seals. Many current manufacturers state that biodiesel blends, typically between B5 and B20 that adhere to the American Society of Testing and Materials formulation standard (ASTM D 6751) do not void OEM warranties. Fewer manufactures provide coverage as biodiesel concentrations exceed 20% (National Biodiesel Board, 2006). Ensuring fuel compatibility within engine specifications and tolerances is critical to maximizing engine performance and minimizing the likelihood of unintended engine degradation. Jatropha's high solidifying point may restrict usage to regions where ambient air temperature drops below 2°C, contrasted against conventional diesel which has a much lower solidifying point (-14°C), enabling its use in cooler climates. Although this does not present a problem in Ghana, it may in other localities.

6.12 Emissions: Jatropha Biodiesel vs. Conventional Diesel

Conflicting evidence exists regarding the emissions of Jatropha biodiesel: the WSU report (2002) contends that Jatropha biodiesel "contains no sulfur and so emits none", which conflicts with Schrimpff's analysis, suggesting the fuel contains a paltry 0.13% sulfur. Regardless of these inconsistencies, it is evident that Jatropha biofuel may be superior to conventional diesel in that contains negligible sulfur, if any at all. According to the EPA's "Comparative Analysis of Biodiesel Impacts on Exhaust Emissions" (2002), pure biodiesel (B100), predominately from soybean feedstock used in the United States, decreases carbon monoxide and particulate matter by approximately 50%, the emission of unburned hydrocarbons by 67%, and eliminates sulfates entirely. (see Figure 6.3)

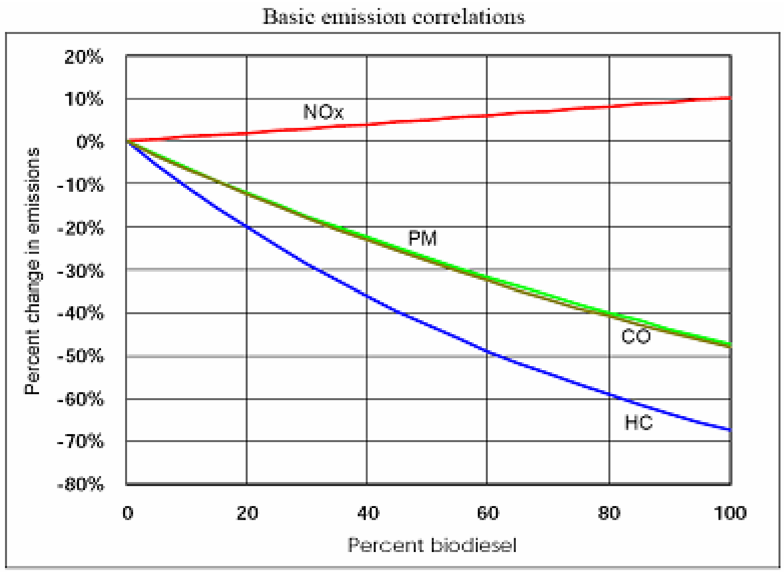

Figure 6. 3: Biodiesel vs. Conventional Diesel (Source: EPA 2002)

The only apparent consequence, according to the EPA, with regard to biodiesel emissions, is a 10% increase in nitrous oxides that occurs due to higher oxygen concentrations present in biodiesel, which increase combustion temperatures and, consequently, nitrous oxide formation. Although there is general consensus that increased nitrous oxide formation occurs during biofuel combustion, other analysis contends that particular emissions increase with Jatropha oil combustion. According to Kumar et al. 2001, "hydrocarbon and carbon monoxide emissions were slightly higher with both Jatropha oil and its methyl ester than with diesel [,] whereas NO levels were lower than with diesel." These inconsistencies can be attributed to many factors, namely, differing experimentation methods, particular fuel constituents, and engine specifications. Many of the sources that analyzed Jatropha emissions, did so with direct injection Lister engines, which likely have different emissions controls (if any at all) from the standard diesel engines tested in the EPA's analysis.

Nonetheless, unlike diesel, Jatropha is a renewable resource that can provide carbon neutral energy production if managed in a sustainable manner. Sustainable cultivation practices would ensure that all carbon dioxide released during the fuel's combustion will be recaptured and sequestered in future plant respiration and biomass. Amid increasing global climate change concerns, some projects have attempted to receive the carbon sequestration payments made available under the Kyoto Protocol's Clean Development Mechanism (CDM). Benge (2006) cites Henning's rough calculation of the anticipated payments that a Jatropha project in Egypt is slated to receive under this provision; payments are approximated at $150 US per hectare, although no formal data has been released.

6.13 Engine Performance: Jatropha vs. Diesel

Figure 6.4 indicates the results of comparative analysis on the engine performance of pure Jatropha (BD 100), a 50% blend of Jatropha and conventional diesel (BD 50), and pure diesel (K 100). The similarity of these fuels' reaction within the fuel pipe and pressurization in the cylinder is striking. With regard to the parameters tested, it appears Jatropha biodiesel and conventional diesel are functionally equivalent when combusted in standard diesel engines.[52]

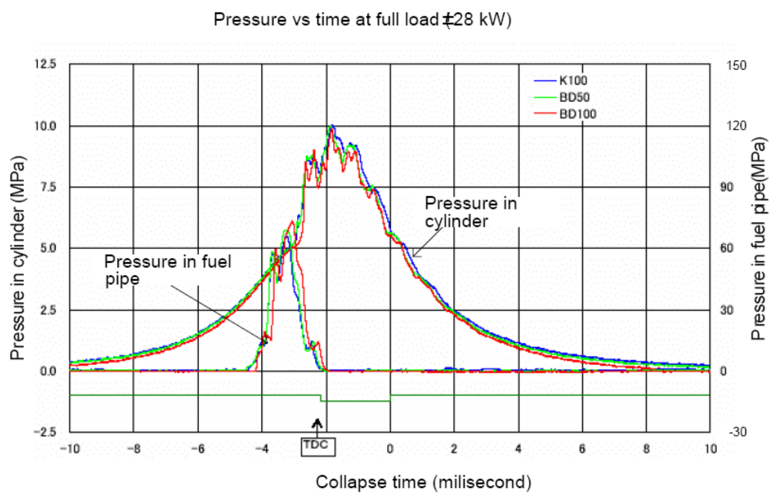

Figure 6. 4: Engine Performance of Pure Jatropha (BD 100), a 50% Blend of Jatropha and Diesel (BD 50) and Straight Diesel (K100).
Source: Manurung

Other analysis on the thermal efficiency of various fuels derived from Jatropha oil, when combusted in a Lister-style compression ignition engine, suggest straight Jatropha vegetable oil is less efficient than its methyl ester or diesel. Kumar et al. (2001) claim that the brake thermal efficiency of Jatropha vegetable oil was 25.6%, which was slightly less than the 27.8% achieved by the methyl ester. In these test diesel exhibited the highest thermal efficiency of 29.4%.

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[52] This figure was attained from an online presentation presented by Dr. Ir Robert Manurung at the Bio-Technology Research Center Institut Teknologi Bandung, however, the date is unknown. Unfortunately, original documentation of this research detailing the methodologies and assumptions underling this experiment was never acquired, either because it remains unpublished or was overlooked by the authors.

6.14 Cost: Jatropha vs. Diesel

The average price of diesel fuel in Ghana in 2005 was US $0.65/L according to Ackom (2005), which is artificially low and does not reflect actual costs, due to substantial government subsidies for fossil fuels. Ackom (2005 citing Schrimpff 2002; Protzen, 1997) claims "production cost" of "Jatropha oil"—although not explicitly stated, it is presumably transesterifed—is between US $0.45 and $0.60 per liter. Heller (1996) references a project in Nicaragua that expects to produce 1,600 tons of methyl esters annually, and the expected production costs were US $0.74 per gallon. No other details are provided to substantiate these facts. Consequently, it is unclear whether these production costs are also achievable for small quantity production or require economies of scale, supporting infrastructure, and supply chains. Although the evidence is inconclusive, if these production costs are accurate, the rationale for promoting economically viable biofuel production in Ghana should intensify, especially if volatility in the world oil markets continues.

6.15 Economic Viability & Conclusions

The Anuanom Biodiesel Project, a collaboration between Jatropha Hamburg, various private partners, and support from the GOG, has been ongoing in Ghana since 2002. As of May 2002, a productive variety of Jatropha with a nut oil content exceeding 60% has been planted in excess of 2,000 hectares in the Greater-Accra, Eastern, and Western Regions of Ghana. The project intended to allocate a quarter of "idle farmland" in Ghana to Jatropha cultivation, achieving a total planted area of 250,000 hectares by 2004 or 2005 (Henning, unknown date). According to Henning, the project was to have reached a "critical stage" in 2003 when the first major yields and payments were anticipated. Unfortunately, attempts to contact Reinhard Henning and locate more recent information as to the status of the project were unsuccessful.

Revenue generation potential for Jatropha products, namely unesterified Jatropha oil, biodiesel, and soap, is entirely predicated on local market demand. Unless Jatropha biodiesel production costs remain competitive with retail diesel prices, its suitability as a fossil fuel substitute will not be possible. Though production costs cited by Ackom (2005) suggest Jatropha biodiesel can be priced competitively with diesel, a project in Tanzania (2002) reported that pure Jatropha oil traded for US $2/L, nearly three times the price of diesel at the time. In this scenario, it was not economically viable as a biodiesel feedstock because local soap manufactures needed the oil as a raw material input for their lucrative enterprise and were prepared to pay a premium (Henning, unknown). Despite demanding such a high price, the prospects for revenue generation seem promising. With prices of Jatropha oil exceeding those of diesel, individuals desiring fuel could sell the oil and receive a greater volume of diesel than what would be achievable by converting the oil into biodiesel.

In the opinion of the authors, Jatropha production intended for use as a biofuel and for spurring economic development seems promising, but warrants further research to determine if it is viable for this particular village. To make a sound determination of the prospect for Jatropha production in Mbanayili, further investigations should answer the following simple, yet fundamental questions:

Technical

- What is the oil content of plant varieties available in Ghana?
- Does the village have a land surplus to be dedicated to Jatropha cultivation?[53]
- Will growing Jatropha negatively impact existing crops?
- What are the anticipated seed and oil yields for Mbanayili?
- What is the probable oil recovery from technologically feasible extraction methods?
- How much technological education will the village residents require for cultivating and processing Jatropha?

Economic

- Do current markets exist for Jatropha in or around the vicinity of Mbanayili?
- If so, what is the current and projected market price?
- What is the potential profitability of cultivating and selling Jatropha products in local markets?
- For what purpose/products is Jatropha currently cultivated?
- What is the most advantageous usage of Jatropha oil for Mbanayili?
- What funding avenues are available to facilitate project deployment?

[53] Using a conversion factor yielding approximately 2,000 L of Jatropha "feedstock" oil per hectare, the lower limit land area requirement for the village to supply ample fuel to power the generator with blended or pure biodiesel would be approximately half a hectare (Fulton et al (2006). The upper limit land area requirement (2.225 ha/yr) was calculated using seed oil yields of 5kg/L (Henning, 2004) and land seed yields of 2,000kg/ha (Heller, 1996). Further detail is provided in section 7.14.

Chapter 7 Supply Side Analysis: Optimal Generation System Modeling

7.1 Energy System Design Overview

This section evaluates optimal off-grid energy system configurations that can power the community center, utilizing the load curve data discussed in Chapter 5. Hybrid Optimization Model for Electric Renewables (HOMER), analytical software engineered by the National Renewable Energy Laboratory (NREL), is the tool used in this analysis. This software calculates which system configurations provide the best option, in terms of cost, for supplying electricity to the community center. HOMER ranks optimal system configurations according to their net present cost (NPC). [54] Sensitivity analyses were also conducted to determine the impact of variations in natural resources, economic, or load conditions on the system, such as unanticipated attenuation of solar radiance or increased electricity consumption; this helps determine which system configurations are robust and adaptable to unanticipated variances in model assumptions.

7.2 Benchmark HOMER Design Schematic

This hybrid energy system, which incorporates the use of renewables, consists of three primary functions: power production, energy consumption, and storage. Power production relies on a PV array and diesel generator.[55] Energy consumption is dictated by a power versus time load curve derived from Chapter 5. Energy storage is achieved with the use of a battery bank and converter. Figure 7.1 illustrates the relationship between these components.

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[54] Net present cost calculates the total cost of purchasing and operating the system over the project's lifetime, discounted back to provide this cost in present value terms.

[55] These power generation sources were selected for a number of reasons: a diesel generator allows for either diesel or biodiesel fuel blends to be evaluated (at least in theory), which conforms to the Government of Ghana's expressed interest in expanding the usage of Jatropha Curcas L. (see Chapter 6). Furthermore, PVs and diesel generators have been used extensively in similar applications in Northern Ghana. Other resources such as mini-hydro and wind were also investigated, but eventually determined to be either unrealistic or less effective for this particular application. (see appendix 3)

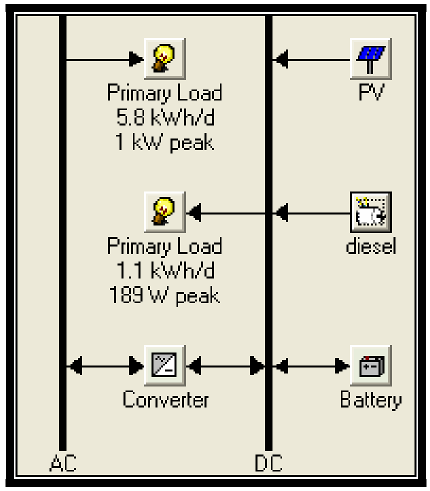

Figure 7. 1: Benchmark HOMER Schematic
Source: NREL, 2006

Utilizing HOMER 2.2 beta[56], the benchmark simulation is comprised of two independent loads, alternating current (AC) and direct current (DC). The PV array and the generator produce DC power that can be fed directly into the DC load without AC conversion. Excess energy produced by either the PV array or the generator that surpasses both load requirements is stored in the battery bank. If the DC load requirements exceed the energy production of the PV array and the generator, stored energy in the battery bank is directly fed into the DC load. Meeting AC energy load requirement necessitates that this energy be converted from DC to AC. The converter allows for energy transformation from DC to AC, or vice versa. Given that neither the PV array nor the generator produce AC energy, the converter should transform just enough energy to AC to meet this load requirement in order to minimize conversion losses; in short, transformation of energy from AC to DC energy is not necessary with this system configuration.

7.3 Benchmark Simulation

The benchmark simulation attempts to faithfully represent reality, although the lack of available site specific data often proves a challenge. In compensation, alternative simulations and

[56] At the time this model was created, the added functionality available in 2.2 was deemed potentially useful. Thus, analogue models were created and run in HOMER 2.19 "alpha" to determine if altered computational algorithms or design errors in the beta version affected model results. This test verified that the optimization and sensitivity results were equivalent between both software versions. Though a few of the cost calculations differed slightly, this variance had negligible influence on optimization and sensitivity outcomes.

sensitivity analysis were conducted to elucidate shortcomings in the benchmark case. After an explanation of the benchmark simulation, the results of the alternative models will be discussed, lending a more nuanced comprehension of modeling assumptions and their impacts on optimal system configurations. Overall, the results of these tests indicate model robustness, as many attempts to identify highly sensitive parameters were unsuccessful.

7.4 Solar Irradiance

Solar irradiance observed in Ghana fluctuates throughout the year, corresponding to seasonal and regional variation. Ground irradiation values tend to be higher in the northern regions, averaging about 5.42 kWh/m^2/day (see Table 7.1), compared to the national average of 5.1 kWh/m^2/day.

Table 7. 1: Solar Irradiation Potential of Ghana

Reference	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average kWh/m^2/day
EC/JICA (national - ground)	4.97	5.36	5.48	5.65	5.46	4.83	4.56	4.38	4.73	5.36	5.41	4.98	5.10
EC/JICA (national - satellite)	5.56	6.09	5.86	5.62	5.36	4.87	4.66	4.51	4.73	5.42	5.65	5.41	5.31
EC/JICA (northern region - ground)	5.31	5.59	5.70	5.87	5.86	5.47	5.02	4.80	5.05	5.59	5.63	5.17	5.42
EC/JICA (northern region--satellite)	5.56	6.32	6.26	6.15	6.00	5.51	5.10	4.78	5.23	5.91	5.77	5.41	5.67
NASA 2007	5.81	6.23	6.31	6.27	5.87	5.44	5.01	4.67	5.13	5.73	5.79	5.72	5.66
NREL (flat tilted) 2005	-	-	-	-	-	-	-	-	-	-	-	-	5.5-6.0

Seasonality also has a significant impact on the availability of solar insolation. It tends to be the lowest during the rainy season (April through October) and highest in the dry season (November through March) (Alhassan, Pers. Comm., 2006; JICA, 2006). Another climatic phenomenon that can impact the availability of solar insolation for PV generation, unique to the region, is called a harmattan. A harmattan is a low level, widely dispersed dust storm: during the dry season, fine sand particles are transported by the prevailing seasonal winds from the Sahara to equatorial regions of Africa. Ghana is a recipient of the subsequent dust fallout from the Sahara. Factors such as this can diminish the amount of solar insolation reaching the ground, causing a disparity between ground and satellite data (JICA, 2006). To accommodate for the variance between the reported availability of solar radiance and the effects of meteorological phenomena, sensitivity analysis was conducted on this parameter. Benchmark solar resource data was imported directly from NASA (a function available in HOMER's "solar resource inputs" table) by specifying the latitude (9^o 28' North) and longitude (0^o 55' West) of Mbanayili (see Figure 7.2).

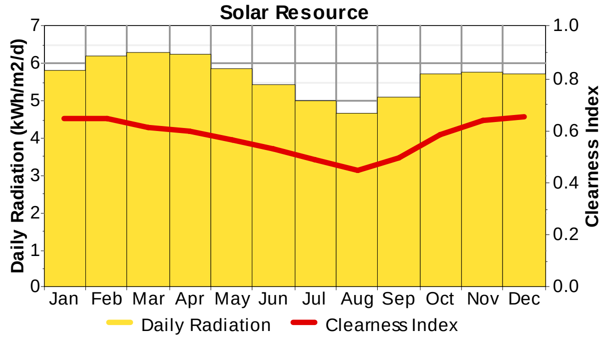

Figure 7. 2: HOMER (NASA) Solar Irradiation Potential of Ghana[57]
Source: NREL, 2006

The "scaled annual average"[58] resource available at this particular site, according to NASA, is approximately 5.6 kWh/m^2/day. Concerned that the data from NASA—which is likely derived from satellites as opposed to ground measurements—might be overly optimistic, a comparison was drawn from other data sources: NREL's Solar and Wind Energy Resource Assessment maps (see Figure 7.3) and JICA's data, provided by the GOG's Energy Commission (EC), presented in Table 7.1.

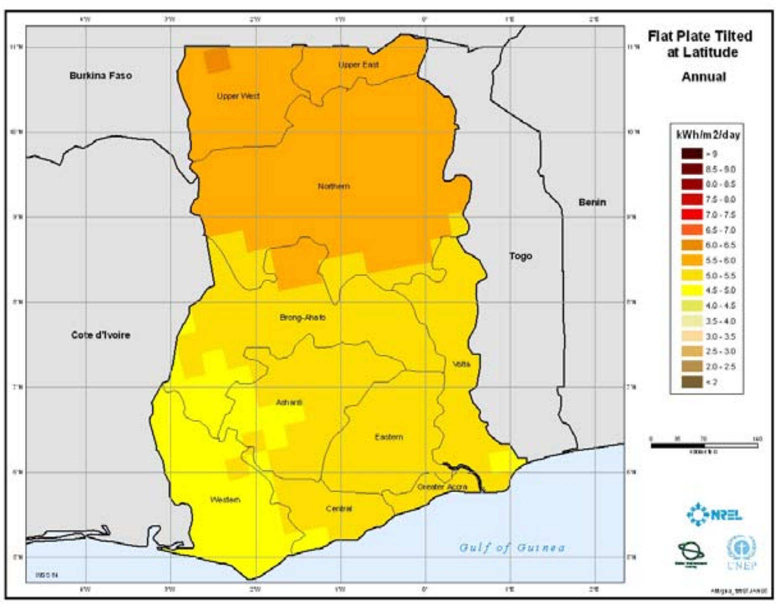

Figure 7. 3: NREL Solar Irradiation Potential of Ghana (kWh/m2/day)
Source: NREL

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[57] The "clearness index" indicates how much extraterrestrial radiation available at the specified location is attenuated by the atmosphere (Lambert, 2004).

[58] The scaled annual average parameter defaults to the corresponding annual average resource (kWh/m^2/day) available at the site, and was created to facilitate sensitivity analysis (Lambert, 2004).

Flat plate tilted solar irradiation values provided by NREL, constructed by combining both direct normal and horizontal irradiation values, indicate a solar resource availability of 5.5-6.0 kWh/m^2/day in the northern region. The Energy Commission indicates a discrepancy between ground and satellite irradiation values for this region as well; yearly averages are 4.42 and 5.67 kWh/m^2/day, respectively (JICA, 2006). Due to the variation in the data reported, the additional sensitivities evaluated on this parameter are 5.0 and 6.0 kWh/m^2/day, demonstrating the influence solar variation has on system configurations and costs.[59]

7.5 Photovoltaic

Capital and replacement cost assumptions (see Table 7.2) were taken from JICA's report (2006 citing the Renewable Energy Service Project (RESPRO)) and converted from Euros using a $1.25 exchange rate (10/2006). Operation and maintenance costs[60] are difficult to assess, but are considered minimal with routinely maintained renewable energy systems (JICA, 2006). In this model a nominal fee was ascribed to this constraint ($20/yr for 500w).

Table 7. 2: Photovoltaic Array Constraints[61]

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
0.05	268	268	20
0.1	502	502	25

Lifetime (yr)	Derating Factor (%)	Slope (degrees)	Azimuth	Ground Reflectance (%)
25	88	9.47*	0*	20*

Source: NREL, 2006

Thus, total O&M costs were represented by including maintenance wages and miscellaneous costs into the software's "system fixed O&M costs" parameter. This will be discussed further in a following section (7.12), which details economic input assumptions. The twenty-five year lifetime of the PV array is considered industry standard. The derating factor is 88% and accounts for the added losses in the conversion of solar irradiance to energy by the PV array due to various factors (e.g. dust accumulation on the array and high ambient temperatures) that would result in the PV module producing less than its rated output. A number of sample

[59] See the section on sensitivity analysis (7.15) for details.
[60]To clarify, component O&M costs represent specific costs incurred for a particular component, but do not account for maintenance personnel wages; these are included in the "system fixed O&M cost" parameter. It is important to recognize that the software computes O&M cost independently from replacement, fuel and labor costs, which other resources appear to consider included in O&M costs. The distinction is not always clear as to how other resources define this term.
[61] All default software parameters will be denoted with an asterisk in tables.

HOMER models were evaluated, the majority of which represented this parameter with values ranging between 88%-92% (Lambert, 2003). Recognizing the potential negative impacts of climatic phenomena, such as harmattans (dust storm) and the high ambient temperatures exhibited in this region, a conservative value of 88% was decided upon. The slope (angle relative to horizontal) and azimuth (cardinal direction the panels are tilted) at which the PV array is articulated and mounted are calculated by the software. The slope default settings are 9.467°, corresponding approximately to the site's latitude. The software's default azimuth setting for all locations in the northern hemisphere is 0°, or due South.

7.6 DC Generator

Most standard AC diesel generators cost between $800 and $1,000 per kW (Jimenez and Olsen, 1998). HOMER's optimal configuration requires no more than a 1.5 kW generator for all cost effective system configurations.

Table 7. 3: Generator Cost Constraints

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1	1500	1500	0.12
1.5	2250	2250	0.15

Lifetime (hrs)	Minimum Load Ratio (%)
25,000	30*

Source: NREL, 2006

Unfortunately, few manufacturers offer diesel generators in this low power range category and they appear to be fairly specialized equipment. Even though it would be less expensive to use an oversized AC diesel engine, fuel efficiency drops considerably if engines are run at low loads (Jimenez and Olsen, 1998). For this reason, a small DC diesel generator was chosen. These tend to be considerably more expensive than their AC counterpart, but the performance is far superior with respect to fuel efficiency and reliability (Polar Power, 2006). Also, having a DC generator that can power the vaccine refrigerator and lights without the use of a converter will ensure that this critical load is met. As with other component cost assumptions that were substantiated from the RESPRO's data (2006), generators were never installed over the duration of the project, consequently, substantiating this assumption with the same method is not possible. Polar Power Inc. offers small 1-3.5 kW diesel generators outfitted with high quality proprietary DC alternators. According to their price list, Yanmar or Lombardini diesel engines fitted with a 1.5kW DC alternator demand a 50%-300% price premium over AC counterparts on a per kW basis. This would be prohibitively expensive for this application. Assuming price concessions for developing counties, which are often available, or the potential to outfit these engines with a less expensive DC alternator, only a 50% premium was added to generator cost assumptions.

Expected total maintenance costs over the generators' lifetimes are one to one and a half times the initial capital costs. Maintenance costs were derived in a rudimentary fashion by dividing the initial capital costs by the expected 25,000 hr lifetime of the generator (Jimenez & Olsen, 1998). Since this calculation only accounts for maintenance costs, to reflect both O&M costs, this number was multiplied by two for the 1kW generator, totaling $0.12/hr. (see equation below)

7.6.1 Generator O&M Cost Calculation

$$\frac{\$1{,}500}{25{,}000hr} \times 2 = \$0.12/hr$$

Using this same method with the higher initial capital cost of DC generators would unjustifiably burden these more reliable generators with unrealistic O&M costs and may subsequently skew results. To compensate for this, only an additional 25% was added to the O&M cost for the 1.5kW generator (US $0.15/hr) beyond O&M costs for the 1kW version. Concerned that this calculation method would overestimate the O&M costs associated with diesel energy production compared to other system components, thereby causing unintended underutilization of the generator by the software's optimization algorithms, sensitivity analysis was conducted on all O&M component costs.[62]

7.7 Diesel Fuel Characteristics

On a per kW basis, initial costs for diesel generators are inexpensive compared to those of PV; fuel costs are the primary expense when operating a generator. In Ghana the average price for diesel in 2005 was $0.65/liter, the price used in the simulation (Ackom, 2005).

Table 7. 4: HOMER Generator Fuel Constraints

Fuel Cost ($/L)	Fuel Intercept Coeff. (L/hr/kW)	Fuel Slope (L/hr/kW output)	Lower Heating Value (MJ/kg)	Density (kg/m^3)	Carbon Content (%)	Sulfur Content (%)
0.65	0.08*	0.35	43.2*	820*	88*	0.33*

Source: NREL, 2006

[62] See section 7.15.1

Although economies of scale have not been realized with Jatropha production, some studies have suggested that production costs are between \$0.45 and \$0.60/liter (Ackom, 2005). The previous study conducted on the feasibility of Jatropha as an alternative to diesel fuel suggests their similar characteristics when combusted as fuel in diesel generators, justifying utilizing Jatropha and diesel as proxies for one another—independent of emissions. Nonetheless, to maintain model realism, generator benchmark conditions were designed to emulate diesel fuel inputs[63], because this fuel can be procured with certainty, unlike Jatropha fuel (either esterfied or unesterfied), which requires supportive agribusiness and infrastructure that are currently nonexistent in northern Ghana.

7.8 Load Characteristics

AC and DC electrical configurations were considered for system modeling. Ultimately, the load was partitioned into two sectors, creating individual DC and AC loads. The DC sector will accommodate the lights and vaccine refrigerator, while the remaining amenities (e.g. radios and fans etc.) will remain on an independent AC sector. This will ensure reliable power to the critical amenities, that is, the vaccine refrigerator and the lights. Most common appliances require AC for operation, not DC. In realistic conditions, this will minimize the likelihood of power losses in the event of ancillary equipment failure in items such as the converter or battery bank. If ancillary equipment failure does occur, power from the generator or PV array can be fed directly into the DC sector to ensure this critical load is met, without reliance on ancillary equipment.

Load curve data derived from the needs assessment (discussed in Chapter 5) was converted into text files, representing hourly energy consumption for both the AC and DC sector loads for an entire year (8760 hrs). Once uploaded, HOMER creates an average load curve by extrapolating from the text file data to simplify calculations. This aggregate data is provided below in Figures 7.4 and 7.5, and Tables 7.5 and 7.6.

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[63] All fuel inputs were taken from the HOMER software's default diesel settings with the exception of the "fuel slope", which was increased from 0.25 to 0.35 to represent slightly less efficient generators common in the developing world. Sensitivity analysis was also conducted on this parameter, detailed in section 7.17.3.

7.8.1 DC Load Profile

Energy requirements for the DC load are fairly minimal, with a peak annual average of 1.08 kWh/day and an annual peak of 0.118 kW.

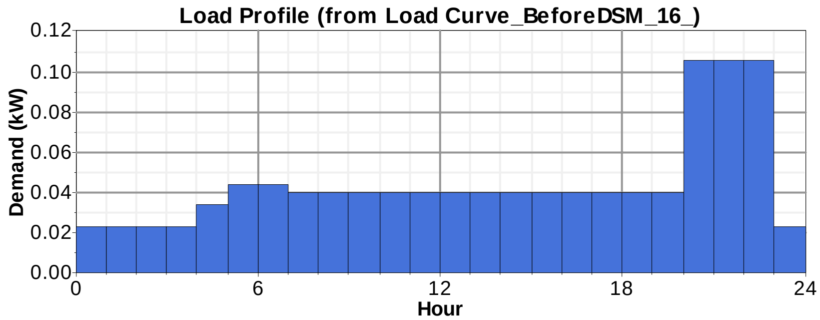


Figure 7. 4: DC Load Profile

Table 7. 5: DC Load Characteristics

Annual Average	Annual Peak	Load Factor	Daily Standard Deviation	Hourly Standard Deviation
1.08 kWh/day	0.118 kW	0.381	18.9%	50.2%

Source: NREL, 2006

The load factor, which is defined as the ratio of average load to peak load, is 0.381 for the DC sector, indicating that peak load requirements are approximately three times greater than average load requirements. Also, the daily and hourly standard deviations for this load are 18.8% and 50.2%, respectively.[64]

7.8.2 AC Load Profile

In contrast to the DC load profile, the AC load requires substantially more energy, having an annual average of 5.7 kWh/day and an annual peak of 2.6 kW. Since this load exhibits far more volatile fluctuations in average to peak load, the capacity factor is significantly smaller than that of the DC load at 0.0927.

[64] There are two different methods for calculating loads with HOMER. Modelers can either create an hourly load profile, as has been done in this analysis, or create average monthly and weekend load profiles. The authors chose the former method, as this is generally considered to be more representative of actual load conditions. When using the latter method, modelers are able to input their own added hourly and daily "noise"; with this method, some type of unknown stochastic noise pattern is always applied to the calculation. However, when uploading hourly load data, the added noise fields are calculated by HOMER and are not subject to editing. When checking the subsequent load profile, it does not appear as though randomness is added to calculations; rather, it appears to calculate standard deviation. As per a correspondence with Peter Lilienthal and Tom Lambert, HOMER software developers, they have verified that the noise parameter actually calculates standard deviation. The parameter is called noise to facilitate laypersons' understanding. However, in this analysis, it will be referenced as "standard deviation", not "noise".

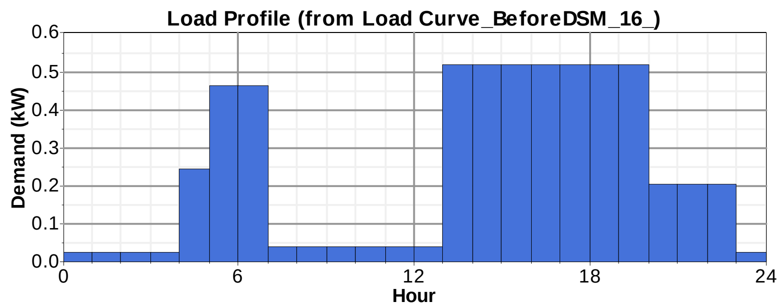


Figure 7. 5 AC Load Profile

Table 7. 6: AC Load Characteristics

Annual Average	Annual Peak	Load Factor	Daily Standard Deviation	Hourly Standard Deviation
5.7 kWh/day	2.6 kW	0.0927	79.2%	412%

Source: NREL, 2006

This indicates the peak load is approximately 11 times greater than the average load conditions. This is further exemplified by the noticeable increase in daily and hourly standard deviations, which are 79.2% and 412%, respectively. Combined daily energy consumption for both AC and DC loads is 6.78 kWh/day.

7.9 Converters

Converters (comprised of both an inverter and rectifier) allow for the system to transition between alternating and direct currents. DC current from the PV array can be directly fed into the batteries or the DC load. However, most appliances run off either sine wave or modified sine wave alternating current.

Table 7. 7: Converter Constraints

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
0.225	237	237	10
0.45	261	261	15

Inverter Lifetime (yr)	Inverter Efficiency (%)	Rectifier Capacity Relative to Inverter	Rectifier Efficiency (%)
15*	90*	80	85*

Source: NREL, 2006

In this application an inverter will be needed to modify the current from the DC generator, batteries, and the PV array to the AC load. Rectifiers function in the opposite way by converting DC back to AC. Presumably, the rectifier constraint above is omitted from calculations since this system lacks any AC energy production, rendering conversions from AC to DC obsolete unless surplus energy is sent to the AC load. Once again, pricing parameters were acquired from the RESPRO costs published by JICA (2006).

7.10 Batteries

Batteries have posed a significant problem to the long-term success of previous renewable energy (RE) projects undertaken in Ghana (JICA, 2005). Due to insufficient funds available for replacement batteries, substandard substitute batteries are sometimes utilized. This subjects other system components to operating outside specified tolerances and specifications, inadvertently causing the system to function inefficiently. With the expected lifetime of most RE systems being twenty-five years, batteries would need to be replaced several times over this duration. The lifetime of a battery is contingent on many factors, including brand specification, ambient temperatures, and charging and dispatch regimes. Dependent on these factors, average life expectancy can vary drastically, ranging between three and eight years (Jimenez & Olsen, 1998). The HOMER software projects the life expectancy of the batteries used in the benchmark simulation to be 7.86 years. This requires batteries be replaced approximately three times over the twenty-five years of the system's anticipated life.

7.11 Battery Costs and Specifications

Cost assumptions for batteries were taken from capital costs reported by the RESPRO. This project utilized 216 Ah (amp hour), deep cycle DC batteries. The HOMER software provides a number of preloaded batteries available for modeling purposes.

Table 7. 8: Battery Constraints

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	550	550	5

Hoppecke 4 OPzS 200 Vented lead-acid, tubular-plate, deep-cycle battery	
Nominal Voltage	200 Ah*
Nominal Voltage	2V*
Round Trip Efficiency	86%*
Min. State of Charge	30%*
Float Life	20 years*
Max. Charge Rate	1 A/Ah*
Max. Charge Current	40 A*
Lifetime Throughput	680 kWh*
Suggested Value	671 kWh*
Max. Capacity	234 Ah*
Capacity Ratio	0.374*
Rate Constant	1.08 1/hr*

Source: NREL, 2006

From these choices, a Hoppecke 4 OPzS vented lead-acid, tubular-plated, deep cycle battery was decided upon as an appropriate surrogate for modeling. A detailed listing of this battery’s specifications is provided above.

7.12 Economic Inputs

Ghana exhibits rather volatile economic conditions. Interest rates vary dramatically, ranging from 19.5% to 45% over the last decade (Government of Ghana, 2005). These rates can greatly influence optimal system configurations, because the HOMER software ranks each system by its net present cost (NPC).

Table 7. 9: Economic Inputs

Economic Inputs	
Annual Real Interest Rate	8%
Project Lifetime	25
System Fixed Capital Costs	-
System Fixed O&M Costs	$500/yr
Capacity Shortage Penalty	-

Source: NREL, 2006

Due to interest rate variability in Ghana, a wide range of rates was considered in the sensitivity analysis. However, analyses conducted by JICA and other similar studies typically represent interest rates at 8% as a baseline when performing financial calculations, independent of actual rates experienced in the country, in order to facilitate comparative analysis between results. All cost will be distributed over a twenty-five year project lifetime, which is considered typical for modeling renewable energy projects (Lambert, 2003). As stated earlier, O&M and replacement costs for renewable energy projects are notoriously difficult to assess, but are of critical importance for successful project deployment. The RESPRO's difficulty in recapturing O&M costs was compounded by their reactionary and piecemeal maintenance regime; they often conducted service only after a system had become defunct. However, according to JICA, renewable energy components are relatively maintenance free as long as routine service is conducted to ensure that the system is functioning optimally. For this reason, "system fixed O&M costs" were designed to provide sufficient funds for a full-time employee to manage maintain and provide security for the community center. This individual should be paid higher than average wages for the Mbanayili residents; average monthly income is 16.4 USD for men and 6.4 USD for women. (see Chapter 4) A dollar a day is nearly twice the average pay for villagers and should be ample enough to entice an individual with strong ties to the community to remain and perform these tasks. Thus, annual fixed system O&M costs for the benchmark scenario will be 500 USD, allocating approximately 365 USD to wages and the remaining 135 USD to be earmarked for future O&M costs. Concerned that benchmark assumptions for this parameter were overly optimistic, sensitivity analysis was conducted to determine how total lifetime system costs would increase if substantially more funds were required for wages or maintenance.

7.13 Other Constraints

The capacity shortage factor is a parameter in the HOMER software which allows the modeler to specify the maximum percentage of time the load(s) can go unmet. As the capacity shortage factor approaches zero the system becomes more reliable, but increasingly expensive due to the extra investment in the capital equipment necessary to meet that requirement.

Table 7. 10: Other HOMER Constraints

Constraints	
Maximum Annual Capacity Shortage	10%
Minimum Renewable Fraction	0%

Operating Reserve as a Percent of Load	
Hourly Load	10%*
Annual Peak Load	0%

Operating Reserve as a Percent of Renewable Output	
Solar Power Output	25%*
Wind Power Output	0%

Source: NREL, 2006

This system was designed to be considerably more reliable than the grid, which is prone to energy shortfalls due to rapidly increasing demand as well as insufficient and archaic infrastructure (Ackom, 2005). A 10% capacity shortage factor was used for the reference model, but the HOMER software often optimizes designed systems that are far more reliable than what is required by this constraint. The software allows for the modeler to specify a minimum renewable fraction, which essentially forces the model to incorporate the use of renewables independent of whether or not this is the most parsimonious approach for energy production. Since our load profile is based on hourly data, not averages, the need to specify significant added operating reserves that would compensate for unanticipated increases in load demands or decreased energy production did not seem critical. Specifying substantially larger operating reserves than are necessary to meet actual load conditions often requires additional installed operating capacity, potentially increasing capital costs beyond what is reasonably justifiable. Consequently, it was unnecessary to apply operating reserves larger than the software's default settings: solar operating reserves as a percent of renewable output are 25% and operating reserves as a percent of hourly load are 10%.

7.14 Benchmark Simulation Optimization Results

Figure 7.6 ranks feasible system configurations for benchmark conditions from lowest (27,429 USD) to highest (60,809 USD) net present cost (NPC). The software's engineers designed HOMER to rank feasible systems by NPC as opposed to the average cost of electricity (COE).

PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
0.50	1.5	5	1.5	LF	$ 7,747	$ 27,429	1.088	0.34	0.07	890	2,074
	1.5	5	1.5	LF	$ 5,373	$ 30,641	1.218	0.00	0.08	1,341	3,510
0.90	1.5		1.5	CC	$ 6,869	$ 41,944	1.675	0.32	0.09	1,955	6,069
2.50		30	2.0	CC	$ 28,660	$ 44,454	1.812	1.00	0.10		
	2.0		1.5	CC	$ 3,373	$ 60,809	2.401	0.00	0.07	3,568	8,760

Figure 7. 6: Benchmark Optimization Results
Source: NREL, 2006

They argue that it is a much more reliable and less biased metric for making these determinations, because it is a conventional mathematical formula does not require a number of arbitrary assumptions, unlike the COE, which requires several. For example: "if the system supplies less than 100% of the electric demand, should you calculate the cost per kWh of demand, or per kWh of load actually supplied?" (Lambert, 2005). Considering NPC, hybridization is the optimal system configuration for this scenario, consisting of: a 0.5 kW PV array; a 1.5 kW diesel generator; five 200 Ah batteries; and a 1.5 kW converter. This is also the optimal configuration when considering the COE as the determining criteria, which is US $1.09/kWh. Though this is substantially higher than the cost of grid electricity in Ghana, approximately 381 cedi/kWh (US $0.04/kWh at 2/07 exchange rate) under the lifeline tariff, if the actual cost of grid electricity generation (at least US $0.08/kWh) and extension were accounted for, this price would be more competitive (JICA, 2006). A 1996 Global Environmental Facility (GEF) report estimating rural electrification options for Ghana's Mamprusi East District, which appears to be a pre-study for the RESPRO, concluded that the cost of grid electrification would be US $1.3/kWh if each of the 1,661 households consume 0.03 kWh/day. (See Table 7.11) Furthermore, this analysis concluded that 834 households could also be electrified with a PV/Diesel hybrid system for US $1.3/kWh. This is not to suggest that direct comparisons can be drawn between this HOMER model and the GEF report, but rather that the results of this simulation comport with other similar research.

Table 7. 11: Costs of Options for Rural Electrification of Mamprusi District East (Ghana)

Measure\ Option	Grid Connection	Diesel mini-grid	PV/Diesel Hybrid	PV Home Systems
Costs per household[1]	US$2893	US$2966	US$2829	US$1706
Cost per kWh[2]	$1.3/kWh	$1.4/kWh	$1.3/kWh	$0.8/kWh
Emissions per household	2190 tonnes CO_2	2190 tonnes CO_2	547.5 tonnes CO_2	0 tonnes CO_2
Total Costs	$4,805,733 (1661 hh's)	$4,925,746 (1661 hh's)	$2,359,469 (834 hh's)	$1,410,642 (827 hh's)

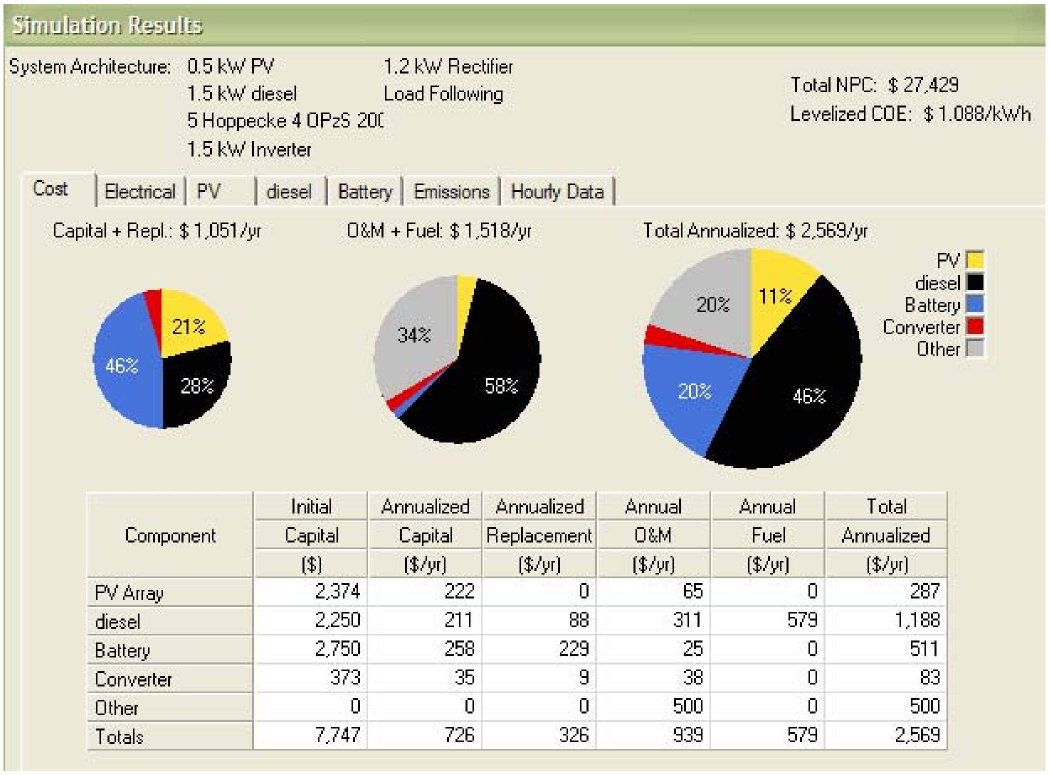
[1] The total costs per household (hh) are calculated on the basis of a 20 year project horizon, discounted at 10%.
[2] The costs per kWh assume that the household consumes 0.3 kWh per day under all options. This is likely the case for the PV options, but under the grid and mini-grid options, the consumption may rise above this level.

SOURCE: GLOBAL ENVIRONMENTAL FACILITY 1996

The software was specified to allow either a load following or cycle charging dispatch strategy for the generator. The optimal system configuration utilizes a load following strategy that only produces enough power to meet primary load requirements; secondary priorities, such as recharging the batteries, will be satisfied by the PV array. On the other hand, a cycle charging dispatch strategy operates the generator at full capacity if it is beneficial for ancillary purposes, every time it is initiated to meet load conditions. With this strategy, surplus power exceeding load requirements would be diverted to charging the batteries (Lambert, 2004). This dispatch strategy is not utilized in the optimal system configuration, likely due to the static and periodic nature of Mbanayili's load profile.[65] Adding standard deviation, a smaller capacity shortage factor, or added operating reserve requirements might increase the use of cycle charging dispatch in optimal simulation results.

The maximum capacity shortage of the model was intentionally restricted to 10%. As stated earlier, this parameter is only an upper limit and the software's optimal configuration indicates a 7% capacity shortage occurred in this scenario. This means that load demands are met 93% of the time, compared to the Ghanaian grid, which is notoriously unreliable, experiencing frequent energy shortfalls. Figure 7.7 details system costs from benchmark simulation results. As shown, initial capital costs are fairly evenly distributed amongst the PV array, the diesel generator, and the battery bank.

[65] This "static and periodic" nature is detailed in section 7.17.2.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	2,374	222	0	65	0	287
diesel	2,250	211	88	311	579	1,188
Battery	2,750	258	229	25	0	511
Converter	373	35	9	38	0	83
Other	0	0	0	500	0	500
Totals	7,747	726	326	939	579	2,569

Figure 7. 7: Benchmark Optimization Cost Results
Source: NREL, 2006

Annualized replacement costs for batteries are noticeably higher (US $229/yr) compared to other system components, accounting for the approximately ten replacement batteries that will be needed over the project's duration. With an anticipated life expectancy of 12.1 years, annualized replacement costs for the generator will be allocated for the purchase of two more generators. Unfortunately, with a 25,000 hour operating life[66], which is considered a fairly reasonable, if not an optimistic assumption, the last generator purchased will be operational for less than a year. No replacement costs are associated with the PV array since the project duration and the PV lifetime are both twenty-five years. Annual O&M costs are primarily attributed to operating the generator and maintenance wages. With the benchmark parameters, HOMER calculates a yearly diesel fuel usage of 890 liters at a cost of 579 USD per year.

[66] Some argue the modeling of generators in developing countries should compensate for the effects of poverty on replacement schedules; there is greater incentive to continue repairing system components as opposed to incurring replacement costs. However, the absence of data would have rendered any attempts to model this arbitrary and was omitted from assumptions.

Utilizing a conversion factor yielding approximately 2,000 L of Jatropha "feedstock"[67] oil per hectare, this lower limit land area requirement for the village to supply ample fuel to power the generator with blended or pure biodiesel would be approximately half a hectare (Fulton et al, 2006). (see equation below)

Jatropha Land Area Requirment Calculation:

$$\frac{890\,liters\,/\,yr}{2{,}000\,liters\,/\,hectare} = 0.445\,hectares\,/\,year$$

$$\frac{890\,liters\,/\,yr \times 5kg\,/\,liter}{2{,}000\,kg\,/\,hectare} = 2.225\,hectares\,/\,year$$

An upper limit land area requirement (2.225 ha/yr) was calculated using seed oil yields of 5kg/L (Henning, 2004) and land seed yields of 2,000kg/ha (Heller, 1996).

Figure 7.8 displays a typical daily power output (kW) of the PV array in the benchmark scenario correlated to hours of the day over a 365 day period. As shown, power output begins shortly after sunrise at 6am and ceases after sunset, around 6pm. Given that Ghana is equatorially situated, the hours corresponding to sunrise and sunset remain relatively static throughout the year. Power output during the day steadily increases in the morning and peaks around noon every day.

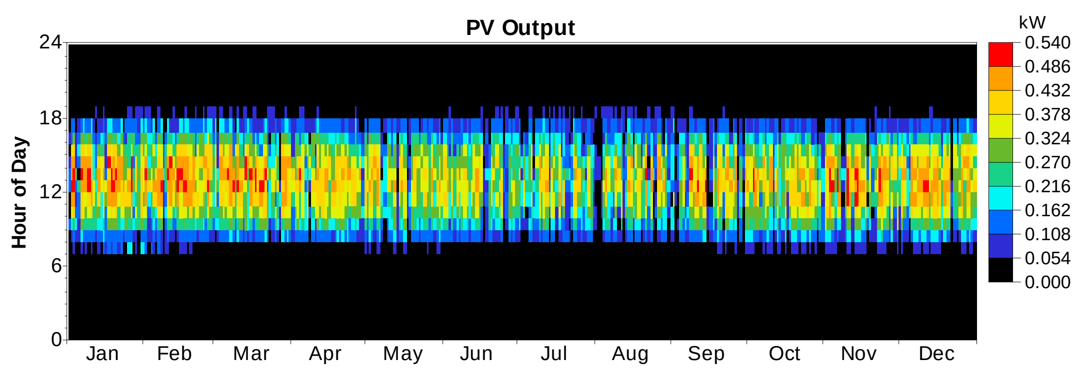


Figure 7. 8: Photovoltaic Output (kW) at Hour of Day vs. Day of Year
Source: NREL, 2006

Due to seasonal variation, power production from the array begins diminishing during the month of April and continually wanes until early August when more solar irradiation becomes available as the rainy season concludes.

[67] Though this conversion uses a "feedstock" as opposed to "fuel" oil figure, according to the National Biodiesel Board (2007) transesterification of vegetable oil to biodiesel can be achieved with 98% efficiency.

Figure 7.9 details the generator's daily power output over a given year. With the load following dispatch regime, power output from the generator will only be used to compensate for production shortfalls from the PV array to meet prescribed power demands. Contrasting this figure against the AC load profile (see Figure 7.5), where peak demand originates, there is a clear correspondence between peak AC demand (around 6:00 and from 13:00-20:00) and diesel generator output. Otherwise, generator usage appears to occur predominately in the early morning and late evening during the absence of solar irradiance.

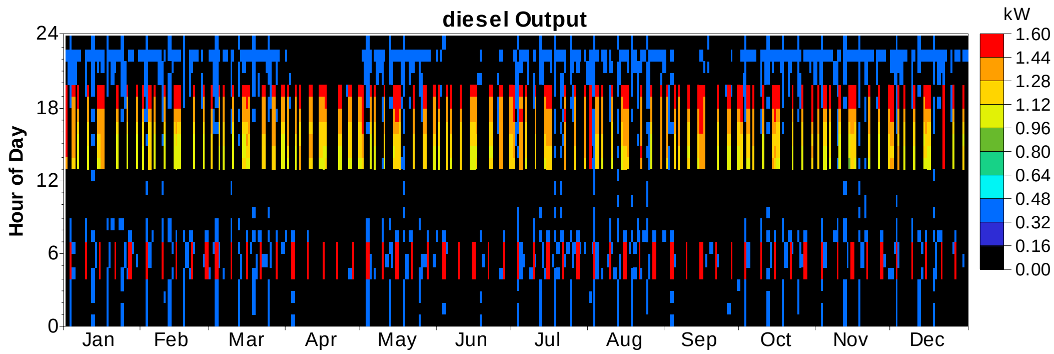


Figure 7. 9: Generator Output (kW) at Hour of Day vs. Day of Year
Source: NREL, 2006

7.15 Benchmark Simulation Sensitivity Analysis

Over the course of this research, several iterations of the model were constructed and certain parameters were observed to have significant impacts on optimal system configuration and cost requirements. These were determined to be ideal parameters for conducting sensitivity analysis. Table 7.12 provides both the original and the sensitivity parameters applied to the benchmark HOMER model.

Table 7. 12: Sensitivity Values

Parameter	Benchmark	Sensitivities		
AC Load (kWh/d)	5.78	0	3	6
Global Solar (kWh/m^2/d)	5.66	5	6	-
Diesel Price ($/L)	0.65	0.45	0.85	-
Interest Rate (%)	8	15	20	-
Max. Annual Capacity Shortage (%)	10	0	20	-

Source: NREL, 2006

The DC load provides power to essential amenities, namely the vaccine refrigerator and lighting fixtures. Therefore, sensitivity analysis on this parameter was omitted because it is required for critical health services. The AC load, however, not only contributes to peak load demands and substantially higher power requirements of the system as a whole; it is also comprised of numerous nonessential amenities. Sensitivities were evaluated on this parameter to determine how variances (ranging from 0 to 6 kWh/d) in this load would affect total system costs and optimal system configurations. As mentioned earlier, there are significant disparities in the reported availability of solar irradiance for the region. Available annual average solar irradiance imported from NASA and applied to the benchmark model (5.66 $kWh/m^2/d$) was likely determined from satellites, not ground measurements. A value of 5.42 $kWh/m^2/d$ is provided by the Ghanaian Energy Commission as the anticipated annual average solar irradiance available in northern Ghana. To evaluate the impacts of anomalous reductions in available solar irradiation, a range of 5.0 to 5.66 $kWh/m^2/d$ was analyzed. Baseline diesel fuel costs were taken from prices observed in Ghana, which were approximately US $0.65/L in 2005 (Ackom, 2005). To determine the significance of fuel price fluctuations from either diesel purchases or Jatropha production, a range of US $0.45/L to $0.85/L was evaluated. Interest rates in Ghana are volatile and significantly higher than the 8% figure used as a benchmark constraint. Since interest rates are a major determining factor in NPC calculations and, subsequently, HOMER's optimal system ranking, interest rate sensitivities were run ranging from 8% to 20%. The intent was to construct a power supply for the community center far more reliable than that of the Ghanaian grid. A 10% maximum capacity shortage factor was considered in the benchmark constraint. An alternative factor of 20% was also appraised, given concern that this reliability may inflict prohibitively expensive equipment costs.

Results from this analysis on the whole indicate that hybridization (red) is the optimal system configuration, independent of plausible variation in initial model parameters. The vast majority of sensitivities had marginal influence on system costs and hence optimal configuration types. Only sensitivities that produced dramatic affects on either cost structures or configuration types will be discussed in detail. In the simulation, depicted in figure 7.10, all parameters are restricted to baseline conditions except interest rates (y-axis) and AC load demands (x-axis).

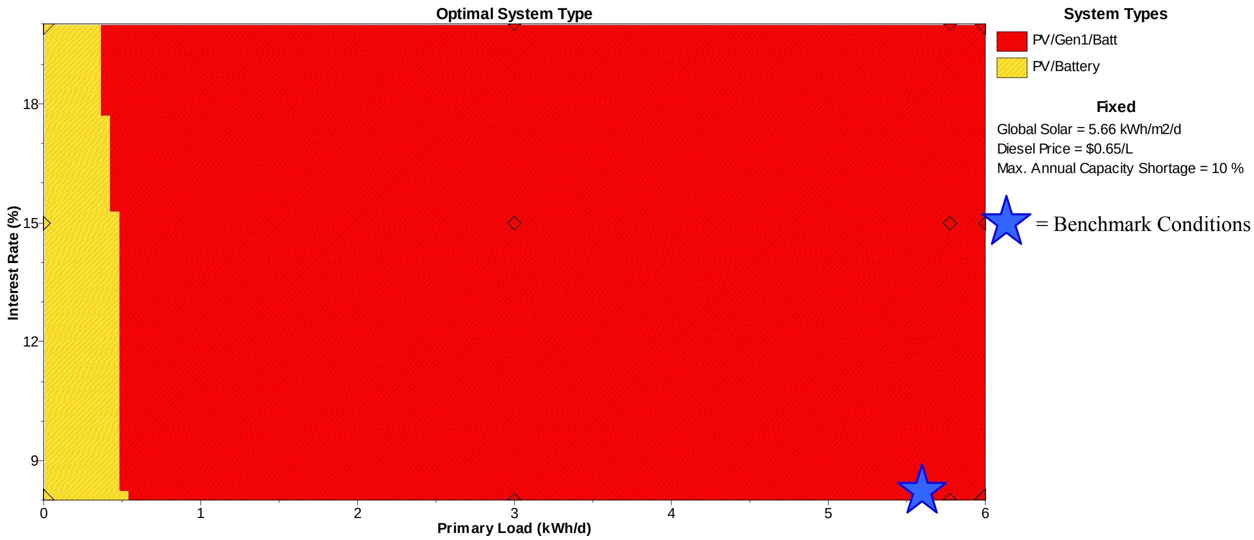


Figure 7. 10: Sensitivity Results: Interest Rates vs. AC Load
Source: NREL, 2006

For reference, the intersection of all benchmark parameters is represented by the star. These results illustrate the conditions in which a PV system without a generator would be optimal (yellow). Substantial reductions in power demands from the AC load, below 0.5 kWh/d, would be necessary in order to justify the construction of a PV only generation system. System configurations in this hypothetical scenario are relatively insensitive to interest rates. According to this analysis, AC load requirements remain the most influential exogenous constraint. Despite the interest rate's negligible impact on optimal system configurations, it does, however, have dramatic effects on the system's total NPC. Observations from Figure 7.11 show a reduction in NPC from the benchmark of $27,429 (8%) to $16,154 (20%) as interest rates increase.

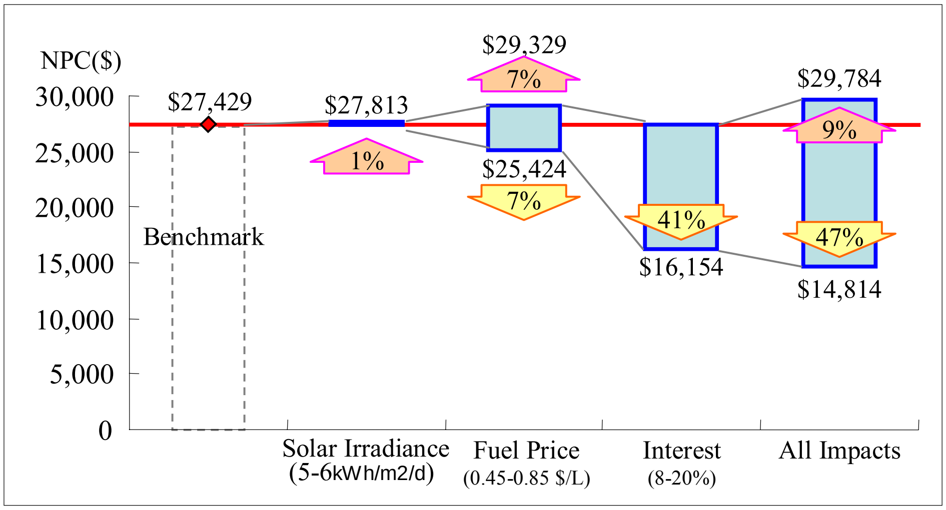


Figure 7. 11: Sensitivity Results: Exogenous Constraints
Source: NREL, 2006

This is not surprising, as interest rates influence NPC calculations dramatically, dictating how heavily a stream of payments are discounted from one period to the next (see equation below); they remain the most critical exogenous factor, with respect to total system costs.

Net Present Cost Calculation:

$$NPC = C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+r)^3} \ldots\ldots \frac{C_n}{(1+r)^n} = C_0 + \sum_{n=1}^{t} \frac{C_n}{(1+r)^n}$$

Whereby, NPC = net present cost

C = total annual costs in any period

r = interest rate

n = project lifetime

Interest rates do not influence optimal system configurations significantly, despite their dramatic impact on NPC, because the effects are evenly distributed amongst capital, replacement, and O&M costs equally, with one exception. In these simulations the PV array has the exact anticipated lifetime as the system as a whole (twenty-five years), consequently, NPC calculations do not include PV replacement costs; PV costs (besides O&M, which is minimal) are entirely encapsulated in the initial capital costs that are unaffected by interest rates. However, as interest rates increase, there is greater incentive to postpone purchases because the future is discounted so heavily. This tends to handicap the PV array costs, which are almost entirely accounted for as initial capital, more so than the total cost for a generator, which is largely comprised of fuel costs that can be deferred over time. With high interest rates, the ability to defer incremental fuel payments over time makes the generator more affordable. As previously discussed, the total NPC is dramatically reduced from $27,429 with an interest rate of 8% to $16,154 with a 20% interest rate. As shown in Figure 7.12, differences in initial capital costs are negligible, entirely justified by the 0.1 kW reduction in PV array capacity.

Primary Load (kWh/d) 5.78 Global Solar (kWh/m2/d) 5.66 Diesel Price ($/L) 0.65 Interest Rate (%) 8

Double click on a system below for simulation results.

PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
0.50	1.5	5	1.5	LF	$ 7,747	$ 27,429	1.088	0.34	0.07	890	2,074

Primary Load (kWh/d) 5.78 Global Solar (kWh/m2/d) 5.66 Diesel Price ($/L) 0.65 Interest Rate (%) 20

Double click on a system below for simulation results.

PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
0.40	1.5	5	1.5	LF	$ 7,279	$ 16,154	1.383	0.28	0.07	947	2,241

Figure 7. 12: Optimization Results: Interest Rate Variance (8-20%)
Source: NREL, 2006

As the generator becomes more affordable, and in compensation for decreased PV capacity, there is an increase in yearly fuel use and operating hours of the generator. This analysis further substantiates the utility of hybridization, especially in countries where there is economic volatility. The flexibility allows for incremental adjustments in cost effective energy production dependent on variations in economic conditions over time. If economic conditions were drastically altered after the project's inception, rendering one energy production method superior to another, two options are available with hybridization: more fuel could be purchased to augment generator operating hours or more capacity in the PV array could be installed.

7.15.1 Cost Factor Sensitivity Analysis

Determining operations and maintenance (O&M) costs poses formidable challenges and should be evaluated carefully. These costs are often drastically underestimated and many case studies have attributed the abandonment of similar projects to the lack of long-term financial support for O&M (Ahiatau-Togobu, 2003). The RESPRO in northern Ghana has endured this problem to a degree that threatens the project's long-term viability. Though the RESPRO collects fees (lifeline tariff is $2/month) for service, the high transaction costs associated with fee collection over the project's widely dispersed customer area exceeds funds recaptured from the tariff that are earmarked for O&M. Battery replacements account for the majority of the O&M costs incurred by this project. The disparity between fees captured by the tariff and the actual O&M costs is directly attributable to the project's rapidly deteriorating fiscal health; consequently, the project is in dire need of redevelopment and downsizing to remain solvent (JICA, 2006). Personnel are also needed to maintain optimal performance of the system; PV array surfaces need to be continually cleaned and tilt angles adjusted. To represent long-run fiscal stability and project success, replacement, O&M, and fuel costs need to be evaluated. Figure 7.13 displays the optimization results conducted on these integral financial aspects (with the exception of fuel costs, which were evaluated in the previous section). Baseline assumptions were contrasted against various cost factors that were applied to initial constraints. This feature functions by multiplying the original baseline constraints by any factor of the modeler's choosing. The purpose of this is to examine the influence that variation in individual component costs will have on total system NPC, and thus the optimal system configurations. Also, there is concern that benchmark diesel generator initial capital, replacement, and O&M costs were overestimated; the aim here is to determine under what cost constraints a stand-alone generator would become economically viable, and hence optimal.

PV O&M Multiplier 4 | Gen1 Capital Multiplier 0.5 | Gen1 O&M Multiplier 0.5 | Batt. Capital Multiplier 1 | Batt. O&M Multiplier 1

Double click on a system below for simulation results. ◉ Categorized

PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
	1.5	5	1.5	CC	$ 4,248	$ 25,240	0.997	0.00	0.07	1,342	3,255
0.40	1.5	5	1.5	LF	$ 6,154	$ 25,368	1.003	0.27	0.07	994	2,409
0.40	1.5		1.5	CC	$ 3,404	$ 35,329	1.411	0.16	0.10	2,226	6,849
	2.0		1.5	CC	$ 1,873	$ 45,893	1.812	0.00	0.07	3,568	8,760
2.50		30	2.0	CC	$ 28,660	$ 52,941	2.157	1.00	0.10		

Figure 7. 13: Optimization Results: Cost Factor
Source: NREL, 2006

In HOMER the capital cost multipliers were correlated to replacement costs, because the same figures were used for both, ensuring they will be altered simultaneously. In short, these tests indicate that quadrupling PV O&M cost while halving all generator costs (capital, replacement and O&M) influences optimal system configurations; in this scenario a standalone generator becomes the primary source of energy production. However, if the same conditions are applied, with the exception of reverting the capital and replacement costs for the generator back to benchmark parameters, hybridization once again becomes the optimal system configuration, because component O&M costs in the model account for a small fraction of the total system cost. This is depicted in Figure 7.14, in which a standalone generation system is only optimal in limited conditions.

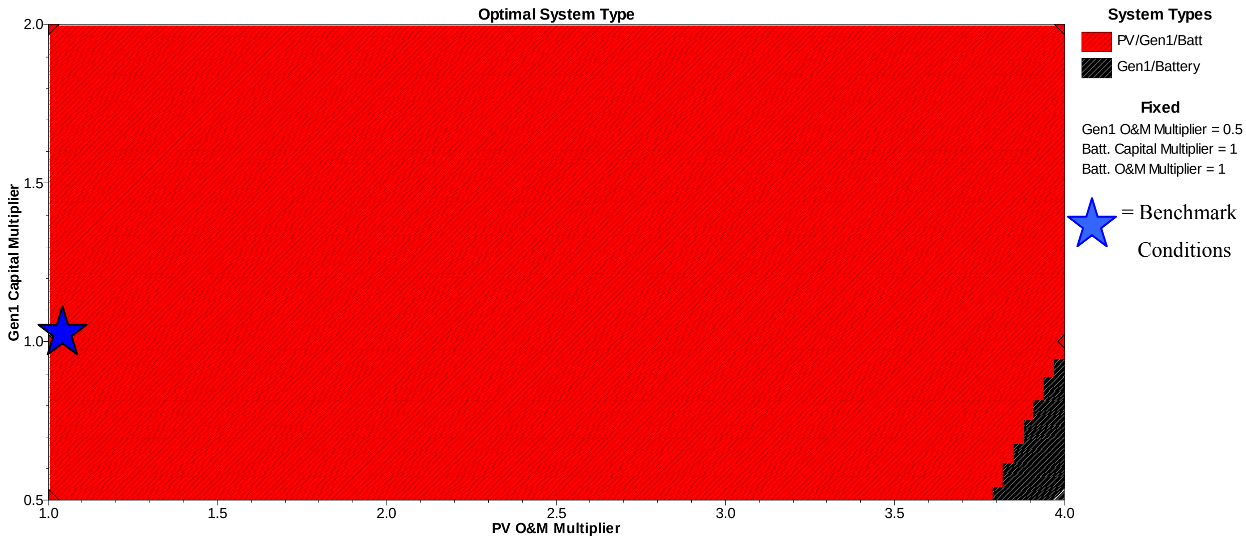


Figure 7. 14: Sensitivity Results: Cost Factor
Source: NREL, 2006

For this to occur, three criteria must be met: (1) the PV O&M multiplier must exceed 3.8; (2) the generator capital/replacement cost multiplier must be between 0.5 and 1; and (3) the generator O&M multiplier must be set to 0.5. It appears that unless benchmark cost assumptions are significantly underestimated for the PV array (by a factor of 4) and overestimated for the generator (approaching a factor of 2), hybridization remains the optimal system configuration.

7.16 Alternative Models

7.16.1 AC Only Load Profile Simulation

The bifurcated load system configuration described in the benchmark simulation is considered ideal, but is not always practical, depending on the availability of system components. There is concern that specialized renewable DC vaccine refrigerators, lighting fixtures, and bulbs might not be easily procured in northern Ghana. Therefore, an alternative HOMER model was created to examine how optimization results would be impacted if DC components were unavailable, requiring the use of only AC appliances. Another HOMER simulation was conducted to determine how optimal system configurations would adjust if this situation occurred. (see Figure 7.15)

				PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
				0.50	1.5	5	1.5	LF	$ 7,747	$ 27,429	1.088	0.34	0.07	890	2,074

				PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
				0.50	1.5	5	1.5	LF	$ 7,747	$ 27,778	1.101	0.33	0.07	911	2,144

Figure 7. 15: AC/DC (Top) vs. AC Only (Bottom) Load Configuration
Source: NREL, 2006

An AC only text file was created and uploaded to HOMER by combining both the benchmark AC and DC hourly load profiles. The results of this simulation indicate that in the event DC components are unavailable, an AC only configuration will have negligible impact on optimal system configurations—hybridization remains optimal—and total NPC. The only apparent difference between the results is a slight increase in the generator operating hours from 2,074 in the benchmark simulation to 2,144 in the AC only version.

7.16.2 Fixed System O&M Analysis

Initial "fixed system O&M" costs used in benchmark model conditions ($500/yr), to provide a wage for maintenance personnel and miscellaneous repair costs may be overly optimistic. Since these costs are evenly distributed over total system costs and are not attributed to any particular component, optimal system configurations remain unaffected by manipulating this parameter. However, fixed O&M costs will contribute directly to total annualized costs and NPC, independent of which optimal system configuration is analyzed.

7.17 Conclusions and Model Limitations

Overall the authors are pleased with the design of the various HOMER simulations used throughout this analysis, especially considering the constrained time, geographic, and monetary confines under which this analysis was conducted. Though painstaking efforts were taken to construct the models in a pragmatic fashion, over the course of our analysis certain limitations were identified and are enumerated below.

7.17.1 Generator Costs

Costs for all system components were taken from the RESPRO, and given their extensive experience electrifying households in Northern Ghana using renewable energy systems, these assumptions were deemed adequately substantiated. However, the RESPRO never utilized generators in any of their rural electrification systems. Consequently, generator cost assumptions were taken from a number of other sources that may not reflect the actual cost incurred if a generator were to be procured in Ghana. This is also compounded by the fact that benchmark simulations utilized a DC generator as opposed to the more common AC variety. To further enhance the model's realism, determining the actual capital, operation, and maintenance costs associated with purchasing and operating a specific generator in Ghana would be valuable, despite the fact that sensitivity analysis conducted on all of these assumptions indicated that their influence on optimal system configurations was minimal.

7.17.2 Applying Standard Deviation (Noise) to AC and DC Load Profiles

As mentioned earlier, standard deviation (or stochastic variance) was not applied to our load profiles. Profiles were derived by adding all appliance power consumption associated with a particular activity for a given hour of the year, and then compiling this hourly data for all 8,760 hours in a year. This results in periodic and homogeneous peaks and troughs in the load profile, which is not representative of the more nuanced consumption that would likely occur. Incorporation of this randomness would be more indicative of reality. Consequently, peak load demand and thus total system costs would be expected to increase slightly.

7.17.3 Fuel Curve Assumptions (Jatropha and Diesel)

HOMER's default diesel fuel efficiency curve was used in this analysis with the exception of the "fuel slope", which was increased from 0.25 to 0.35 (max. efficiency of 32% to 24%, respectively) to represent the often antiquated and less efficient equipment that is common in the developing world (see Figure 7.16). Furthermore, evidence suggests Lister engines run on Jatropha vegetable oil have a "brake thermal efficiency [of] 25.6% (Kumar, 2001).

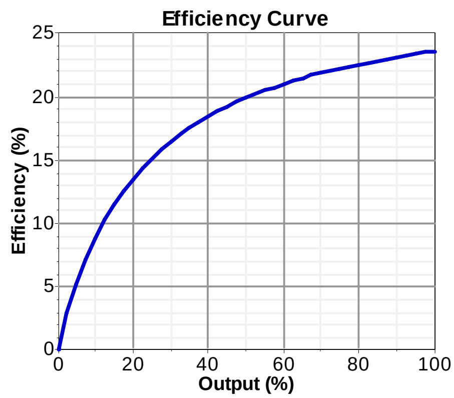


Figure 7. 16: Diesel Fuel Efficiency Curve
Source: NREL, 2006

Nonetheless, modeling a particular generator with a specified fuel efficiency curve would yield more accurate results. Future analysis should take this into account. Analysis with HOMER's default "fuel slope" parameter was found to have **no** significant impact on optimal system configurations, although slightly less fuel was consumed on a yearly basis (from 890 liters to707 liters) than benchmark conditions. (see Figure 7.17)

	PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
	0.50	1.5	5	1.5	LF	$ 7,747	$ 27,429	1.088	0.34	0.07	890	2,074

	PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
	0.50	1.5	5	1.5	LF	$ 7,747	$ 26,157	1.037	0.34	0.07	707	2,074

Figure 7. 17: Generator Efficiency Impacts on Optimal System Configuration
Source: NREL, 2006

Significant evidence exists supporting the use of Jatropha biodiesel as a proxy for diesel. However, initial attempts to model unesterifed Jatropha oil in a Lister-style engine were not successful because of the difficulty in determining an appropriate fuel efficiency curve for this obscure biofuel and engine. The ability to accurately model the combustion of Jatropha biofuel (as opposed to biodiesel) in a Lister-style engine would help illuminate the technical and financial feasibility of supplying rural electrification with these simple, inexpensive engines.

Chapter 8: Financially Sustainable System Modeling - Simulation

8.1 Background for Sustainable System Modeling

In the previous chapter, an optimum electricity generation system for Mbanayili was constructed based on people's preference for electricity. The annual cost and initial cost of the system were 2,569 USD and 7,749 USD, respectively. To keep this generation system working, villagers have to cover these costs by themselves or have to get financial support from the government. In other words, the financial capability of the village is an important factor for the electrification project to be a success.

In Chapter 8, this study analyzed the financial feasibility of sustaining the optimum system first. The analysis showed that the current system was not sustainable in terms of the village's limited financial resources. Consequently, as the next step, the study explored ways to curtail the electricity consumption of the community center to reduce cost, and conducted a cost simulation based on the more restricted consumption patterns. As a result, the simulation suggested several sustainable generation systems. Then, in deciding the optimal system for Mbanayili, the study analyzed the influence of reduced consumption on villagers for each system, and proposed the optimal sustainable generation system for the village.

8.2 Sustainability Rule

The unsuccessful outcomes by the past electrification projects (see Chapter 2) suggest that mechanisms to cover electricity generation costs have to be developed when a village is first electrified. The failures of the projects were mainly due to the inability to cover electricity generation costs for sustaining the generation systems. As discussed in Chapter 2, because the financial resources of the government of Ghana are limited, the government cannot cover all rural electrification costs. Thus, consumers need to share these costs if they intend to be electrified. However, the villager's financial capability is also not enough to allocate a substantial fraction of their meager income to electricity costs (Mbanayili's monthly average income is 118,803 cedis (13.2 USD)). Therefore, under these constraints, for the success of an electrification project, it must be designed in a manner that allows the villagers to cover all costs. In this respect, a member in the Japan International Cooperation Agency (JICA) suggested (a member of JICA, Pers. Comm., 2006), "Foreign investors or international development organizations such as the JICA may be able to cover the initial (capital) costs. However, at least the operation cost needs to be covered by local people for sustaining a generation system." In his opinion, the operation cost, which is generated periodically for a long time, cannot depend on foreign organizations' funds, because it is impossible for the organizations to indefinitely support villages and generation systems.

In making a feasible plan and providing a financially sustainable generation system, this study set a sustainability rule, based on the JICA's comment, which states that **the annual expenses of a generation system must be covered by villagers**. In this chapter, the study aims to design a generation system whose cost can be covered by Mbanayili villagers and thus satisfies this rule.

8.3 Willingness-to-Pay (WTP) Analysis

8.3.1 Data Screening

To design a sustainable generation system, villagers' potential to pay electricity cost was analyzed. First, interviewees were asked how much they are willing to pay for electricity use in the community space. Their willingness-to-pay was quite high (3.06 USD (27,643 cedis) per month per person, accounting for 23.2% of their income). One of the reasons is that villagers have high expectation for electrification, as a way to improve their standard of living. Another probable reason is that due to the low level of mathematical ability, villagers did not accurately understand how much they can pay from their income for electricity. Actually, 8.3% of the interviewees answered they are willing to pay for electricity more than their incomes.

To compensate for such errors, the actual affordability of electricity by villagers had to be analyzed to correctly calculate their willingness-to-pay. To begin with, to get the conservative value of the willingness-to-pay, women's data were not used, because women's life depends heavily on men's income (Doss, 2005). For example, current energy expenses of almost all women interviewees (36 out of 39) could not be covered by their individual incomes. Thus, women's willingness-to-pay is also based on their family income from husbands and fathers. In addition, according to the local volunteer for this project (Alhassan, Pers. Comm., 2006), women have less power to decide what to buy in family. In this Islam dominant region, men usually have the right to decide. Therefore, women's answers might not accurately represent the willingness-to-pay for electricity because men (husbands or fathers) may be opposed to pay. For these reasons, this study assumed that only men pay for electricity.

In addition, the affordability of electricity for men was examined using collected data in interviews. As equation (a) shows, at least villagers' income needs to be equal to or lower than the sum of pre-existing energy cost for kerosene, fuelwood and charcoal, and willingness-to-pay in order for the people to be able to pay the amount of willingness-to-pay from their income. In other words, the data that passes this affordability check can be considered credible. Only the willingness-to-pay data of villagers that could satisfy the equation was used in this study.

Affordability Check:

(a): Income ≥ (Willingness-to-Pay for Electricity - Pre-Existing Energy Cost)

43% of men's data passed this check. Next, using that data, the total willingness-to-pay of Mbanayili was estimated.

8.3.2 Willingness-to-Pay Estimation for Mbanayili

The average of these forty men's willingness-to-pay was 27,700 cedis per month (3.08 USD). This value, however, cannot be directly applied to all male villagers to estimate the total willingness-to-pay of Mbanayili, because the distribution of the sampled population was skewed through the affordability check. As seen in Figure 8.1, 60% of the sampled men belong to the highest income group (more than 150,000 cedis per month).

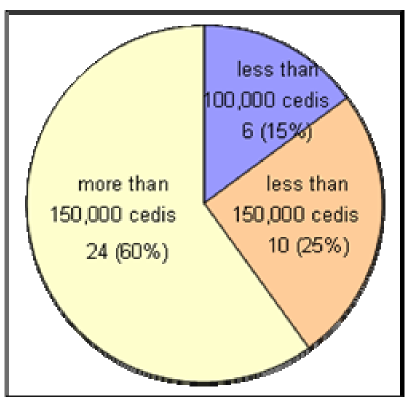


Figure 8.1: Income Distribution of the Sampled People (Number of Persons, %)

To adequately reflect the income distribution of Mbanayili, the willingness-to-pay data was averaged by income group. Figure 8.2 shows the percentage of willingness-to-pay in income for each group. According to the figure, people with higher income are more willing to pay for electricity.

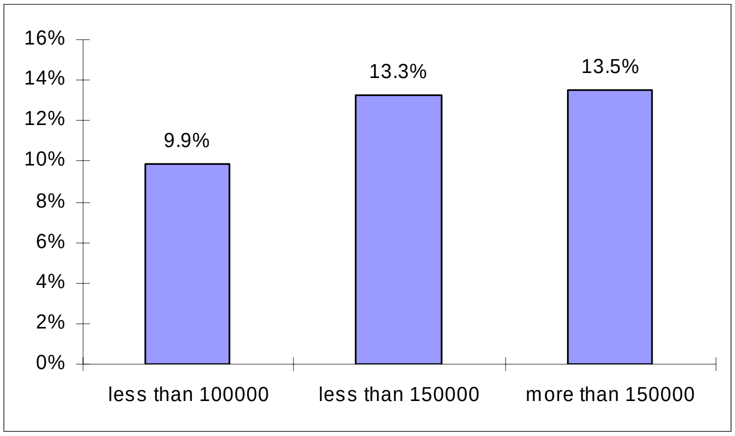


Figure 8.2: Percentage of Willingness-to-Pay for Electricity in Income by Income Group

Table 8.1 shows the calculation of the average willingness-to-pay per person for Mbanayili. First, the average willingness-to-pay by income group (C) was calculated using the percentage of willingness-to-pay in income (A) and the average monthly income for each income group (B).

(C) = (A)*(B)

Then, (C) was weighted by the income distribution of Mbanayili (D).

(E) = (C)*(D)

The total of the weighted willingness-to-pay for each income group is the average willingness-to-pay per person in Mbanayili, which is 2.09 USD (18,776 cedis) per month.

Table 8. 1: Calculation of Average Willingness-to-Pay per Person

Income Group	(A) % of WTP in income	(B) Average monthly income (cedi)	(C) Average WTP (cedi)	(D) Weight (Men's share by income group)	(E) Weighted WTP
less than 100,000	9.9%	61,565	6,095	44%	2,687
less than 150,000	13.3%	116,597	15,507	26%	4,002
more than 150,000	13.5%	297,380	40,146	30%	12,087
				Average WTP(cedi) per person	18,776
				Average WTP(USD) per person	2.09

The monthly willingness-to-pay of Mbanayili (2.09 USD) is greater than that of the northern area's average (1.5 USD (14,000 cedis)) (JICA, 2006), according to JICA's research. In this regard, the volunteer explained two possible reasons (Alhassan, Pers. Comm., 2006). First, Mbanayili is somewhat wealthier than other villages. Since the village is close to markets in Tamale, villagers have more chances to sell crops and products at a higher price directly in the markets without paying shipping cost. Second, Mbanayili villagers have greater familiarity with electricity and electrical appliances due to their close proximity to an electrified city, Tamale (see Chapter 4). Compared to other northern villages, they could easily perceive the benefit from electricity use.

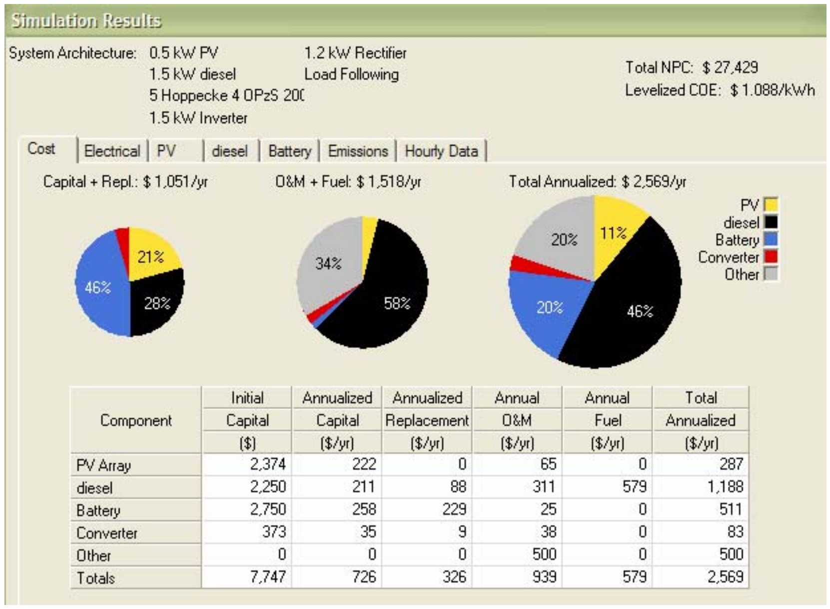
Lastly, the willingness-to-pay value per man of Mbanayili was converted to the value for the community center. Supposed there are 1,165 men in the village who are of working age[68] and can pay electricity cost, the village's potential for paying the cost was 2,431 USD per month (21,882,436 cedis, 2.09 USD/person multiplied by 1,165 persons). Since only 100 villagers can use the center at the same time because of the center's limited capacity (see Chapter 3), the willingness-to-pay of Mbanayili for the community center is 60 USD per month or 720 USD per annum (2,431 USD/month*(100 consumers/ 4,050 residents)).

8.4 Sustainability Check

Using the willingness-to-pay data, the sustainability of the optimum system, developed in Chapter 7 (called "benchmark model" in this chapter), was examined.

The HOMER showed three kinds of annual costs - replacement cost, operation and maintenance cost (O&M) and fuel cost - for the benchmark model (Figure 8.3). The sum of these costs (1,844 USD) was more than twice the sustainable level (720 USD). The people's willingness-to-pay was insufficient to even cover O&M costs (939 USD). Thus, the benchmark model does not satisfy the sustainability rule. To reduce the costs sufficiently enough to comport with community actual ability to pay for electrical services, alternative measures need to be taken.

[68] Working age was defined as the age between 15 and 64 years old in this study. As the share of male workers in Ghana population, 28.8 percent (Theodora.com: http://www.theodora.com/wfbcurrent/ghana/ghana_people.html) was used for the calculation.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	2,374	222	0	65	0	287
diesel	2,250	211	88	311	579	1,188
Battery	2,750	258	229	25	0	511
Converter	373	35	9	38	0	83
Other	0	0	0	500	0	500
Totals	7,747	726	326	939	579	2,569

Figure 8.3: Costs of the Benchmark Model

8.5 Demand Side Analysis

8.5.1 Necessity of Cost Reduction from Demand Side

The development of cost reduction measures can be approached from both supply and demand perspectives. The supply-side approach is to minimize the cost of generation system based on the given amount of electricity use and electricity consumption pattern. In this study, the HOMER has designed the least cost generation system based on the results of the potential demand analysis (Chapters 5 and 7). This means that the benchmark model reflects the most cost effective generation system under current assumptions regarding electricity needs. Thus, to get additional cost reduction to satisfy the sustainability rule, the demand-side approach also needs to be considered.

8.5.2 Introduction of Demand Side Management

Demand side management (DSM) has attracted much attention as a way to save electricity cost in both developing and developed countries (Loughran et al., 2004; Finamore et al. 2003 etc). The Natural Resource Defense Council (Finamore et al., 2003) defined DSM as a mechanism to promote energy efficiency through educational and/or incentive programs. According to Gellings et al. (1989), DSM measures that change the electricity consumption curve can be classified into six categories: 1) peak clipping, 2) valley filling, 3) load shifting, 4) strategic conservation, 5) strategic load growth, and 6) flexible load shape. From this, two main strategies for cost reduction could be identified. The first strategy is to decrease electricity consumption at certain time intervals, such as peak load time, or employment of a more pervasive strategy curtailing energy usage throughout all time intervals. The size of required generation capacity is based primarily on the amount of peak load consumption. Thus, reducing peak load by DSM programs such as setting higher electricity prices corresponding to these intervals can allow generation system downsizing, leading to a decrease in requisite capital and maintenance costs. In addition, energy-efficient technologies can be used as measures for total cost reduction. For example, promoting energy-efficient appliances such as compact fluorescent lamps (CFLs) can significantly decrease electricity consumption through the year (for example, the substitution of CFLs for incandescent lamps can reduce one third of the peak load in Bombay, Weizsacker et.al., 1998). These aspects are considered as fundamental measures for the DSM. The second strategy for cost reduction is to shift the time of electricity consumption from peak periods to off-peak periods. Reducing peak load by time shifting can also contribute to cost reductions. The advantage in this strategy is that consumers do not need to decrease total electricity consumption in order to reduce costs, but merely redistribute their consumption to create a more homogeneous load profile.

This study explored measures to decrease electricity cost from the first strategy, reducing electricity consumption, but did not address the second strategy, time shifting, because of the limited time availability of interviewees. To analyze the impact of the time sifting strategy, more data are needed such as the sensitivity of people's benefit regarding time shifting for each activity, thus many more questions need to be asked. Since it was inappropriate to further burden interviewees with increased time commitments, this study was unable to consider the second strategy.

8.5.3 Demand Side Analysis - Simulation Method

The impacts of cost reduction by DSM measures were simulated. The study focused on two parameters that significantly influence cost behaviors: 1) **adoption criterion for electrical appliances**, i.e. which kind of electrical appliances the village can use for each activity, and 2) **the permission of electricity use for activities**, i.e. whether the village is allowed to use electricity for each activity. Simulation patterns were set by varying the values of these parameters (these patterns are explained later in this chapter).

In addition, the study considered the impact of demand side management on villagers' benefit as well. Curtailing electricity consumption to achieve cost reductions decreases villagers' benefit derived from electricity use. Thus, the impacts of both cost reductions and forgone benefits need to be considered simultaneously in order to choose the optimal usage pattern to maximize benefits under realistic cost constraints.

Based on the results of cost simulation and impact analysis of benefit reductions, this chapter concludes by suggesting the optimal system for the village.

8.5.4 Simulation Steps

The sustainability rule requires villagers to cover annual costs by their income. To satisfy the rule, the annual costs need to be decreased by DSM. As stated above, however, this is very difficult owing to the villagers' limited financial resources. To cover all annual costs, their electricity consumption will be highly restricted. Thus, in considering the feasibility of this project, the scope of cost reduction should be discussed.

Before the discussion, the characteristics of the annual costs were clarified. As seen in Figure 8.4, the costs were categorized by two dimensions; payment frequency and availability of other cost-covering options.

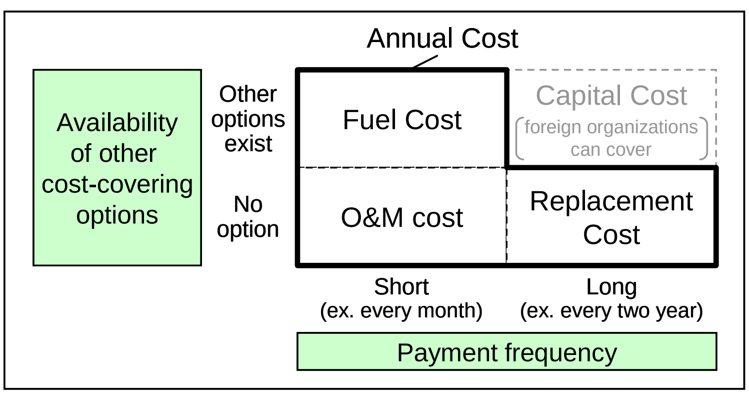


Figure 8.4: The Characteristics of Annual Costs

To begin with, based on the payment frequency, the costs are categorized into two groups (short or long). For example, O&M cost and fuel cost incur annually or monthly. Thus, every year, villagers have to pay for them. In contrast, replacement cost does not necessarily incur every year. For example, battery needs to be replaced periodically, but, once every 7-8 years. In other words, annualized replacement cost does not need to be covered each year. To sustain a generation system, thus, covering fuel cost and O&M cost by villagers' income should be prioritized.

Other aspect is whether villagers can have other financial resources to cover each cost other than villagers' current income. While O&M cost and replacement cost cannot be covered by other financial resources, villagers can have other resources for fuel cost. This is because, as discussed in Chapter 6, Jatropha system has potential to provide fuel and increase villagers' revenue. For example, the village may be able to produce the fuel (Jatropha oil) by harvesting from their lands (see Chapter 6 and discussed in Section 8.8). If the Jatropha oil production is feasible in Mbanayili, the fuel cost can be covered partly by the oil production. In addition to this, saved pre-existing energy costs for kerosene, fuelwood and charcoal by electrification can be used for fuel to generate electricity in the community center. For example, using CFLs in the community center somewhat reduces the consumption of kerosene for lights at homes, in turn reducing kerosene costs for household use. Villagers can use this saved money for the fuel cost in the community center. Furthermore, Jatropha oil production may be able to increase villagers' income (for example, producing soaps made from Jatropha oil would be profitable. see Section 8.8). These options can decrease the fuel cost or increase people's income, thus villagers do not necessarily pay all of the fuel cost from their current income. In contrast, O&M cost and replacement cost have no other cost-covering options. Therefore, these two costs need to be covered only by villagers' income.

The results of this analysis suggests that O&M cost has the highest priority to be covered in terms both of payment frequency and the availability of other cost-covering options, while replacement cost and fuel cost are the second. Thus, first, this study targets only O&M cost for the cost reduction and explored a consumption pattern that can meet the sustainability rule (**Simulation I:** O&M ≤WTP). To be sustainable, covering the largest item of the annual costs, i.e. O&M cost (37% of annual costs), would be the minimal requirement. Second, the study additionally considered replacement cost and simulated consumption patterns to determine fiscally sustainable systems (**Simulation II**: O&M + replacement cost ≤ WTP). Since foreign organizations can support only initial costs, replacement costs also need to be covered by villagers to sustain a generation system in perpetuity. This study, however, did not analyze Simulation III (O&M + replacement cost + fuel cost ≤ WTP). This is because, as stated above, other cost-covering options can be taken. To conduct the simulation, the impact of these options should be assessed because its impact significantly influences the results of the simulations. Since currently many uncertainties for the impact exist (see Chapter 6), Simulation III was not analyzed.

Apart from load curve data, the benchmark model's standard values for other parameters were set, such as interest rate (8%), maximum annual capacity shortage (10%) and fuel price (0.65USD/L) (see Chapter 7). Then, the HOMER software configured the least cost generation system based on each electricity consumption pattern controlled by the DSM.

8.6 Simulation I (O&M ≤ WTP)

8.6.1 Simulation Patterns

To reduce O&M costs, two directions were considered (Figure 8.5).

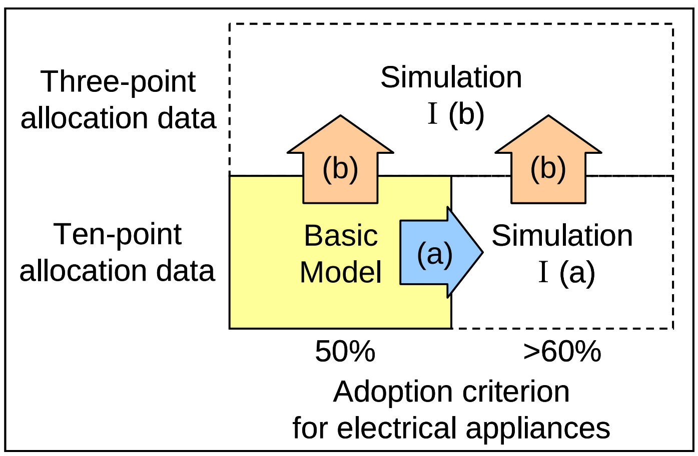


Figure 8.5: Two Directions of Simulation I

One is to change the adoption criterion for electrical appliances (**Simulation I (a)**). In the benchmark model, electrical appliances for each activity were considered acceptable, if more than 50% of the people would like to use them (see Chapter 5). Shifting this cut-off criterion (called "adoption criterion for electrical appliances") from 50% to 60% or more would curtail electricity consumption and provide cost reductions. Another way is to use different type of preference data to change the shape of electricity load curve (**Simulation I (b)**). The benchmark model used ten-point allocation data that represents villagers' preferences for electricity under the least constrained usage (see Chapter 5). As analyzed before, however, considerable cost reductions would be needed to satisfy the sustainability rule, requiring a more stringent constraint. Thus, three-point preference allocation data that reveals people's needs under limited electricity provisions will facilitate cost reductions better than the previous ten-point allocation method. Using the restricted preference data, this study conducted cost simulation and analyzed cost reduction impacts[69].

8.6.2 Analysis of Simulation I (a)

The impact of shifting the cut-off line of the adoption criterion for electrical appliances was analyzed using ten-point allocation data. Figure 8.6 shows the results of Simulation I (a). As illustrated, the O&M cost decreases as the adoption criterion for electrical appliances become more restrictive. The 80% adoption criterion that rejects the use of many electrical appliances (see Table 8.2) could reduce O&M costs from the benchmark model by 16.7%. The cost (782 USD), however, was still greater than the willingness-to-pay of Mbanayili.

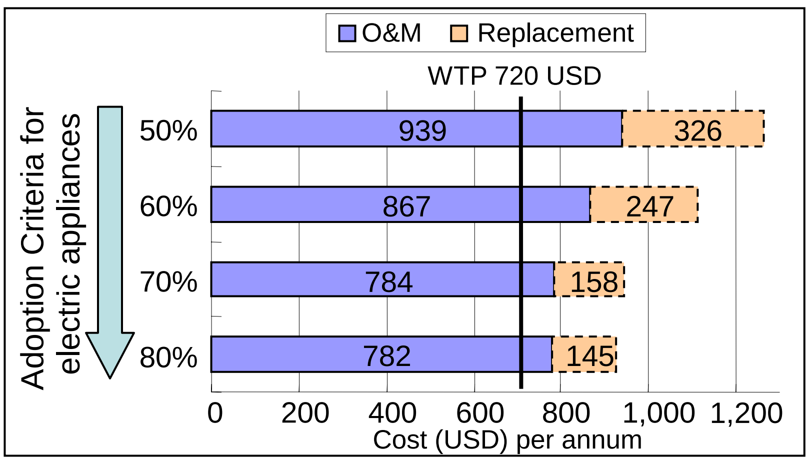
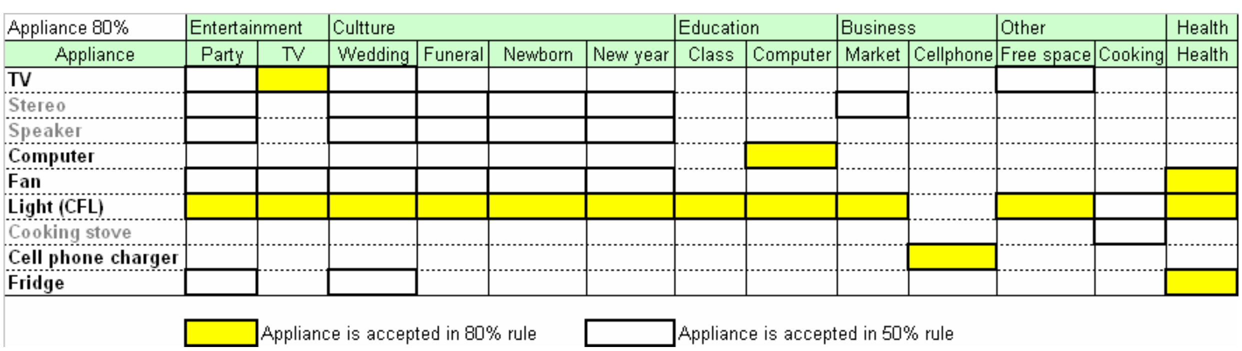


Figure 8.6: Simulation I (a) – Simulation Results

Table 8. 2: Accepted Electricity Appliances (Adoption Criteria 50% and 80%)



To satisfy the sustainability rule, a further increase in the adoption criterion percentage (beyond 80%) is required. Surpassing the 80% adoption criterion, however, constrains electrical

[69] Using five-point allocation data is another option. Under current assumptions, however, this method could not decrease electricity cost. Thus, this study did not consider this option.

appliances usage only to lighting for many activities. Though lighting is the most critical, the villagers' desired benefits from electricity use would be severely restrained. Thus, this study decided an 80% adoption criterion is the upper limit to entice enough interest in the project.

Consequently, the study concluded that Simulation I (a) cannot satisfy the sustainability rule.

8.6.3 Analysis of Simulation I (b)

As observed in Figure 8.7, the use of three-point allocation data with 50% as the adoption criterion reduced O&M costs by approximately 7% compared to the benchmark model. In addition to this, the change of the adoption criterion from 50% to 80% provided an additional 10% cost reduction, which required less cost than the result of Simulation I (a). These patterns, however, could not satisfy the sustainability rule yet (the O&M costs is still more than 720 USD).

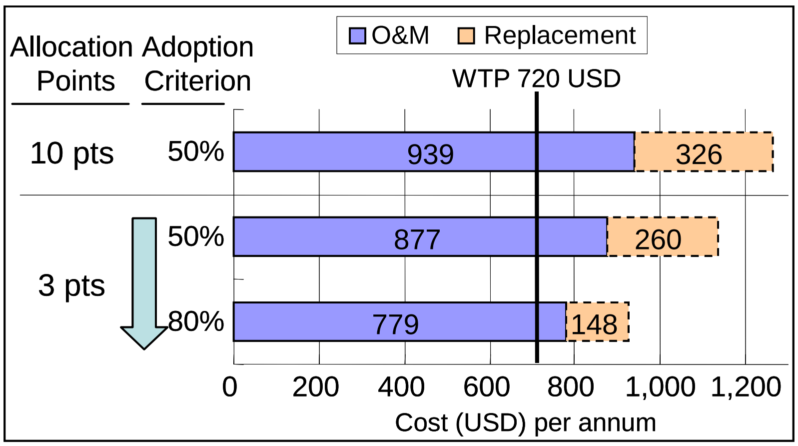


Figure 8.7: Simulation I (b) – Simulation Results

The findings from Simulation I (a) and (b) suggested that only changing the parameters of the adoption criterion for electrical appliances is insufficient to meet the sustainability rule. Thus, to explore other cost reduction measures in Simulation I, cost-benefit analysis was conducted to evaluate the cost-effectiveness of each activity.

8.6.4 Cost-Benefit Analysis

In analyzing cost-effectiveness for each activity, the study created a Cost Benefit Index (CBI) and calculated the values of the CBI for all activities in the benchmark model. The CBI was defined as follows;

Cost Benefit Index (USD/point)

= Cost (electricity cost by activity[*1]) / Benefit (allocated preference points by activity[*2])

$$\text{*1: Cost} = \text{Annual electricity cost} * \frac{\text{Amount of electricity consumption for each activity (Wh)}}{\text{Amount of total electricity consumption (Wh)}}$$

The annual electricity cost includes replacement cost, O&M cost and fuel cost

*2: Benefit = allocated points to each category at the third step (Figure 5.6)

* activity preference (%, Figures 5.14, 5.15)

This index can be stated as the cost requirements necessary to satisfy one preference point for each category. For example, the lowest CBI value for a particular activity indicates that the people's needs for the activity can be met with less cost than any other activity. In other words, this activity is the most cost-effective.

Figure 8.8 shows the values of the CBI by activity. As can be observed in the graph, cooking was the most costly activity. Even compared to the second most costly activity, attributable to weddings, the CBI value of cooking was more than twice as costly as this.

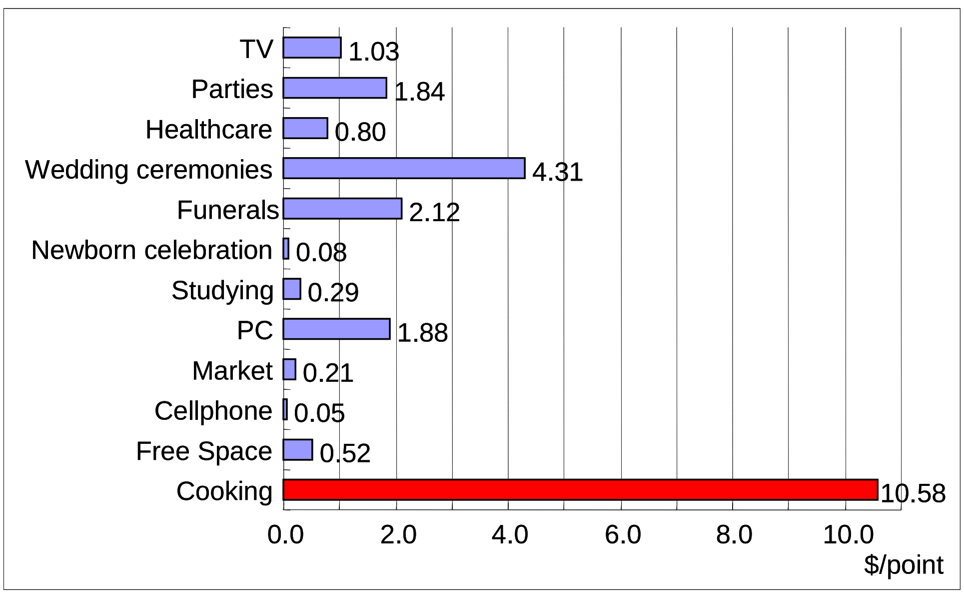


Figure 8.8: The Result of the Cost-Benefit Analysis by Activity

The reason for this is that electric cooking stove required for the activity is energy intensive, consuming 2.6 kW. Consequently, electricity consumption for the activity accounted for 65.6 % of the community center's total consumption. In addition, the activity drastically increased peak load consumptions across all months (from 399 W without the cooking activity to 2,648 W with the activity). Thus, this activity is a critical obstacle to overcome in order to satisfy the sustainability rule. From these results, it was concluded that permitting this costly activity to occur would inhibit the possibility of providing a financially sustainable generation system.

8.6.5 Analysis of Simulation I (c)

The study removed the cooking activity from the activity schedule. The allocated times for the activity (about 80 hours/month) were proportionately reallocated to other activities based on the category and activity preference data. After reassigning other activities, simulations were conducted again by same ways as Simulation I (a) and (b) (called **Simulation I (c)**).

As seen in Figure 8.9, the sustainability rule could be satisfied. As the adoption criterion for electrical appliances was set as 60%, the O&M costs, based on both ten-point data and three-point data, were less than the willingness-to-pay (25% of the O&M cost reduction from the benchmark model).

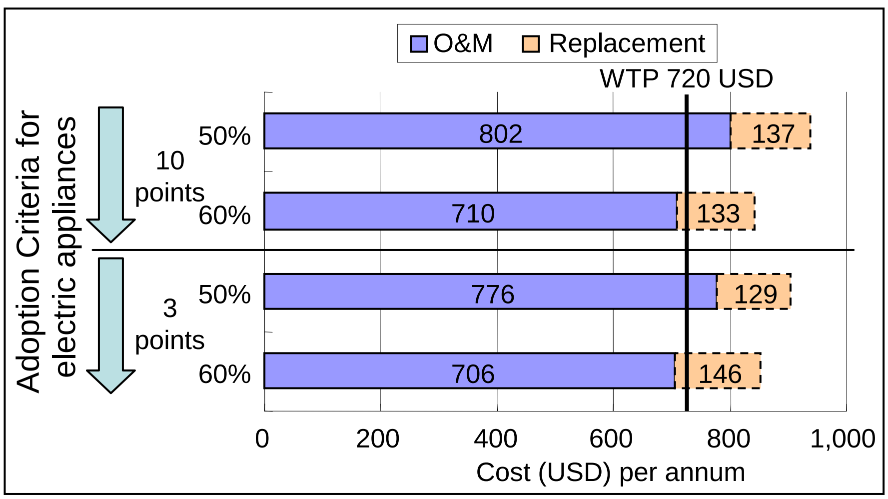
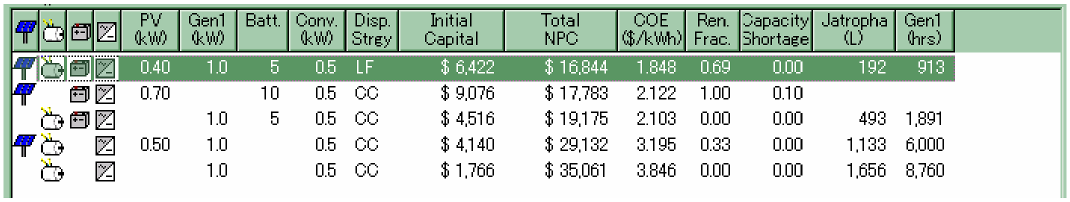


Figure 8. 9: Simulation Results – Simulation I (c)

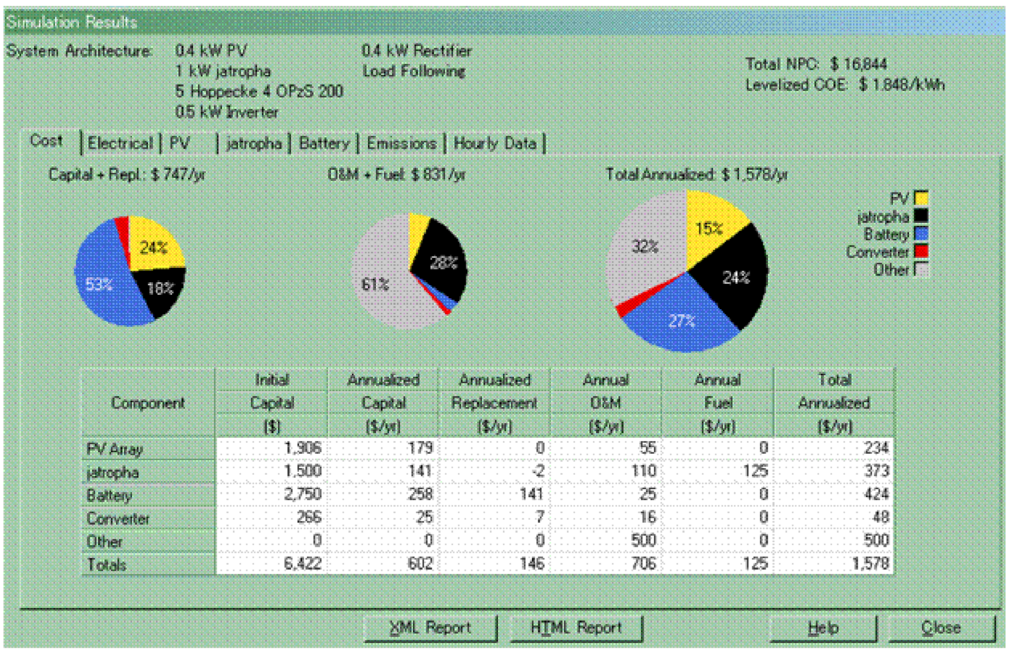
Two patterns that meet the sustainability rule exist, namely (1) ten-point allocation data with the adoption criterion of 60% and (2) three-point allocation data with the adoption criterion of 60%. Since the three-point allocation data better reflects people's preference, (2) would be more desirable choice for Mbanayili residents. As stated in Chapter 5, the ten-point allocation data and the three-point allocation data reflect the villagers' preferences under different conditions. The three-point allocation data represents people's electricity needs with the assumption that electricity consumption is highly restricted, while the ten-point allocation data assumes that an abundant amount of electricity is provided to villagers. In simulation I, the electricity consumption is restricted greatly by not permitting cooking activity and shifting the cut-off line of the adoption criterion for electrical appliances from 50% to 60%. Thus, the pattern using the three-point data (2) was selected as the optimal system for Mbanayili in Simulation I.

Figures 8.10 and 8.11 show the details of the system. This is a hybrid system that is comprised of PV solar generators and Jatropha generators.



PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
0.40	1.0	5	0.5	LF	$ 6,422	$ 16,844	1.848	0.69	0.00	192	913
0.70		10	0.5	CC	$ 9,076	$ 17,783	2.122	1.00	0.10		
	1.0	5	0.5	CC	$ 4,516	$ 19,175	2.103	0.00	0.00	493	1,891
0.50	1.0		0.5	CC	$ 4,140	$ 29,132	3.195	0.33	0.00	1,133	6,000
	1.0		0.5	CC	$ 1,766	$ 35,061	3.846	0.00	0.00	1,656	8,760

Figure 8.10: Optimal Generation System in Simulation I



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	1,906	179	0	55	0	234
jatropha	1,500	141	-2	110	125	373
Battery	2,750	258	141	25	0	424
Converter	266	25	7	16	0	48
Other	0	0	0	500	0	500
Totals	6,422	602	146	706	125	1,578

Figure 8. 11: Costs of the Optimal Generation System in Simulation I

8.7 Simulation II (O&M + Replacement Cost ≤ WTP)

8.7.1 Background of Simulation II

With a view to a strictly fiscally sustainable system, consumers have to cover not only the O&M cost, but also the replacement cost in order to keep the generation system working. Because replacement costs are incurred periodically and perpetually, foreign organizations such as cooperative agencies and donors cannot cover them, due to the difficulty of indefinite support. Thus, in Simulation II, the study explored ways of meeting the sustainability rule, which states that both the O&M cost and the replacement cost must be covered by villagers.

Simulation II excluded the same cooking activity as Simulation I. In addition, only three-point allocation data was used, because this simulation required greater electricity conservation to satisfy the rule.

This simulation considered the replacement costs only for the cost of the expendable goods that are involved in sustaining the generation system (see Chapter 7). In other words, the replacement costs for electrical appliances such as CFLs were not included (the costs of electrical appliances are shown in Table A.2.2 of the Appendix), because the lifetimes of electrical appliances, which influence annual replacement cost, depend both on their use and their maintenance. In particular, dust from the dirt floors may damage electrical appliances, shortening their lifetimes. Since more data is needed to estimate a reasonable lifetime for each appliance, the study did not consider the replacement costs.

8.7.2 Simulation Patterns

Initially, as conducted in Simulation I, the adoption criterion percentage for electrical appliances was varied. As observed in Figure 8.12, when 80% is set as the criterion, the sum of the O&M cost and the replacement cost is less than 720 USD, meaning that the system is sustainable (this model is called "80% model" in this study).

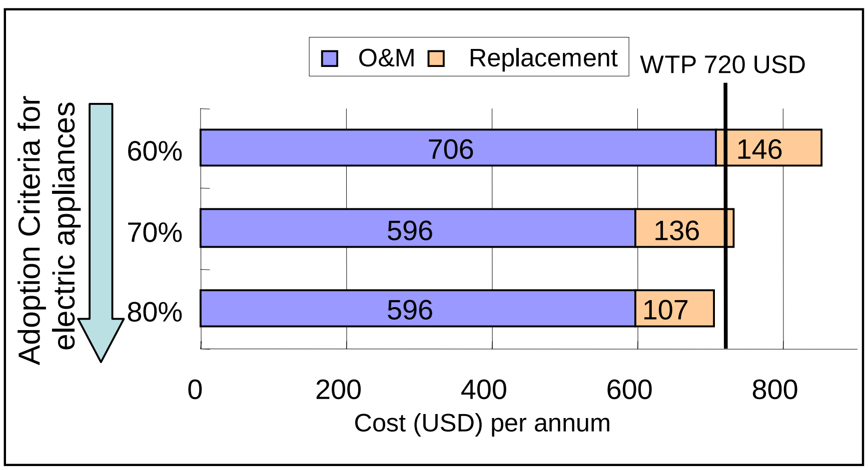


Figure 8.12: Simulation Results – Sensitivity of the Adoption Criterion for Electrical Appliances

Table 8. 3: Adopted Electrical Appliances (Adoption Criterion: 50% and 80%) without Cooking Activity

	Activity												
	Entertainment		Cultture				Education		Business		Other		Healthcare
Appliance	Party	TV	Wedding	Funeral	Newborn	New year	Class	Computer	Market	Cellphone	Free space	Cooking	
TV	□	■	□								□		
Stereo	□		□	□	□	□			□				
Speaker	□		□	□	□	□							
Computer								■					
Fan	□	□	□	□	□	□							■
Light (CFL)	■	■	■	■	■	■	■	■	■		■		■
Cooking stove													
Cell phone charger										■			
Fridge	□		□										■

■ Financially Sustainable System ($720) □ Benchmark Model ($1,844)

This system, however, is problematic. As discussed in Simulation I, and shown in Table 8.3, if 80% is set as the adoption criterion for electrical appliances, many activities are only permitted the use of lights, not any other appliances the villagers may have wanted. In other words, people's demands for other appliances are highly suppressed. To maximize people's benefit from electricity use, the study explored other ways to permit more electrical appliances.

The percentage of the adoption criterion needs to be lowered from 80% to allow the use of more electrical appliances. This, however, increases the electricity cost. To balance this problem, the study set different percentages for the criterion based on the popularity of each category or activity. Using this method, four types of simulations were created (see Figure 8.13).

a) The percentages of the adoption criterion for popular activity categories were decreased, instead of incremental percentages for less popular categories.
b) The least popular categories were denied the use of electricity, in order to allow more appliances in other categories.
c) The factors of both (a) and (b) were considered. That is, the least popular categories were not allowed to use electricity at all and the more popular categories were given lower percentages for the adoption criterion.
d) While (a), (b) and (c) applied different percentages of the adoption criterion by category, the rule applied in (b) was applied to each activity.

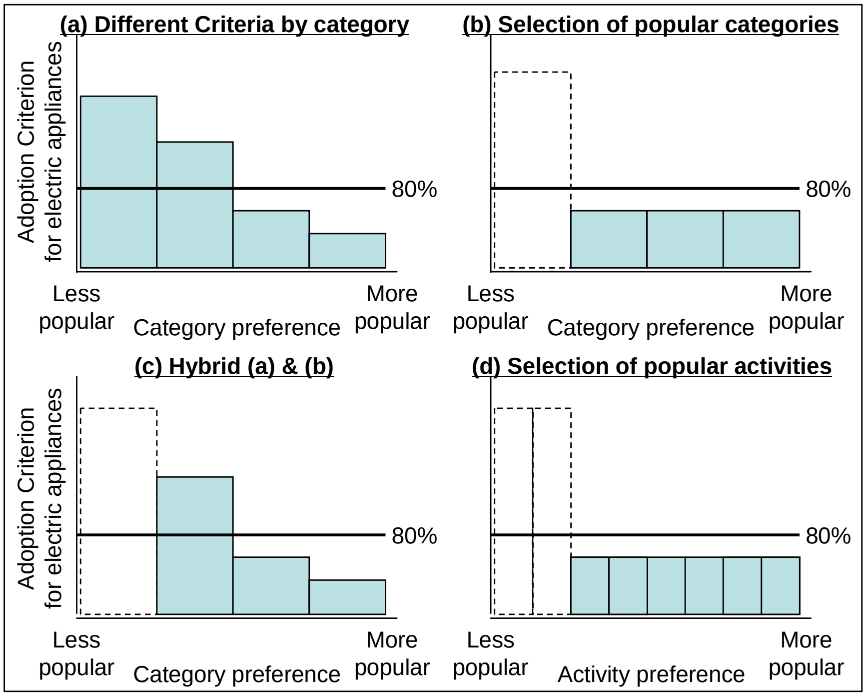


Figure 8.13: Simulation Types in Simulation II

Using these simulation types, the study generated eleven simulation patterns (Patterns A thru K, see Tables 8.4 and 8.5).

Table 8. 4: Simulation Patterns of Type (a), (b) and (c)
(Percent of the Adoption Criterion for Electrical Appliances)

Type	Pattern	% of the allocated points (three-point allocation)			
		<10% (Culture, Others)	<15% (Entertainment)	<20% (Business)	>20% (Health, Education)
Type (a)	Pattern A	80%	70%	60%	50%
	Pattern B	90%	80%	70%	60%
Type (b)	Pattern C	No electricity	70%	70%	70%
	Pattern D	No electricity	70%	60%	50%
Type (c)	Pattern E	No electricity	80%	70%	60%

No electricity: Not allowed to use electricity

Table 8. 5: Simulation Patterns of Type (d)

	Adoption criterion for electric appliances					
	50%		60%			70%
Activity*	Pattern F	Pattern G	Pattern H	Pattern I	Pattern J	Pattern K
Class	Yes	Yes	Yes	Yes	Yes	Yes
Market	Yes	Yes	Yes	Yes	Yes	Yes
Television	Yes	Yes	Yes	Yes	Yes	Yes
Party	Yes	Yes	Yes	Yes	No	Yes
Wedding	Yes	No	Yes	No	No	No
Funeral	Yes	No	Yes	No	No	No
Cellphone	No	No	No	No	No	No
Newborn	No	No	No	No	No	No
Free Space	No	No	No	No	No	No
Computer	No	No	No	No	No	No

*:Decending order by activity preference

Yes: Electricity use is permitted, No: Electricity use is banned

8.7.3 Results of Simulation II

Using adjusted electricity consumption data based on the simulation patterns, the optimum generation system for each pattern was configured by HOMER. Table 8.6 shows a summary of the simulation results.

Table 8. 6: Simulation Results – Simulation II

Pattern	Initial Cost	Annual Replacement Cost	Annual O&M cost	Sum of Annual Costs	Sustainability Check
Pattern A	4,922	596	139	735	NG
Pattern B	4,922	596	124	720	OK
Pattern C	4,922	596	113	709	OK
Pattern D	4,922	596	139	735	NG
Pattern E	4,922	596	104	700	OK
Pattern F	6,422	766	116	882	NG
Pattern G	6,422	711	73	784	NG
Pattern H	6,422	690	128	818	NG
Pattern I	6,326	626	192	818	NG
Pattern J	4,922	596	90	686	OK
Pattern K	4,922	596	107	703	OK

(Unit:USD)

As seen in this table, five patterns, B, C, E, J and K, could satisfy the sustainability rule. That is, these patterns are affordable for Mbanayili villagers.

Interestingly, the HOMER only selected solar generation for the optimum systems of these patterns. The hybrid system that consists of both solar generation and Jatropha generators was not chosen, although it was used in the benchmark model and chosen as the optimal system in Simulation I. This is partly because generation capacity could be downsized to minimize initial costs owing to the greatly reduced electricity consumption.

8.7.4 Evaluation of the Patterns

The study identified six patterns of generation systems that satisfy the sustainability rule (80% model and Patterns B, C, E, J and K). Discussion among Mbanayili's villagers might enable them to select the generation system that maximizes their own benefits. However, it would be difficult to reach a consensus, because the village has a variety of preferences that differ according to gender, income, and age, as discussed in Chapter 5. To support their decision, this study analyzed each pattern's benefits and evaluated the patterns using the results of the preference analysis (Chapter 5). Then, the optimal pattern for the village was proposed.

To identify the best out of six patterns, this study evaluated the benefit impacts of each pattern on villagers. Since the precise measurement of all potential benefits is difficult to assess (no research relating to this evaluation was found), the study employed a comparative approach that focused on the differences in benefits among the patterns. For example, a difference between Pattern J and others is that only Pattern J bans electricity use for party activity. In this fashion, the study only analyzed the benefit impacts of the difference, and evaluated the patterns based on the result of the impact analysis.

In addition, to adequately comprehend the impacts of each pattern, this study focused mainly on three important demographics: 1) elderly men (specifically, more than 40 years old), 2) people of the upper income level, and 3) women. This is because the influences of these portions of the population are critical for the success of an electrification project, in terms of both sustaining a generation system and improving their standard of living. First, elderly men have important decision-making power in Mbanayili. Important village matters are decided at meetings where Mbanayili's leaders, many of whom are forty years old or above, are in attendance (Alhassan, Pers. Comm., 2006). Therefore, these men's opinions cannot be ignored so that a generation system is accepted. In other words, the benefit impact of elders needs to receive enough attention. Second, financial resources to keep the generation system working are limited in Mbanayili. Thus, the more affluent people's financial support is vital for the success of the electrification project. To receive support, their needs have to be satisfied to as great an extent as possible. Lastly, the study also considered women's benefits. As much research shows (World Bank, 2000a; World Bank, 2000b etc), women's empowerment is very important for rural development, and their access to electricity is a significant means of improving their living standard. Therefore, impacts on women were analyzed along with the impacts on elderly men and the affluent class.

Simultaneously comparing every difference of the benefits from the six patterns would be highly complicated because each pattern provides a variety of benefits to different segments of villagers. To simplify the evaluation, this study initially formed three pairs and compared each one. Then, whichever pattern had higher benefits within the pair was compared to another pattern that was more advantageous in another pair. By following this format, six patterns were compared and evaluated (Figure 8.14). Round 1 paired two patterns that permit similar electrical appliances.

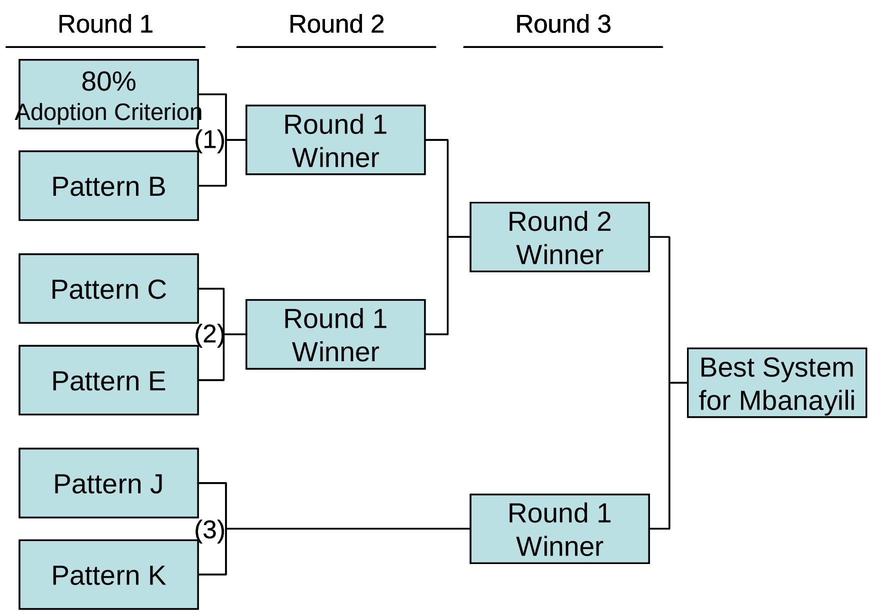


Figure 8. 14: Evaluation Orders

8.7.5 Evaluation Results – Round 1

This round compared three pairs (1), (2) and (3) (see Figure 8.14). Then, the differences of the benefits between two patterns in each pair were analyzed.

Round 1-(1): 80% Adoption Criterion vs. Pattern B

By applying 80% adoption criterion for electrical appliances to all activities (80% model), the generation system could be sustainable. This system, however, did not permit many electrical appliances (see Table 8.3). In contrast, Pattern B used different percentages by category for the adoption criterion (see Table 8.4). Owing to changes of percentages, one more electrical appliance was permitted in Pattern B than in the 80% model.

Table 8. 7: Round 1-(1): Permitted Electrical Appliances

	TV		Party	Wedding	Funeral	Newborn		New Year	Study	Computer		Market	Free Space	Cellphone	Health		
	CFL	TV	CFL	CFL	CFL	CFL	Audio	CFL	CFL	CFL	PC	CFL	CFL	Charger	CFL	Fan	Refrigerator
80%	O	O	O	O	O	O	-	O	O	O	O	O	O	O	O	O	O
Pattern B	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

As Table 8.7 illustrates, Pattern B permits audio for newborn celebration parties, which was the only difference between the two patterns. Figure 8.15 represents the supporters of this appliance use for newborn celebration parties broken down by gender. As shown, 80% of females voted for the audio use. Since giving more benefits to women as well as more opportunities for electricity use to villagers, Pattern B is more desirable for Mbanayili.

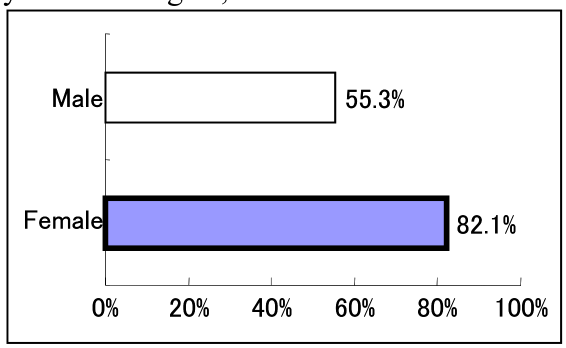


Figure 8.15: Percentage of Supporters for Audio Devise Use in Newborn Celebration Party by Gender

Round 1-(2): Pattern C vs. Pattern E

Both Patterns C and E do not permit electricity use for the least two popular categories, that is, “culture” and “others”. In exchange for this electricity consumption reduction, Pattern C lowers the percentage of the adoption criterion for all electrical appliances from 80% to 70%. On the other hand, Pattern E sets several different percentages for other categories based on category popularity (see Table 8.4). The only difference between the two patterns is that Pattern C allows television use for party activity (Table 8.8) because of its lower percentage of the adoption criterion for entertainment category as compared to Pattern E (Pattern C: 70%, Pattern E: 80%, see Table 8.4).

Regarding Pattern C's greater allowance of electrical appliances, it is undoubtedly preferable to Pattern E. In particular, this pattern would attract high-income people, as more than 95% of this group demanded television use in the party activity (see Figure 8.16).

Table 8. 8: Round 1-(2): Permitted Electrical Appliances

	TV		Party		Study	Computer		Market	Cellphone	Health		
	CFL	TV	CFL	TV	CFL	CFL	PC	CFL	Charger	CFL	Fan	Refrigerator
Pattern C	O	O	O	O	O	O	O	O	O	O	O	O
Pattern E	O	O	O	-	O	O	O	O	O	O	O	O

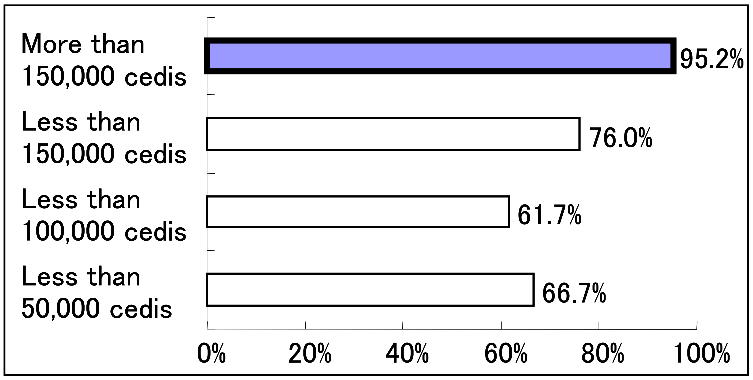


Figure 8.16: Percentage of Supporters for Television Use in Party Activity by Income

Round 1-(3): Pattern J vs. Pattern K

Pattern K and Pattern J set different percentages for the adoption, i.e., 70% and 60% respectively. In addition, another difference is that Pattern J dropped the party activity from the activity schedule in order to be sustainable (Table 8.5).

The comparison between these two patterns is more complicated than the previous two, because each pattern attracts different segments of villagers. As Table 8.9 represents, Pattern J permits fan and audio use for one or two activities, while Pattern K allows electricity use for the party activity.

Table 8. 9: Round 1-(3): Permitted Electrical Appliances

	TV		Party		New Year			Study	Market		Health		
	CFL	TV	CFL	TV	CFL	Fan	Audio	CFL	CFL	Audio	CFL	Fan	Refrigerator
Pattern J	O	O	-	-	O	O	O	O	O	O	O	O	O
Pattern K	O	O	O	O	O	-	-	O	O	-	O	O	O

To compare the benefits of the patterns, the study began by analyzing potential supporters of Pattern J, specifically, for audio use during the New Year party and market activity (the benefit impact of the fan was not considered because the appliance is used only during the dry season (Chapter 5), thus its impact is considerably limited.).

Table 8. 10: Percentages of Preferences for Audio Use for Markets and Newborn Celebration Parties by Age, Income, and Gender

For Market		For Newborn celebration	
Age	% of supporters	Age	% of supporters
10's	45.5%	10's	45.5%
20's	69.0%	20's	74.1%
30's	50.0%	30's	57.5%
40's and above	41.7%	40's and above	54.2%
Income Level	% of supporters	Income Level	% of supporters
less than 50000	70.0%	less than 50000	80.0%
less than 100000	58.3%	less than 100000	56.3%
less than 150000	42.3%	less than 150000	57.7%
more than 150000	51.7%	more than 150000	62.1%
Gender	% of supporters	Gender	% of supporters
Female	56.4%	Female	82.1%
Male	56.4%	Male	55.3%

Table 8.10 indicates the percentages of the supporters by segment for audio use. As shown in the table, the lowest income group preferred audio use for the both activities more than other income groups. Another finding is that women more supported audio use for newborn celebration party activity. These results suggest that the lowest-income group and women support Pattern J.

Next, potential supporters for Pattern K were explored. Figure 8.17 suggests that people who prefer electricity use for party activity would support Pattern K. Thus, the attributes of the supporters for the party activity were specified. Two steps were taken. Initially, using category preference data (see Chapter 5), supporters' attributes of entertainment category, which includes the party activity, were clarified. Then, since the entertainment category has two activities: party and watching television, the attributes of the supporters for the party activity were specified.

As shown in Chapter 5, elderly or affluent people, in particular, were more likely to prefer this category (Figures 5.9 and 5.10). Figure 8.17 represents the preferences of elderly people and affluent people. As shown on the left diagram in the figure, the reason that elders preferred the entertainment category was the opportunity for watching television, not parties. In fact, every elder who voted for the category preferred this activity. These findings suggest that even if the village chooses Pattern J, which does not permit the party activity with electricity, the elders would not object to the decision, as long as they are able to enjoy watching television. On the other hand, affluent people may oppose the decision, because the reason that they voted for the entertainment category was primarily to have the party activity. As the right diagram of

Figure 8.17 shows, among the high-income supporters for the entertainment category (52% of affluent people voted for the category), the party activity was preferred more than watching television (Television: 17%, Party: 31%). Therefore, some affluent people may not support Pattern J. Since the percentage is less than one-third, however, the impact of the objection would be limited.

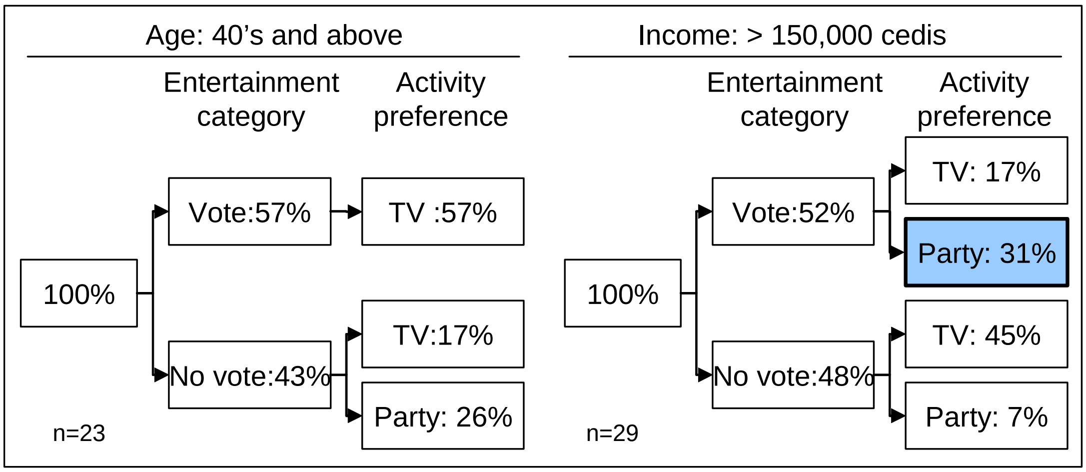


Figure 8. 17: Preferences of Elderly People (40 years old or above) and Affluent People (more than 150,000 cedis of monthly income) for Entertainment Category and Activities in the Category

From these results, the study concluded that Pattern J is preferable for Mbanayili. This is because the majority of women would support Pattern J. Since they have less economic and social power in the village, increasing the benefits of these segments by Pattern J would contribute to the success of the electrification project (collaterally, this pattern provides benefits to low-income people too. This pattern would support the improvement of their standard of living).

Furthermore, the findings suggest that the influential groups for this selection -affluent people and elderly people- would not oppose the decision, and if they did, the impact of the objection would be limited.

8.7.6 Evaluation Results – Round 2

In Round 1, the study identified Patterns B, C, and J as the optimal choices in each pair for Mbanayili. Then, Patterns B and C were compared in Round 2, and the better option was selected.

Round 2: Pattern B vs. Pattern C

Table 8.11 shows the permitted electrical appliances for both Patterns B and C. The main differences between them are that Pattern B allows the use of lights (CFLs) for some activities such as weddings and funerals, while Pattern C permits watching television during party activity.

As observed in Figure 8.16, Pattern C would attract affluent people. In contrast, Pattern B's cultural activities, such as weddings and funerals, would be preferred by male, elderly, or affluent people (Figures 5.8, 5.9 and 5.10). Since affluent people are attracted by the both patterns, it is unclear about which pattern they chose. Thus, based on the impacts only on elderly people and women, the optimal pattern was selected.

Table 8. 11: Round 2: Permitted Electrical Appliances

	TV		Party		Wedding	Funeral	Newborn		New Year	Study	Computer		Market	Free Space	Cellphone	Health		
	CFL	TV	CFL	TV	CFL	CFL	CFL	Audio	CFL	CFL	CFL	PC	CFL	CFL	Charger	CFL	Fan	Refrigerator
Pattern B	O	O	O	-	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Pattern C	O	O	O	O	-	-	-	-	-	O	O	O	O	-	O	O	O	O

As stated in Chapter 5, elders prefer the cultural activities more than the younger people, which include weddings, funerals, newborn celebration parties and New Year parties. Figure 8.18 provides more detailed data. As seen, the oldest people (40's and above) more supported the culture category than other age groups. For example, in the category preference survey (second step, five-point allocation), about 80% of elders allocated at least one point to this category. In addition, fewer elderly people supported television use during party activity. As Figure 8.19 shows, their preference for the appliance was lower than that of other age groups. From these results, the study concluded that Pattern B would more accurately reflect elderly people's preferences, thus would garner their support.

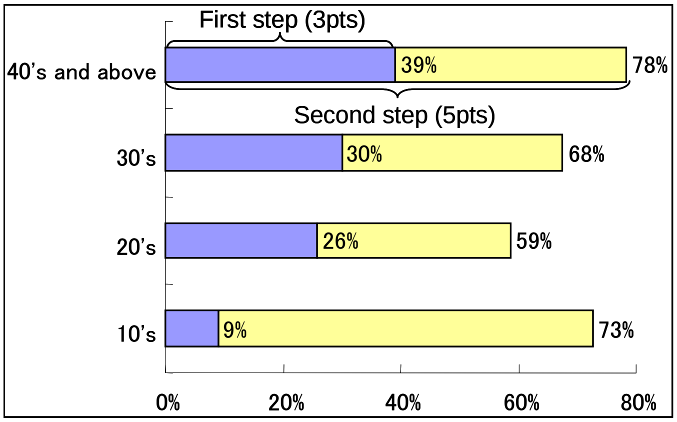


Figure 8. 18: Percentages of People Who Chose the Culture Category at First (three-point allocation) and Second (five-point allocation) Steps

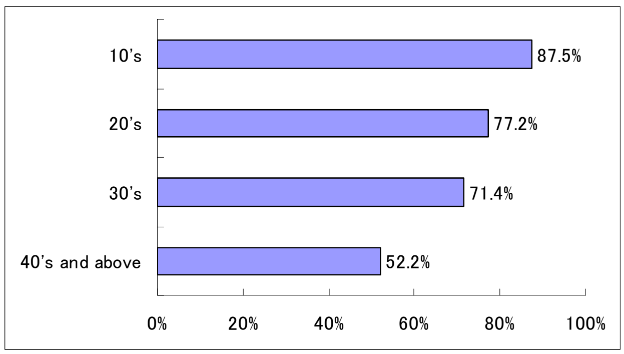


Figure 8.19: Preference for Television in Party Activity

On the other hand, women's preferences were different from elders'. As discussed in Chapter 5, women preferred watching television more than men. However, their preference for television use during party activity was almost the same as men's (men: 71%, women: 72%). Therefore, even if Pattern C is not selected, the benefit impact on women would not be different from the impact on men. However, the demand of 72% of women for television is not negligible. To evaluate the impact of the demand, the study provided a diagram (Figure 8.20) using activity preference data for women (see Figure 5.22). As this figure illustrates, women preferred the television activity to the party activity (television: 82%, party: 18%), and only 15% of women preferred the party activity and desired television use in this activity. In other words, 56 % out of 72 % of women preferred the watching television activity to the party activity. This finding suggests that more than half of the women's needs for television use can be satisfied in the television activity, not in the party activity. Therefore, even if television use is not permitted in the party activity, that is, if Pattern B is selected, the benefit reduction on women would be limited.

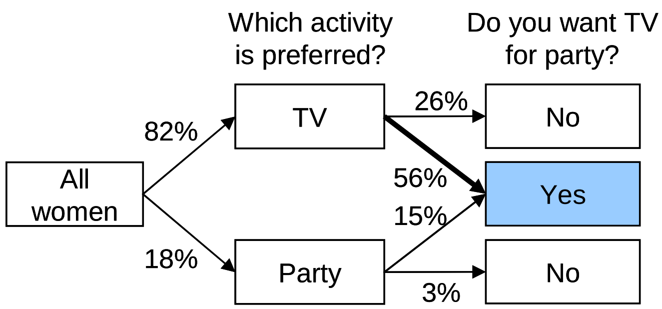


Figure 8.20: Women's Preference for Two Activities (TV and Party) and for Television in the Party Activity

In short, Pattern B would attract elderly people because it allows electricity use for cultural activities. In addition, fewer elders preferred Pattern C's benefit, which is television use during party activity. Furthermore, Pattern B's adverse impact on women is limited because their needs of watching television are not restricted in Pattern C. From these results, the study concluded that Pattern B is preferable for Mbanayili.

8.7.7 Evaluation Results – Round 3 (Final)

Finally, the study compared Pattern B with Pattern J and suggested an optimal consumption pattern and generation system for Mbanayili.

Round 3: Pattern B vs. Pattern J

As observed in Table 8.12, the electricity consumption patterns of Pattern B and J are significantly different. Pattern B allows electricity use for many activities; however, only lighting can be used for four activities. On the other hand, Pattern J permits fan and/or audio for two activities to compensate for lack of electricity use during six activities such as weddings.

Table 8. 12: Round 3: Permitted Electrical Appliances

	TV		Party	Wedding	Funeral	Newborn		New Year			Study	Computer		Market		Free Space	Cellphone	Health		
	CFL	TV	CFL	CFL	CFL	CFL	Audio	CFL	Fan	Audio	CFL	CFL	PC	CFL	Audio	CFL	Charger	CFL	Fan	Refrigerator
Pattern B	O	O	O	O	O	O	O	O	-	-	O	O	O	O	-	O	O	O	O	O
Pattern J	O	O	-	-	-	-	-	O	O	O	O	-	-	O	O	-	-	O	O	O

As previously discussed, electricity use for cultural activities in Pattern B would attract both elderly people and affluent people (Chapter 5), while Pattern J would gain support for audio use from women (Table 8.10).

This study could not decide the optimal pattern using these results, because both patterns yield benefits to different population groups, and such benefits are equally important in terms of both the success of the electrification project and rural development. To find the optimal system for the village, additional data is needed to analyze the extent to which each pattern provides benefits to villagers.

However, the optimal pattern may be decided from other standpoints: 1) increasing the number of people who experience electricity use and 2) maximizing the utilized capacity of the community center. Since Pattern B provides many parties and ceremonies with electricity to villagers throughout the year, more people can have experience of using electricity (currently, fewer villagers have used electricity, see Figure 5.1). In addition, the community center can be effectively used, if Pattern B is selected. More timeslots of the community center are scheduled by activities in Pattern B than in Pattern J (see Tables 8.4 and 8.5).

If these two benefits are important factors for the success of the electrification project, Pattern B can be regarded as the optimal system for Mbanayili. Figures 8.21 and 8.22 show the details of Pattern B's system. It was comprised of only solar generation (the activity schedule of Pattern B is shown in Table A.4.1 of the appendix).

PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Jatropha (L)	Gen1 (hrs)
0.40		5	0.5	CC	$ 4,922	$ 12,611	2.383	1.00	0.04		
0.40	1.0	5	0.5	LF	$ 6,422	$ 14,224	2.595	0.97	0.00	15	81
	1.0	5	0.5	CC	$ 4,516	$ 17,099	3.119	0.00	0.00	325	1,396
0.50	1.0		0.5	CC	$ 4,140	$ 27,417	5.001	0.36	0.00	1,020	5,515
	1.0		0.5	CC	$ 1,766	$ 34,815	6.351	0.00	0.00	1,621	8,760

Figure 8. 21: Optimal Generation System in Simulation II

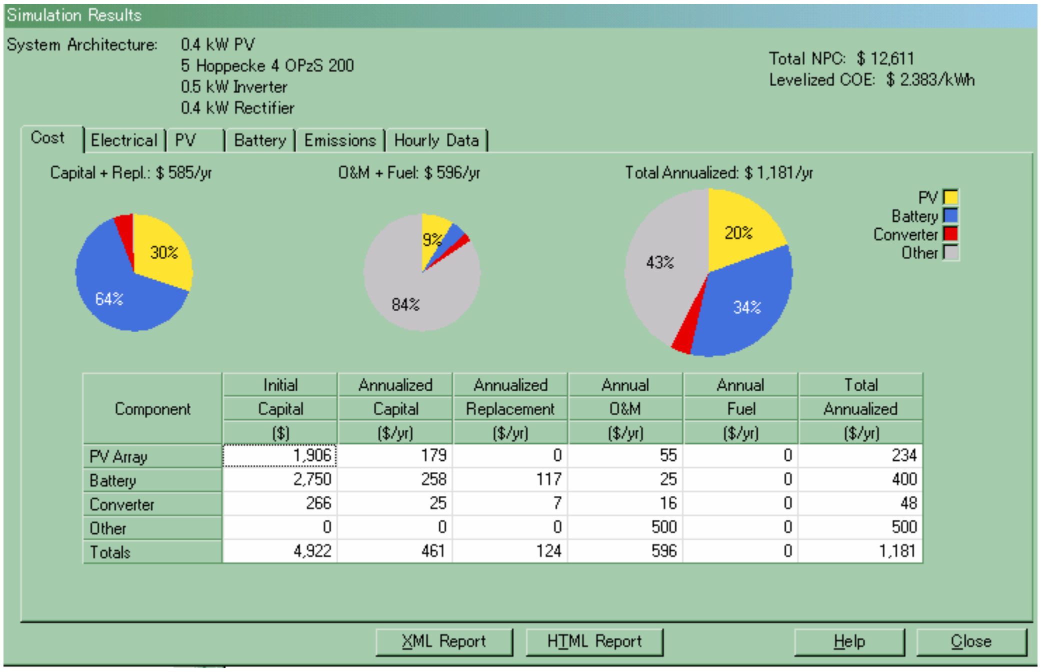


Figure 8.22: Costs of the Optimal Generation System in Simulation II

Figure 8.23 summarizes the evaluation results in Simulation II.

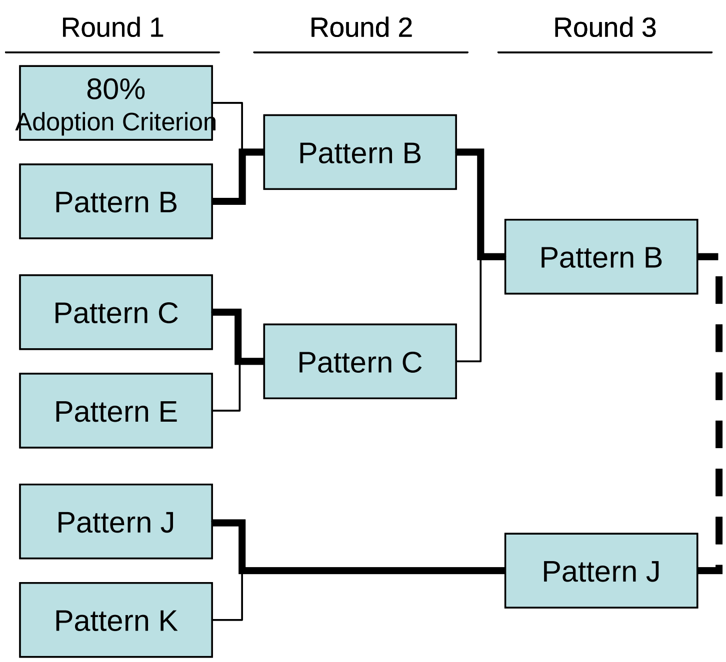


Figure 8. 23: Summary of the Evaluations

8.8 Revenue Generation Potential

As discussed before, the potential of Jatropha oil production exists (see Chapter 6). This production can contribute to Mbanayili's income growth and provide a cost-covering option for the fuel cost of a generation system (see Section 8.5.4). In this section, the study estimates the potential of the revenue generation by the Jatropha oil production.

8.8.1 Providing Job Opportunity for Women through Jatropha

According to interview results, some women do not have jobs, or if they do, their incomes are very low compared to men's (see Chapter 5). Currently 20.5% women work in micro enterprise, which produces Shea butter. This proposed revenue generation scheme is providing job opportunities for women in addition to their current jobs, and thus improving their financial status. In general, providing job opportunities to women has more impact on income growth and improvement of living standard than providing jobs to men (Forsythe et. al., 2000). Also, increasing women's income can contribute significantly to women empowerment and poverty reduction (Forsythe et. al., 2000). This study analyzed the potential of job opportunity provided from Jatropha for unemployed women. From interview data, 5% of the women do not have job. The age range of women assumed to be working is 15-69. Based on Ghana's population data in 2005 (US Census Bureau, 2006), 28.7% of the population are women between 15 and 69 years old. So there are 4,050*28.7% = 1,163 working-age women in Mbanayili. Therefore, there are 1,163*5% = 58 women without employment.

KAKUTE (Kampuni ya Kusambaza Teknolojia), a successful project in Tanzania, sheds light on revenue generation through harvesting and processing Jatropha. According to the economic analysis of the project by Henning in 2004, the KAKUTE project consists of three revenue generating activities: 1) collection of seeds, 2) oil extraction and 3) soap making. Values added for one person of each of the activities are 0.29 USD/hour, 0.73 USD/hour and 2.49USD/hour, respectively. To adequately reflect Ghana's price level, values added of KAKUTE project were converted using purchasing power parity (PPP) (WHO, 2000).[70] Therefore, values added per person for Ghana would be 1) collection of seeds: 0.11 USD/hour, 2) oil extraction: 0.27 USD/hour, and 3) soap production: 0.91 USD/hour, and hence could be thought of as the target performance for revenue generation.

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[70] PPP of Ghana and United Republic of Tanzania in the year 2000 is 1,124.83 and 357.967, respectively.

8.8.2. Revenue Generation Scenario

To analyze potential impacts of revenue generation in Mbanayili, this study has assumed that through training and experience, the village can achieve the same performance as KAKUTE project. The figure below illustrates a proposed scenario for creating job opportunities for Mbanayili women.

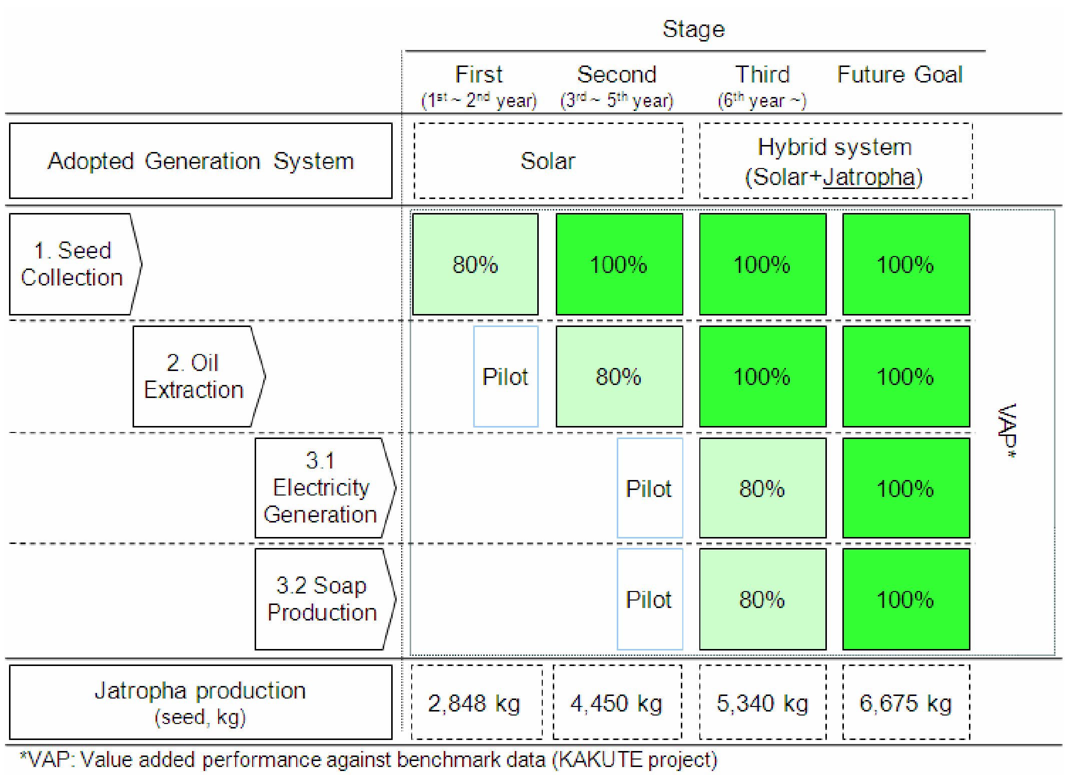

Figure 8. 24: Revenue Generation Implementation Scenario

Optimum power generation system under the current income level uses just solar power (see Section 8.7.7). Thus, this project assumes that in the first and second stages, this solar power generation system is installed and operated in Mbanayili. Then, from the third stage, the village aims to have a hybrid system, which utilizes both solar and Jatropha (benchmark model, configured in Chapter 7) to satisfy demand under the minimum control for their electricity consumption by revenue generation. In the first and second stages, this revenue generation project will increase villagers' income. In addition to this, as stated above, providing access to electricity promotes income improvement to all villagers. Thus, the income increase can help make the hybrid system affordable.

Implementing this program would involve allowing lead-time for education, training and equipment installation. Thus, the scenario consists of four stages; and the scope of the project gradually expands during the first three stages. At the first stage, the program only focuses on seed collection, which consists of harvesting the crops and selling the seeds. At the second stage, the scope is expanded to oil extraction. And starting from the third step, Jatropha oil is used for the hybrid electricity generation system as well as for soap production.

For the time being, all crops can be sold on market since they are not used as fuel for electricity generation. In the first stage, villagers gain experience from Jatropha seed collection. After being trained for oil extraction, they begin selling Jatropha oil in the second stage, and thus earn more revenue. From the third stage, with the villagers' 100% performance in oil production, the village will be capable of supplying the oil for the benchmark hybrid electricity generation system. As indicated in Chapter 7, the amount of oil necessary for the hybrid system (the benchmark generation model) is 890 L/year. The eventual goal of this scheme is not only to self-supply Jatropha oil for generating electricity but also to earn revenue. Therefore, we set the additional amount of the oil for revenue generation at 20% and 50% of the amount required for generating electricity in the third and future periods, respectively. This is illustrated in Figure 9.1. So Jatropha seeds required for such amount of oil is 890 L/year * 120% * 5 kg/L [71] = 5,340 kg of seeds per year, and 890 L/year * 150% * 5kg/L = 6,675 kg/year. 890 liters of the oil extracted will be used for electricity generation first, and the remaining oil will be supplied to soap production.

In addition, the study incorporates value added performance (VAP)[72] into the analysis to take into account the learning period before the villagers are capable of achieving the same performance as the successful KAKUTE project. Here the study assumes a gradual increase in performance within two to three years after the training. The VAPs of four activities in four different stages are shown in Figure 8.24. The assumption is that in each activity, after just being trained, people can work at 80% of the KAKUTE project's performance.[73] Then, in the next

[71] 5 kg of seeds are required for 1 liter of oil (Henning, 2004)

[72] Value added performance is defined as the relative value added level of the villagers to that of the KAKUTE project

[73] This paper assumes 80% learning curve, which is a general pattern for labor. (Ebert, 1976)

stage, the same performance of this benchmark project is achieved owing to learning effect. In addition, the figure shows seed production in the four stages based on the VAPs.[74]

8.8.3 Impact Analysis

This section assesses possibility and impacts of the proposed revenue generation scheme. Land requirements for Jatropha production, job opportunity for Mbanayili women, and revenue generated are identified.

8.8.3.1 Land Area Requirement

From the seed production, land area required in each stage can be calculated using the formula below and the seed yield of 2,000 – 3,000 kg/ha (Heller, 1996). The results are shown in Table 8.13.

$$Land \quad area \quad requirement = \frac{L/yr * kg/L}{kg/ha}$$

Table 8. 13 : Land Area Requirement in Each Stage of the Revenue Generation Scheme

Stage	1	2	3	Future
Land requirement (ha/yr)	1.19 - 1.78	1.48 - 2.23	1.78 - 2.67	2.23 - 3.34

This land requirement would be one of the constraints to implement the revenue generation scheme. Though the study could not verify the land availability for Jatropha production, the required land size appears to be reasonable for Mbanayili.

8.8.3.2 Job Opportunities for Women

Using the benchmark data from KAKUTE on workforce requirements (see Table A.4.2 in the Appendix), numbers of workers needed for the first, second, third, and future stage in Mbanayili are 6, 13, 16, and 22, respectively (see Table A.4.3). As calculated in Section 8.8.1, eventually this revenue generation scheme will reduce unemployment rate in women by 37.9% (=22/58).

[74] The seed production in the future stage is the seed production in the third stage multiplied by 150% and by VAP of 100%. So the production is 4,450 kg/year * 150% * 100% = 6,675 kg/year.

8.8.4 Revenue Potentials

With this scheme, the revenues generated at each of the stages are as displayed in Figure 8.25. Aggregate annual revenue in the first, second, third, and future stages are 157 USD, 437 USD, 1,180 USD, and 1,833 USD, respectively. This means, in the future stage, this scheme increases Mbanayili's gross income by 0.6%.

Note that the saved energy costs are not revenue generated but rather avoided fuel cost of supplying electricity. In the third stage, with the VAP of electricity generation at 80%, the operator is still incapable of efficiently running the generator. Consequently, 890 liters of oil input will yield 80% of electricity demanded. As a result, additional 20% of 890 liters of the fuel needs to be purchased to fulfill electricity demand, thus decreasing the energy cost saving. However, in the future, when the generator operator accumulates sufficient skills, the village will achieve full saving on fuel cost (i.e., VAP is 100%). That is, all of 890 liters fuel cost is saved. However, one concern is the benchmark model uses the diesel generator. To be compatible with the diesel generator, Jatropha oil has to be transesterified. Consequently, an additional system is needed to transesterify Jatropha oil.[75] Therefore, the saved energy costs will be lower.[76] In addition to avoiding diesel fuel costs, the villagers will earn greater revenue from selling more seeds, oil, and soap.

[75] The additional system consists of tanks, ethanol, and potassium hydroxide supplies

[76] There is currently no data available on how much the additional equipment and supplies would cost. Therefore, the cost of this system could not be accurately estimated.

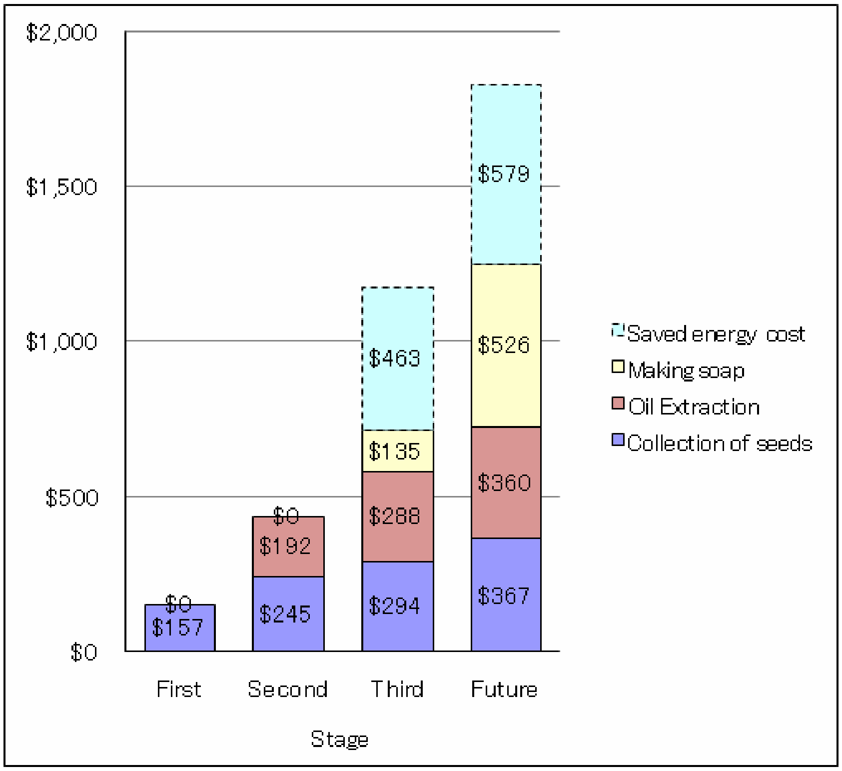

Figure 8. 25: Revenues from Jatropha for Mbanayili

As can be seen in Figure 8.25, revenue in the third stage increases drastically from the second stage (37% increase). Also, making soap which provides more value added will contribute significantly to income growth（28.7% of income increase). Furthermore, cost saving for fuel cost also shares 32% of revenue generation impact.

8.9 Conclusion and Discussion

In this chapter, after establishing the sustainability rule (annual costs must be covered by villagers), the study conducted two types of simulations (Simulation I and II) and discussed the results. The optimal sustainable generation systems for Mbanayili were then proposed. The results suggested that sustainable systems can be achieved through demand side management. These simulations, however, required significant restrictions to the villagers' electricity consumption, resulting in inability to meet some of their needs for electricity. To maximize people's benefit from electricity use, other options of decreasing electricity cost need to be explored, thus further research is needed. For example, time shifting may be another effective way to reduce the cost with minimum benefit loss.

Simulation II explored the feasibility of six sustainable generation systems in terms of their impact on controlling electricity consumptions within particular population groups, specifically elderly people, affluent people and women. The results suggested that the different interests of these groups would influence the selection of an optimal generation system for the village.

These simulation results suggested that Mbanayili villagers' income is insufficient to satisfy many of the villagers' demands. As long as a sustainable generation system is configured based on the current affordability, their electricity consumption would be highly restricted. Thus, actions should be taken not only to minimize electricity cost, but also to increase people's income.

Thus, this study showed the potential of revenue generation from Jatropha oil production. Jatropha may be able to contribute to the economic development in rural Ghana by providing extra revenue and biofuel for the generation system.

Though further research is needed to address uncertainties that were not covered in this study, this case study could present a paradigm for finding an optimal financially sustainable electricity generation system in rural villages. As of now, few rural electrification studies, which design generation systems based on people's needs, demand, and affordability for electricity, have been conducted (UNDP/ World Bank, 2003). Thus, the results of this study can hopefully guide future research as well as policy decision-makings regarding the promotion of rural electrification.

Chapter 9 Recommendations for Project Implementation

9.1 Summary of the Project

Ghana's electrification plan has stagnated because of the lack of a long-term strategy and financial resources (Chapter 2). To promote Ghana's rural electrification, this project has proposed an environmentally and financially sustainable generation system. First, to achieve cost-effective electrification, the idea of partial electrification was suggested. The study focused on the role and function of the community center as a public area for serving the villagers' needs using electricity. Electrifying only the community center will significantly reduce electrification cost while still being capable of providing access for electricity to all villagers (Chapter 3). Second, in Chapters 5 to 8, a sustainable electricity generation system was explored using a case study, Mbanayili, a rural village in northern Ghana (Chapter 4). This project first focused on the demand side, i.e. potential demand for electricity in the village. The villagers' preferences for electricity were identified by interviews. In addition, electricity consumption of the village was estimated using these preferences (Chapter 5). The study then focused on the supply side. An optimal electricity generation system was configured based on the potential electricity demand (Chapter 7). Furthermore, the potential of renewable energies was evaluated. The study identified the potential of Jatropha oil production in Mbanayili (Chapter 6). Last, financial sustainability to keep a generation system working was explored. Using the result of willingness-to-pay analysis, the study identified a financially sustainable generation system that maximizes people's benefits while meeting their affordability requirements. Also, a revenue generation opportunity through Jatropha production was examined (Chapter 8). Through these chapters, this study showed the feasibility of sustainable rural electrification, promoting rural electrification plan of the NES and contributing to the improvement of people's standard of living.

This chapter presents specific guidance for implementation of the rural electrification plan for Mbanayili and other villages in northern Ghana.

9.2 Suggested Further Research

The data availability was a critical problem in this study. In particular, no data regarding people's demand was found in other research. Though the field research clarified people's needs, owing to the time constraint of the research, the number of interviewed villagers is not large enough to be statistically valid for representing the entire village residents. To clearly understand people's needs, a larger sample may be needed. In addition, Mbanayili is very close to a city, Tamale, thus this village may have different characteristics from other northern villages. For example, while many Mbanayili villagers have seen electric appliances, people in other rural villages may not have much knowledge about electricity (see Chapter 5). That is, this village's data may not represent all characteristics of other northern villages. Conducting this research in other villages would contribute to removing Mbanayili's bias and generalize people's potential demand for electricity. With more extensive data collection, the study could be refined and thus applicable to projects in other communities. In addition, people's preferences are changing over time as can be observed from the preference difference between age groups described in Chapter 5, thus the load curve needs to be revised based on periodical preference analysis.

Furthermore, some model assumptions established in this project might be difficult to substantiate with certainty. For example, batteries or other equipment for electricity generation cannot be procured at assumed price levels in rural Ghana because transportation and immature markets may become barriers for northern villages to receive required equipment. In addition, assumed price structures may not accurately represent what is feasible under realistic or future conditions. For example, Ghana's interest rate over the last ten years is very volatile, ranging from 19.5% to 45% (Ministry of Finance, Government of Ghana, 2005). Although many of the model assumptions were based on data from the literature and similar projects, certain parameter specifications were not available or were difficult to quantify. Consequently, these specifications were based on the best estimates by the team.

Photovoltaics can play an important role in electrifying Ghana given solar irradiance available; photovoltaics have been extensively used in various electrification projects in Ghana in the past (JICA, 2006). Renewable energy derived from hydropower or wind resources was not considered a feasible option for power generation at Mbanayili because endowments of these resources are scarce in Northern Ghana. To some degree, recognition of this limited availability of alternative sources for energy production in the region has influenced the Government of Ghana's decisions to examine the feasibility of Jatropha biofuel production. The government's decisions, in part, are to offset the growing national trend of expanding thermal generation capacity, which is entirely reliant on fossil fuel imports (UN Energy, 2006). As stated earlier in Chapter 7, the prospects are promising for utilizing Jatropha cultivation as a means to spur economic development and for use as a locally produced biofuel. Although, to make any conclusive determination as to the viability and net benefits from Jatropha production for Mbanayili residents, fundamental questions must be answered (see Section 6.15) In particular, the potential market for Jatropha and the productivity of Jatropha oil in northern Ghana's climate should be firstly studied.

9.3 Recommendations for Implementation

In addition to having the carefully designed electricity consumption model and generation system, adhering to such consumption limit greatly contributes to the project's success. Also, developing and maintaining adequate skills to operate the project is needed. Furthermore, as learned from past rural electrification projects, collecting payments is essential for the project's sustainability. Taking into account these concerns, this section suggests a consumption management scheme, measures to sustain engineering skills in the village, and a payment collection scheme.

9.3.1 Necessity of Electricity Consumption Management

To be successful, controlling villagers' electricity consumption would be important. If the village cannot appropriately manage electricity consumption based on an activity schedule, the proposed project idea will not result in sustained rural electrification. Ensuring that the villagers have activities in the community center, and use only the allowed set of appliances as directed in Chapters 6 and 8, is the key to maintain electricity consumption at a financially sustainable level of electricity generation. According to the interview with one of Mbanayili's leaders, the leader can take responsibility for ensuring that the villagers follow such rules. However, monitoring electricity consumption all the time is very difficult. Thus, a consumption management scheme needs to be developed. For example, a villager may be assigned to manage the appliances. When an activity finishes, he will keep the appliances in the closed room and lock the door to prevent unnecessary electricity use. In addition, building energy conservation awareness for villagers would be a key. This could be done through education and emphasis by the community leaders.

9.3.2 Operational and Maintenance Skill Acquisition

For the generation system to be self-sustained, technical education and training for local operators are vital (World Bank, 2006). However, in Ghana, trained personnel are likely to leave their villages for working in cities with higher wages (a member of JICA, Pers. Comm., 2006).

Thus, it is very difficult to keep required knowledge and skills in villages. A suggested approach to attract the trained personnel to work for the village's community center is

- Select a villager, and not an individual from outside, to be the operator. The villagers have stronger ties to the community and thus are less likely to leave the village.
- Moreover, to attract the operator to work for the village's community center, not only setting the salary to be competitive to jobs in cities but also bestowing honor on the work position are necessary. This will offer the operator financial benefit and an honorable social status. This also explains why a villager is preferred to an outside individual. A villager will be more honored to receive this title than an outsider.

9.3.3 Payment Collection Scheme

Covering initial investment and operation costs is vital for rural electrification but very difficult due to limited financial resources and poverty. RESPRO[77] and DANIDA[78], other rural electrification projects in Ghana, which used different payment methods, show the difficulties in collecting payment. One of the reasons is that collecting payments incurs high transaction costs. For example, since a bank system does not exist in Mbanayili, periodically a person has to visit each home to collect payments. In addition, monitoring costs to prevent villagers' default are needed. Consequently, these projects could not sustain themselves financially. Therefore, effective ways to collect payments need to be studied and identified for the success of rural electrification.

Another concern is how to identify the payers when an activity has more than one participant, which is the nature of most of the activities offered in the community center. If only recipients of the benefits from electricity use pay electricity cost, the village has to identify who uses electricity for every activity. But it is difficult to do so. Moreover, as most villagers' incomes are low and fluctuate across a year, they may not be able to follow a strict payment schedule. Therefore, a flexible payment system that allows the villagers to accumulate funds or defer payment would be preferred. In addition, the pricing and payment schemes have to be

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[77] RESPRO operated under the fee-for-service model. The electricity price was defined according to the existing on-grid electricity price regardless of whether the price would cover O&M cost and recover initial investment (JICA, 2006). Therefore, the project could not generate sufficient income to be sustainably self-funding.

[78] Danish Agency for Development Assistance (DANIDA) promoted the Solar Home System (SHS). The project had the local communities loaned the money from local banks to purchase the SHSs, and eventually transferred all SHSs to the communities. However, the owners of the SHSs failed to pay for the loans (JICA, 2006).

simple so the villagers can operate without depending on outside sources by themselves. All in all, an alternative payment scheme capable of fulfilling the criteria below will be required.

- Ensure that payments are made.
- Offer flexible payment options.
- Establish service fees that are simple for the villagers.
- Provide easy payment monitoring and collection.

To guarantee revenue to the community center and allow flexibility to the payers, a group payment system may be applicable. For example, the village could create several payment groups. Each group consists of twelve people who make payments. In each month of a year, each person takes turn to pay for the service. That is, each of the group members pays once a year on different months. Such informal payment groups are proved to be successful in many remote rural areas in developing countries, including African countries (Nagarajan and Meyer, 2006). In addition, the social pressure to pay electricity bills will motivate the people paying.

For simplicity in making payment, the study suggests monthly fixed prices for villagers. The reason is that many villagers have weak math skills. The fixed fees can avoid calculation, thus prevent payment error. In addition, to cover the costs without putting much burden on the low-income people, three levels of price are determined according to the willingness-to-pay by income group (see Table 9.1). Percentage of income that the villagers[79] are willing to pay and their average income from section 8.3.3 are used for calculating such service fees. Total population of Mbanayili is 4,050. The community space can accommodate 100 persons at a time. Therefore, each villager pays a fraction of 100/4,050 of his/her willingness to pay. The fixed fees calculated are shown in Table 9.1. For example, the most affluent people with more than 150,000 cedis should pay 991 cedis per month for electricity use in the community center.

Table 9. 1 : Payment Levels under the Monthly Fixed Fee Scheme

Income Group	(A) % of WTP in income	(B) Average monthly income (cedi)	(C) Average WTP (cedi)	(E)* Allocated monthly cost for each person (cedi)	(F) Allocated monthly cost for each person (USD)
less than 100000	9.9%	61,565	6,095	150	0.02
less than 150000	13.3%	116,597	15,507	383	0.04
more than 150000	13.5%	297,380	40,146	991	0.11

:(E)=(C)(100 consumers in the community space/4,050 persons of all villagers)

[79] According to section 8.3.1 of Chapter 8, only male villagers able to afford pre-existing energy cost and willingness to pay for electricity are used for estimating the village's willingness to pay for electricity.

Combining the group payment system and the fixed fee scheme together, the group payment scheme for Mbanayili requires each person to pay for the entire year electricity consumption based on his assigned fee in Table 9.1. For example, if his monthly income is less than 100,000 cedis, he has to pay 150 cedis * 12 months = 1,800 cedis, which equals 0.2 USD. Annual payment for villagers is shown in Table 9.2.

Table 9. 2 : Annual Payment under the Group Payment System

Income Group	Allocated monthly cost for each person (cedi)	Annual payment for each person (cedi)	Annual payment for each person (USD)
less than 100,000	150	1,800	0.20
less than 150,000	383	4,596	0.51
more than 150,000	991	11,892	1.32

This approach allows the villagers to accumulate their money across a year to pay for the service. As many of them are farmers, their income fluctuates across a year. They might receive income only in the harvesting season. So, in the period that their income is low, they may not be able to make for monthly payments. On the other hand, annual payment allows the villagers to save over a year.

Also, with this scheme, members of each group are responsible for all payments of their group. Thus, if a person cannot pay in his assigned month, other group member(s) have to pay for him. To prevent this situation, the group leader and members periodically check each others' ability to pay and assist or advise them as needed. If nobody in a group can pay for a few consecutive months, they would no longer be allowed to use electricity in the community center.

Using this scheme, which is similar to a microfinance scheme, the payment would be well managed and help sustain a generation system. At monthly community leader meeting, the leaders check the amount of money collected. If the amount is less than the actual cost, next month's activity schedule may be changed to save electricity consumption and recover the previous month's loss.

9.3.4 Financial Supports

Since this project assumes that the initial cost will be covered by donors, financial support is necessary to start the project. However, the Government of Ghana may not be a promising source of funding due to its low governmental fund. Therefore, financial support from other sources is needed. Possible sources of financial support are the World Bank, foreign governments' organizations, and NGOs. Alternative to donating money to the village, the organization might lend money to the village at a low interest rate and long payback period. As this project can satisfy the financial sustainability rule described in Chapter 8, this project, either on its own or promoted through the Government of Ghana, is likely to attract foreign investors because it assures success. Currently, the World Bank is financing the Volta River Authority to implement the Energy Development and Access Project with $160 million. One of the four project's goals is to expand electricity access utilizing both grid expansion and off-grid technologies. This project could be a potential financier to this proposed community center and together significantly accelerate rural electrification in Ghana.

9.4 Conclusion

To implement this project approach, some problems have to be solved as discussed in this chapter. In particular, the scheme to control people's electricity consumption in accordance with activity schedule, retaining skills to operate and maintain a generation system and the payment collection scheme are important to the success of the project. From the experiences of other projects, ensuring payment collection should be in place before the village is electrified. To solve this issue, this study suggested the group payment system similar to the microfinance scheme. This will not only ensure sufficient revenue for the operating the system but also allow flexibility in payment in the poor rural village. Lastly, the study proposes an implementation plan, a portion of which consists of three electrification stages (see Figure A.5.1). The first stage is when the financially sustainable system is installed (2007 or 2008). After that, in the second stage, the village upgrades to the hybrid system by 2012 through the revenue generation scheme (see Chapter 8). In this stage, people's income is increased by the partial electrification as well. Lastly, by 2020, income increase accumulated during the first and second stages enable the village to afford the electrification of all households. This would contribute to Ghana's National Electrification Scheme (NES). The details of the first two steps are shown in Table 9.3 showing all results in Chapters 5 through 8.

Table 9. 3: Implementation Plan Overview

	Stages 1 and 2	Stages 3 and 4
System Architecture	**Solar Power System (PV array)**	**Hybrid System (PV array and generator)**
System components	0.4 kW PV	0.5 kW PV
	-	1.5 kW Diesel (or Jatropha)
	5 Hoppecke 4 OPzS 200	5 Hoppecke 4 OPzS 200
	0.5 kW Inverter	1.5 kW Inverter
	0.4 kW Rectifier	1.2 kW Rectifier
Total net present cost	$12,391	$27,429
Levelized cost of electricity	$ 2.499/kWh	$ 1.088/kWh
Cost (USD)		
Initial capital cost	4,922	7,747
Annualized capital cost	461	726
Annualized replacement cost	104	326
Annual O&M cost	596	939
Annual Fuel Cost	-	579
Electricity consumption		
Total consumption per year	476.2 kWh	2,506 kWh
Average consumption per day	1.30 kWh	6.87 kWh
Peak load	264 W	2,657 W
Activity Schedule	see Table A.4.1 in the Appendix	see Table A.2.3 in the Appendix
Permitted Electrical Appliances		
Parties	Light(CFL)	Television, Stereo, Speaker, Fan, Light(CFL), Refrigerator
Watching Television	Television, Light(CFL)	Television, Fan, Light(CFL)
Weddings	Light(CFL)	Television, Stereo, Speaker, Fan, Light(CFL), Refrigerator
Funerals	Light(CFL)	Stereo, Speaker, Fan, Light(CFL)
Newborn celebration parties	Light(CFL), Stereo	Stereo, Speaker, Fan, Light(CFL)
New Year parties	Light(CFL)	Stereo, Speaker, Fan, Light(CFL)
Studying (Class)	Light(CFL)	Light(CFL)
Using computer	Computer, Light(CFL)	Computer, Light(CFL)
Market	Light(CFL)	Stereo, Light(CFL)
Cell phone charging	Cellular phone charger	Cellular phone charger
Free space	Light(CFL)	Television, Light(CFL)
Cooking	-Banned-	Light(CFL), Cooking stove
Healthcare	Fan, Light(CFL), Refrigerator	Fan, Light(CFL), Refrigerator
Financial Resources		
Annual costs	Villagers' income (Willingness to pay, 720USD)	Villagers' income (Willingness to pay), increase with revenue generation scheme
Initial costs	Foreign governments, international development organizations	
Revenue Generation from Jatropha		
Processes	Seed collection	Seed collection
	Oil extraction	Oil extraction
		Electricity generation
		Soap production
Jatropha seed production	2,848kg (2007 - 2008) 4,450kg (2009 - 2011)	5,340kg (2012-) 6,675kg (future goal)
Land requirement for Jatropha plantation	1.19 - 1.78ha (2007-2008) 1.48 - 2.23 ha (2009 - 2011)	1.78 - 2.67ha (2012 -) 2.23 - 3.34ha (future goal)
Expected revenues	157 USD (2007 - 2008) 437 USD (2009 - 2011)	1,180 USD (2012 -) 1,833 USD (future goal)
Workers needed	6 individuals (2007 - 2008) 13 individuals (2009 - 2011)	16 individuals (2007-2008) 22 individuals (future goal)
Electricity Price (per month by income level)		
less than 100,000cedis	1,800 cedis (0.20 USD)	(Further research is needed based on future income level)
less than 150,000cedis	4,595 cedis (0.51 USD)	
more than 150,000cedis	11,892 cedis (1.32 USD)	
Reference	Chapter 8	Chapter 7 (benchmark configuration)

Appendix

Appendix 1: Field Research Overview (Chapter 4)

Figure A.1. 1: Mbanayili

Table A.1. 1: Questionnaires

1.Customer Type

1.1 The number of person in family

Name	Age	Gender	Occupation
		Male, Female	Student, Agriculture, Trading, Manufacturing, Other:

1.2 The income of the household/month

	cedis/month

1.3 Current energy use

	Expense/month	Purpose
Gas		Cooking, Lighting, Other:
kerosene		Cooking, Lighting, Other:
Charcoal		Cooking, Lighting, Other:
Fuelwoods		Cooking, Lighting, Other:
Other( )		Cooking, Lighting, Other:

1.4 Distance from the house and the community center

	m from the center of the village

1.5 Knowledge for electricity

	Electricity appliances	Have you seen ?	Have you used ?
1	Radio	Yes, No	Yes, No
2	Electric lamps	Yes, No	Yes, No
3	Fan	Yes, No	Yes, No
4	Refrigerator	Yes, No	Yes, No
5	TV	Yes, No	Yes, No
6	PC or cellphone	Yes, No	Yes, No

2.Activity Information

2.1 Activity needs in the community space

	Category	Activity	**Question:** Preference for activity When
1	Entertainment	Watching TV	-----Sunrise-----breakfast-----lunch----dinner-----
2	Culture	Wedding ceremonies	-----Sunrise-----breakfast-----lunch----dinner-----
3	Culture	Funerals	-----Sunrise-----breakfast-----lunch----dinner-----
4	Culture	New Baby celebrations	-----Sunrise-----breakfast-----lunch----dinner-----
5	Education	Studying (class)	-----Sunrise-----breakfast-----lunch----dinner-----
6	Education	Using computer	-----Sunrise-----breakfast-----lunch----dinner-----
7	Business	Market	-----Sunrise-----breakfast-----lunch----dinner-----
8	Business	Cell phone charging	-----Sunrise-----breakfast-----lunch----dinner-----
9	Others	Free space	-----Sunrise-----breakfast-----lunch----dinner-----
			-----Sunrise-----breakfast-----lunch----dinner-----

2.2 needs for electricity by category (10 scores)

	Point allocation (3pt, 5pt, 10pt)	How much can you pay for electricity?
Entertainment		
Health		
Culture		
Education		
Business		
Others		/month

2.3 The needed appliances for activities (Mainly questions for community leaders)

	Activity	Main appliances	**Question** (which appliances are needed in addition to the main appliances?)
1	Watching TV	TV	Lighting, Fan, Other(
2	Parties	-	Lighting, Fan, Radio, Refrigerator, TV, Speaker, Audio, Other(
3	Wedding ceremonies	-	Fan, Refrigerator, TV, Speaker, Audio, Other(
4	Funerals	-	Lighting, Fan, Speaker, Audio, Other(
5	New Baby celebrations	-	Lighting, Fan, Speaker, Audio, Other(
6	Studying (class)	Lighting	Fan, Projector, Other(
7	Using computer	Laptop, Internet Cable	Lighting, Fan, Other(
8	Markets	Lighting	Audio, Other(
9	Free space (for chatting, reading books)	-	Fan, Refrigerator, TV, Speaker, Audio, Other(

3. Benefit of Activity

3.1 Benefit Analysis

Which do you prefer?

	Option	Time for usage	Ans			Time for usage	Ans
Q1	Watching TV	60		Q2	Studying (Class)	60	
	Parties	60			Using computer	70	
		Time for usage	Ans			Time for usage	Ans
Q3	Markets	60		Q4	Free space	60	
	Cell phone charging	Anytime			Cooking	10	
		Time for usage	Ans			Time for usage	Ans
Q5	Watching TV	60		Q6	Studying (class)	60	
	Using computer	20			Free space	60	
		Time for usage	Ans			Time for usage	Ans
Q7	Parties	60		Q8	Markets	60	
	Using computer	100			Free space	40	

4. Necessity of Fan in rainy season

Needed, not Needed

Appendix 2: Potential Demand Analysis (Chapter 5)

Table A.2. 1: Models and Sources for Electrical Appliances Data for Activity Preference Survey

Activities	Appliances	Power consumption (W)	Total (W)	Products	Information Sources
Watching television	TV	78	373	Sanyo CM29EF8C /A	http://www.sanyo-ssm.com/overseas/products_catalog/products/audio_visual/color_tvs/dynamic_maestro_spec.html
	Fan	240		Sanyo 16-inch fan (60W) * 4	http://www.sanyo-ssm.com/overseas/products_catalog/products/home_appliances/fans_coolers_cleaners_stove/ef_bs16sts_nd.html
	Lighting	55		Steca Solsum ESL 1112 *5	http://store.solar-electric.com/sol12voldcli.html
Parties	Lighting	121	381	Steca Solsum ESL 1112 *11	see above
	Fan	240		Sanyo 16-inch fan (60W) * 4	see above
	Stereo	20		Sony CFD-V8	www.mysonycenter.com (Sony Center Ghana)
Studying (Class)	Fan	240	260	Sanyo 16-inch fan (60W) * 4	see above
	Stereo	20		Sony CFD-V8	see above
Using computer	Computer	150	221	A typical desktop	University of Colorado Environmental Center "A typical desktop PC system is comprised of the CPU, a monitor and printer. CPU requires from 50 to 150 watts for a 15-17 inch monitor."
	Lighting	11		Steca Solsum ESL 1112 *1	see above
	Fan	60		Sanyo 16-inch fan (60W) * 1	see above
Markets	Fan	240	240	Sanyo 16-inch fan (60W) * 4	see above
Cell phone charging	Cell phone charger	3.3	3.3		the Fone Shop http://www.geocities.com/thefoneshop/Products.html
Free space	Lighting	121	381	Steca Solsum ESL 1112 *11	see above
	Fan	240		Sanyo 16-inch fan (60W) * 4	see above
	Stereo	20		Sony CFD-V8	see above
Cooking	Cooking stove	2600	2600	GE® 30" Free-Standing Electric Range Model #:JBS03HWH	General Electric

Table A.2. 2: Electrical Appliance List

Community Center Area	Appliance	Price (each) (Cedi)	Power consumption (each) (W)	Service life (years)	Qty	Total Price (Cedi)	Total power consumption (W)	
Open Space	Television 21"	2,500,000	30	12	1	2,520,000	30	AC
	Radio Cassette	945,000	15		1	945,000	15	AC
	Speaker	426,150	15.9	15	1	426,150	15.9	AC
	Desktop Computer	7,200,000	150	5	1	7,200,000	150	AC
	Ceiling Fan 36"	270,000	55	12	4	1,080,000	220	AC
	CFL	25,000	8	6	11	275,000	88	DC
	Cooking stove 30"	460,000	2600	15	1	460,000	2600	AC
	Cellular phone charger	-	3.3		4	0	13.2	AC
	Refrigerator 46 Liters	1,500,000	17.8	10	1	1,500,000	17.8	DC
Health Clinic	Ceiling Fan 36"	270,000	55	12	1	270,000	55	AC
	CFL	25,000	8	6	3	75,000	24	DC
	Vaccine Refrigerator	1,500,000	12.5	10	1	1,500,000	12.5	DC

Table A.2. 3: Activity Schedule of Year 2007

Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
1-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch										■			■
	After Dinner	■											■	
	Bedtime													
2-Jan	Before Breakfast									■				
	After Breakfast									■				
	After Lunch		■											
	After Dinner	■												
	Bedtime													
3-Jan	Before Breakfast										■			
	After Breakfast			■										
	After Lunch			■										■
	After Dinner			■										
	Bedtime			■										
4-Jan	Before Breakfast			■										
	After Breakfast							■						
	After Lunch										■			
	After Dinner		■											
	Bedtime													
5-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch									■				■
	After Dinner	■												
	Bedtime													
6-Jan	Before Breakfast									■				
	After Breakfast									■				
	After Lunch										■			
	After Dinner	■											■	
	Bedtime													
7-Jan	Before Breakfast													
	After Breakfast							■						
	After Lunch									■				■
	After Dinner		■											
	Bedtime													
8-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch											■		
	After Dinner	■												
	Bedtime													
9-Jan	Before Breakfast										■			
	After Breakfast					■								
	After Lunch					■								■
	After Dinner	■												
	Bedtime													
10-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch										■			
	After Dinner	■												
	Bedtime													
11-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch													■
	After Dinner	■												
	Bedtime													
12-Jan	Before Breakfast									■				
	After Breakfast				■									
	After Lunch				■									
	After Dinner				■									
	Bedtime				■									
13-Jan	Before Breakfast				■									
	After Breakfast							■						
	After Lunch									■				■
	After Dinner		■											
	Bedtime													
14-Jan	Before Breakfast									■				
	After Breakfast							■						
	After Lunch										■			
	After Dinner	■											■	
	Bedtime													
15-Jan	Before Breakfast										■			
	After Breakfast							■						
	After Lunch										■			■
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
16-Jan	Before Breakfast													
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
1-Jul	Before Breakfast													
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities											
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
16-Oct	Before Breakfast									■				
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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16-Nov	Before Breakfast													
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
16-Dec	Before Breakfast													
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Appendix 3: Biofuel Potential from Jatropha Curcas Linn. (Chapter 6)

A.3 Other Energy Sources Considered (not modeled)

A.3.1 Mini Hydropower

The Ghanaian Government has considerable interest in expanding the installed capacity of mini hydropower, specifically in the southern regions of the country. Twenty-one sites have been identified as suitable for the installation of mini hydorpower, however, all of these sites are located in the south (JICA, 2006); no such sites have been identified near Mbanayili. Furthermore, the topography around Mbanayili is quite flat and is not considered conducive for this application (Alhassan, Pers. Comm., 2006).

A.3.2 Wind Resources

Ghana is not endowed with significant wind resources, except for in isolated patches typically located in the mountainous regions, the southern coast, or the Volta River Basin (NREL, 2004). The average national wind speed is less than 3m/s at an elevation of 10 meters; however, wind velocities are higher at elevations beyond 50m above the ground (164 ft). This may be unrealistic for many rural applications, because inexpensive turbine towers do not reach these heights, and towers that do are prohibitively expensive, unless substantial wind resources are available to justify higher capital investment. Few turbines begin to produce power below 5 m/s and many do not provide peak power until wind speeds approach 8-10 m/s. According to the Energy Commission, Tamale, located ca.14 km from the site of this case study, exhibits an average monthly wind velocity of 3.9 m/s (JICA, 2006). Therefore, wind power is not considered a viable option for the micropower systems in Mbanayili.

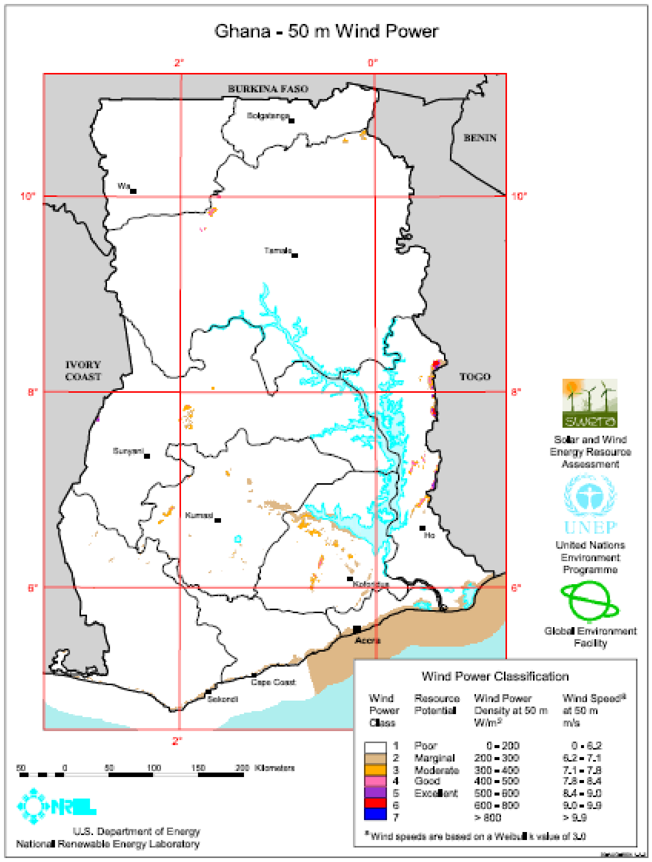

Figure A.3. 1: Wind Power Potential in Ghana (Source: NREL)

As previously mentioned, there is evidence to suggest wind farms might be economically viable in mountainous regions and in offshore installations on the southern cost. A recent study by Riso Laboratory (Denmark) and the Energy Commission (Ghana) indicates strong potential for installing an offshore wind farm. Preliminary estimates claim sustained wind speeds of 5m/s, which is generally considered the minimal requirement for large scale wind projects to be economically viable (Ackom, 2005). Despite the strong desire to incorporate wind into the model—because of its cost competitiveness with grid electricity—there is no evidence to suggest that a wind turbine would be a viable solution for energy production at this site and was thus omitted from this model.

Appendix 4: Financial Sustainable System Modeling (Chapter 8)

Table A.4. 1: Activity Schedule for An Optimal Financially Sustainable System in Simulation II

Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
1-Jan	Before Breakfast													
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
16-Jan	Before Breakfast													
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17-Jan	Before Breakfast													
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
1-Feb	Before Breakfast													
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
16-May	Before Breakfast													
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
		Watching Television	Having Party	Wedding Ceremonies	Funerals	Newborn Celebrations	Muslim New Year Parties	Classes	Using Personal Computer	Markets	Cooking	Free Space	Cellular Phone Charging	Health Activity
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Date	Time Period	Activities												
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Table A.4. 2: Work Rate of KAKUTE Project

	Work rate
Seed collection	2 kg/hour
Oil extraction	5 kg of seeds/hour
Making soap	9.7 bars/hour

Table A.4. 3: Detailed Calculation on Revenue Generation Scheme

		unit	Stage: First year 1-2	Stage: Second year 3-5	Stage: Third year 6	Stage: Future	Benchmark Value Added
Activities	Target seed production	%	80%	100%	120%	150%	
Collection of seeds	Production	kg	2,848	4,450	5,340	6,675	$0.11
	Work time	hr	1424	2225	2670	3337.5	
	VAP	%	80%	100%	100%	100%	
	hourly wage	$	$0.11	$0.11	$0.11	$0.11	
	total value added	$	$156.64	$244.75	$293.70	$367.13	
Oil Extraction	Production	L		712	1068	1335	$0.27
	Work time	hr		890	1068	1335	
	VAP	%		80%	100%	100%	
	hourly wage	$		$0.22	$0.27	$0.27	
	total value added	$		$192.24	$288.36	$360.45	
Electricity generation	Oil input required	L			890.00	890.00	$0.65
	VAP	%			80%	100%	
	energy cost saving				$463.20	$579.00	
Making soap	Production	bar			1794.24	5607	$0.91
	Work time	hr			185.12	578.5	
	VAP	%			80%	100%	
	hourly wage	$			$0.73	$0.91	
	total value added	$			$134.77	$526.44	
	Total hours		1,424.00	3,115.00	3,923.12	5,251.00	
	# of needed workers (@4hrs*60days/yr)		5.93	12.98	16.35	21.88	

	Stage: First	Stage: Second	Stage: Third	Stage: Future
Collection of seeds	$157	$245	$294	$367
Oil Extraction	$0	$192	$288	$360
Making soap	$0	$0	$135	$526
Saved energy cost	$0	$0	$463	$579
Total	$157	$437	$1,180	$1,833

Appendix 5: Recommendations and Future Plans (Chapter 9)

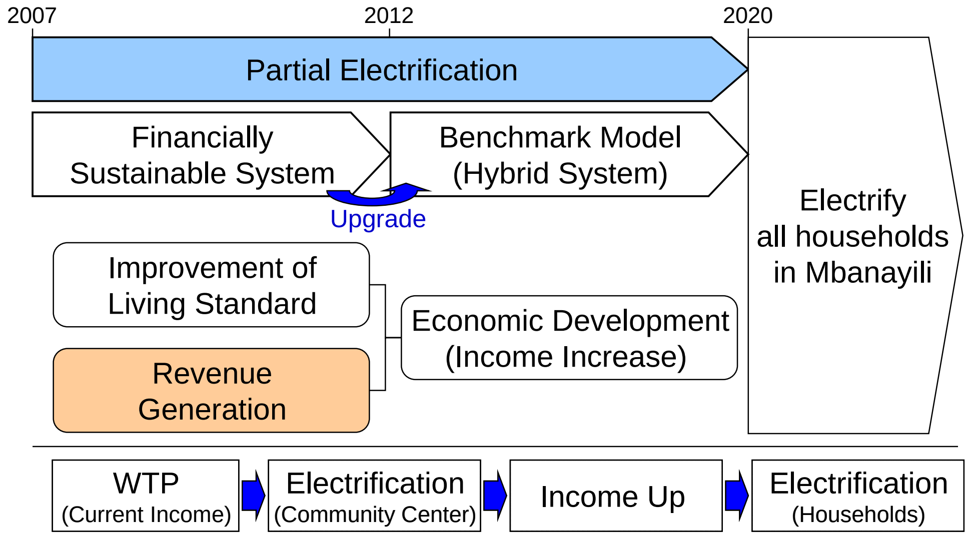

Figure A.5. 1: Implementation Plan

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