



WPI



Sustainable Energy Sources for Rural Ghana

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Abstract

This project investigated renewable energy sources for Mr. Kofi Amofo, a machine shop owner from Ghana, West Africa, who now works in England because high diesel prices in Ghana made his business unprofitable. In addition to a system recommendation, this project created tools to assist in the identification and implementation of compatible renewable energy systems in Ghana. These tools included a questionnaire and flow chart to identify energy options and a database of NGOs in Ghana, to identify possible project sponsors.

Executive Summary

The primary concern of this project was to determine an energy recommendation for a functional renewable power system for Mr. Kofi Anim Amofo, a machine shop owner from Ghana, West Africa. Mr. Amofo moved to and now works in England to pay for daily shop operations in Ghana because the cost of his diesel-generated electricity marginalized his business. With a renewable energy source, he could expand his business, reduce his overhead costs, or both, while reducing the carbon emissions and climate impacts of his business operations.

Our work began with Mr. Amofo's problem, but our later work extended beyond his energy needs and attempted to address the larger problem of energy implementation in Ghana. We developed tools to help other energy-interested Ghanaians determine which energy system would be best for their needs, and how to locate nongovernmental aid to help implement the system.

To begin the project we researched various renewable energy sources, the costs of diesel in Ghana, the social climate of Ghana, and the types of aid reaching the nation from international organizations. We also searched for case studies of power implementation in rural areas, with which we could make our approach as effective as possible. We attempted to obtain an understanding of any obstacles blocking power implementation and industrial development in Ghana.

We developed a list of possible systems for Mr. Amofo's workshop and used climate information, local maps, and anecdotes provided by Mr. Amofo to attempt to determine which systems would be most helpful to his situation, and the most feasible to install. We located numerous vendors and developed estimates of the most inexpensive systems, as well as projected returns of investment and risks of installation. From these factors, we determined that more information was needed to make a final decision, but that a number of introductory data collection techniques could result in a solution in a relatively short period of time. At issue were available wind speeds and the prices of solar photovoltaic systems, and with further study a resolution may be achieved. Wind measurements were readily available, but were problematic in that the entire town's wind speeds over the course of a full day were boiled down into one single, averaged value. A profile of daily wind speeds taken directly from Mr. Amofo's shop would provide a much clearer indication of the potential of wind power. Solar power systems

were so expensive that at the cost of the diesel fuel he would replace, Mr. Amofo would not profit from his investment for the first 19 years of the system's life. However, with rapid development of cheaper and more efficient solar technology, the future will bring systems which will be more suitable for replacement of diesel fuel as a large scale power source.

In our research we came into contact with Hugh Piggott, a man whose specialty is handmade windmills, and who has worked on energy projects in Ghana. We purchased plans for a windmill, which allow Mr. Amofo to have a new business opportunity, making and selling the devices, without substantially increasing his operating costs. In this way, we provided a means to expand his business without increasing the costs which prevent his return home. In addition, should further study prove wind a feasible option, Mr. Amofo can build a small windmill for himself, with which to power his shop.

As we believed Mr. Amofo was not the only person whose business had lost profits due to energy prices, we attempted to widen our project work and to create a number of tools based on the work we had done. Our goal was to provide others wishing to undertake a renewable energy project in Ghana with the tools necessary to determine possible power options and the organizations most suited to the work required to implement such power options. We developed a database of nongovernmental organizations (NGOs) operating in Ghana, and a questionnaire and flow chart intended to determine feasible power solutions for a given area.

We first developed a questionnaire, based on the questions we asked Mr. Amofo in order to determine practical power options for him. The questions dealt with, among other topics, the availability of resources to make systems function, and social structures which may aid or impede installation. The flow chart then uses the resource answers to guide users to suitable power options for their homes or businesses. It also includes a list of equipment for each system, which allows the user to determine which system is most practical for his situation.

We used Microsoft Access to build a database of nongovernmental organizations (NGOs) operating in Ghana. It contains fields for contact information both in Ghana and abroad. The NGO database is organized by each organization's specialty, and allows users to search for applicable organizations for the work they do. The information was collected from Ghana's government website, which contains a listing of organizations operating within Ghana's borders.

We developed a list of recommendations, in addition to these tools, for further study, later projects, and the next steps required to provide Mr. Amofo with a source of energy. Our recommendations for Mr. Amofo are to:

- Acquire more accurate wind measurements over Mr. Amofo's workshop.
- Wait for improvements in solar technology to reduce system prices.

The development of our tools yielded a rather disheartening statistic, in that only 3 of the NGOs we located deal specifically in electrification. Many organizations deal with the largest communities possible, and would be far more likely to support a townwide initiative for power than a single shop. As a result, funding could be problematic for a large energy system for one workshop. To circumvent this problem, we recommend:

- Attempting to involve the chief of his town, and his general community at large, to attract larger NGO support.
- Organizing London's Ghanaian community to support energy projects.

Although we developed tools to aid energy implementation, we did not attempt to make our project work well known, and other projects should attempt to disseminate the tools and processes we have developed. These tools may be useful both in London and in Ghana, and further work should involve Ghana's education system. Collaboration with higher education in Ghana can help to make this work well known and develop methods to reach Ghana's most remote areas. We recommend that further project work should explore:

- Finding means to disseminate tools and attract local (London) attention.
- Involving Ghana's technical schools and universities in energy implementation.

Authorship

The members of this project group assumed roles in order to specialize and be more productive. Steve Kalach took responsibility for electrical infrastructure, and all work pertaining to databases and information cataloging. Mike Brown took responsibility for biofuels and Ghana, and built the tools, databases and flow charts, upon which this project heavily relies. Dan LaFrance assumed the role of primary author for many of the sections, but relied later on heavy editing from all members to produce a finished project.

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1. Introduction

In recent years there has been a growing gap between the respective wealth of the very rich and very poor nations of the world. According to the Human Development report of 2000, “in 1999 the world’s two hundred richest people have approximately \$1 trillion while the incomes of the 582 million people living in the 43 least developed countries only have approximately \$146 billion.”¹ As a result, there has been a growing worldwide effort to decrease this gap and raise standards of living in the world’s poorest nations. This stems in part from the worldwide interest in stopping the spread of infectious diseases, hunger, and poverty. Currently there are “approximately 790 million people in the developing world who are chronically under nourished”² and approximately “30,000 children die each day due to poverty.”³ The first world nations are interested in helping underdeveloped countries establish the infrastructure necessary to sustain themselves; this includes electrical power generation, education, agricultural development, social reforms, and the development of stable democracies.

The need for electrical infrastructure has become paramount in the last decade. However, determining the best power solutions has become increasingly difficult. Petroleum has historically been a standard means of powering generators in areas lacking electrical infrastructure. However, increasing oil prices have made this a prohibitively expensive solution. Demand for oil grew in 2004 by about 2.4 million barrels per day⁴, and with increased demand comes a proportional increase in price. In the US in 1970 a barrel of oil cost about \$10 compared to about \$40 today (in 2003 USD)⁵. Skyrocketing oil costs have made oil and gasoline-based power more expensive to produce, and less viable as an inexpensive energy source. In many nations, the price of petroleum far exceeds the possible earnings of businesses relying on petroleum power, stagnating business growth in the areas which would benefit most from it.

In recent decades, there has also been pressure from the scientific community to reduce carbon emissions due to global warming effects; this has in part led to the Kyoto Protocols for carbon emissions. Under the Kyoto Protocols, 141 nations (including Ghana and the UK) have agreed to lower their carbon emissions. The protocols outline a system of carbon credits, based

¹ Human Development Report: <http://hdr.undp.org/reports/global/2000/en/> pg.82

² World Resources Institute Pilot Analysis of Global Ecosystems:
http://projects.wri.org/project_description.cfm?ProjectID=88

³ State of the World’s Children 2005: <http://www.unicef.org/sowc05/english/index.html>

⁴ Department of Energy Forecasts and Analysis: <http://www.eia.doe.gov/oiaf/ieo/oil.html>

⁵ Department of Energy Forecasts and Analysis: <http://www.eia.doe.gov/oiaf/ieo/oil.html>

on carbon output goals and current output. A nation exceeding its goal (having lower CO₂ production than expected or desired in a given year) can sell its credits to a nation which is lagging behind and producing too much CO₂.⁶ This system creates a free market into which lesser polluters (which tend to be nations not yet fully industrialized and receiving some degree of international aid, including Ghana) can raise revenues by selling carbon production credits.

As part of the UK’s comment to the Kyoto Protocol some government agencies, including the London Borough of Merton have taken the initiative to reduce carbon emissions and promote alternative energy. England, the world’s first industrialized nation, has a history of industrial pollution and is making strides in environmental cleanup with the Borough of Merton as a major leader. Merton’s initiatives include the “Ten Percent Renewables” plan requiring all buildings with floor areas over 1,000 m² to provide at least 10% of their expected power use in renewable energy sources⁷.

Merton also hosts a large Ghanaian population, including some forced to leave home due to sinking business ventures caused by steep inflation as seen in Figure 1. One such individual is Kofi Amofo. His machine shop is powered with a diesel generator, and with diesel fuel becoming more expensive, his business has lost much of its economic viability. He has been in the UK since 2003 working to help fund his business in Ghana. Ghana is experiencing double digit inflation, due largely to petroleum costs more than doubling in the last year⁹. Renewable energy and lessened dependence on

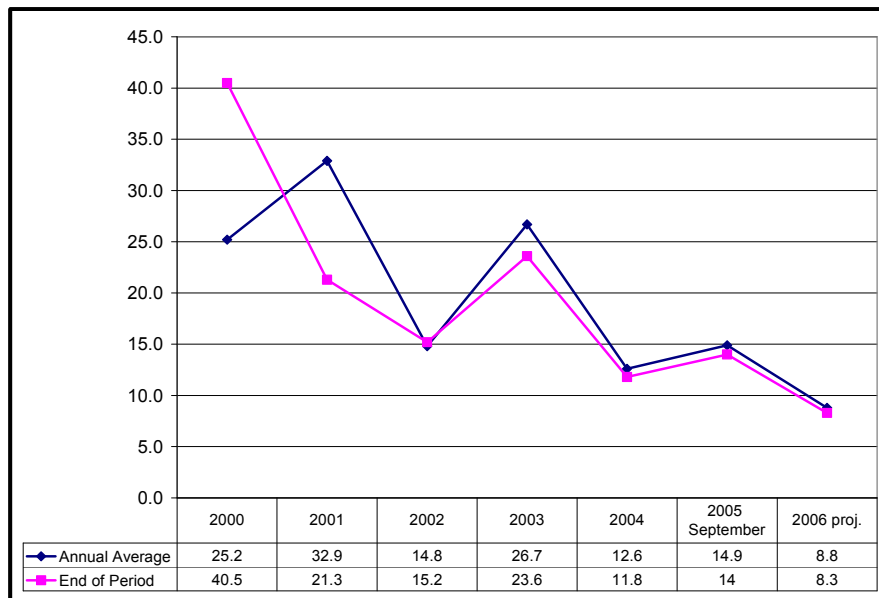


Figure 1: Ghanaian Percent Inflation⁸

⁶ Clauses in the Kyoto Protocols, available for viewing online:
http://unfccc.int/essential_background/kyoto_protocol/items/1678.php

⁷ Taken from Merton’s website, “Ten Percent Renewables Policy”:
<http://www.merton.gov.uk/living/planning/plansandprojects/10percentpolicy.htm>

⁸ Ghanaian National Budget 2006 pg. 41 <http://www.ghanaweb.com/GhanaHomePage/economy/budget2006.doc>

⁹ Taken from Ghana Review International, originally from Ghana Review:
<http://ghanareview.com/review/index.php?class=BEF&date=2006-02-23&id=13207>

petroleum would greatly aid Ghana's growing economy.

The UK relies on a centuries-old coal power structure which pollutes heavily; a short ton of coal burnt creates 2500 to 5000 pounds of CO₂.¹⁰ Ghana, without a highly developed power grid, has potential to develop decentralized low carbon electrical generation, from which it can sell carbon credits to the UK. Decentralized power is necessary to electrify rural areas. Low carbon energy sources bring the potential for Ghana to free up carbon credits for sale in the world market. Some of this money can (among other uses) replace foreign aid in the form of development money, and free up aid funding for other nations in need.

There have been numerous advances in renewable energy technology in the last 10 years, fueled by the Kyoto Protocols and attention to climate change, some of which may be pertinent to Ghana's case. Recently there has been a grassroots movement in the US and EU nations to provide electric and automobile power organically, or with new technologies not involving burning fuels. Solutions in rural areas include biomass, the use of waste matter to provide heat and methane upon decomposition, which can be used as a burnable fuel and reduces both the necessity of landfills and one's dependence on outside power.¹¹ Wind turbines now appear in coastal areas and flat, windy plains and atop mountains in the western hemisphere. Though still more expensive than fossil fuel, wind turbines provide assistance to power grids, and harness wind energy to make their electricity without any emissions. Additionally, since there is little maintenance required for many of them, they provide power for a frozen price rate for their entire lifetime. Ethanol and methanol, staples of drag and stock car racers for years,¹² are now being added to gasoline to reduce toxic emissions and General Motors has released a "Live yellow, go green" advertising campaign pushing more ethanol capable vehicles.¹³ Natural disasters worldwide have led to increased discussion of global warming, and a desire to counteract it via clean renewable power. As a result of increasing demand, there has been heavy research and investment into renewable resources in recent years, and the technology is growing cheaper and more effective, and demand is growing with it.

¹⁰ Department of Energy website: <http://www.eia.doe.gov/oiaf/1605/factors.html>

¹¹ Klass, 29-31

¹² ITDG Biogas and Liquid Biofuels , 4. Taken from:
http://www.itdg.org/html/technical_enquiries/docs/biogas_liquid_fuels.pdf

¹³ Taken from <http://www.gm.com/company/onlygm/>

While Ghana produces over 50% of its power using hydroelectric generators,¹⁴ the nation still depends heavily on fossil fuels. The national power grid is confined to the southern half of the nation and only about half of Ghana's citizens have access to grid power.¹⁵ The rest of their power must be created on site, often using environmentally hostile and expensive diesel generators. The need to power a rapidly industrializing nation is too great to ignore, but there is not enough return on power grid expansion to make the process viable.¹⁶ Independent power sources are necessary, and must also be inexpensive and clean. Diesel fuel, in addition to producing around 20 pounds of carbon dioxide per gallon burned¹⁷, has other noxious and sometimes carcinogenic emissions. Such emissions, in a land without exceptional access to hospitals (especially in rural areas) provide a hazard over long term that could be avoided by using less polluting fuels or alternate means for power production.

Using Kofi Amofo's case as an example, this project's mission is to provide a model for implementation of renewable energy solutions in Ghana. By focusing on an individual and providing a viable solution funded by some form of aid, the London Borough of Merton can provide a methodology and cost estimate for rural Ghanaian areas, and begin to systematically aid those who need help to become more economically independent, or those who wish to repatriate. By creating a list of capable aid organizations, and matching Mr. Amofo's specific needs to a functional renewable energy solution, this project intends to aid Kofi Amofo specifically. With help and a model to follow, it is hoped that we can also aid other rural workers hoping to better access consistent electric power. Along with this we also hope to assist others seeking to return to Ghana but can not due to energy related problems.

¹⁴ Guide to Electric Power in Ghana, 11

¹⁵ Guide to Electric Power in Ghana, 7

¹⁶ Guide to Electric Power in Ghana, 8

¹⁷ Taken from <http://www.eia.doe.gov/oiaf/1605/factors.html>

2. Background

Kofi Amofo, like many others in London, is a Ghanaian national living in the Borough of Merton. He has lived there for 3 years, working to pay for repairs and upkeep of a machine shop in rural Ghana. The diesel generator powering his shop is tremendously costly, and also releases a tremendous amount of carbon dioxide and other caustic emissions. The London Borough of Merton has taken interest in helping to change his power system to something with fewer or no emissions. It is hoped that installing a renewable energy system in his shop can save him energy costs, increase the profits of his business, and promote similar energy systems throughout Ghana. Along with increased financial holdings, emission reduction provides Ghana with a chance to sell carbon credits under the Kyoto Protocols. In order to produce an individualized system which is also widely applicable, his needs and available resources must be obtained. From the methods used to obtain these needs and resources, a methodology can be established for use with other individuals in similar circumstances. In order to understand the problem for Kofi Amofo and for Ghana as a whole, it is important to understand his individual case, and how it relates to the Borough of Merton and the UK, the Kyoto Protocols, the nation of Ghana, renewable energy, and aid in Africa.

2.1 Ghana

Ghana's economic situation is one not common in Africa. The nation, driven by a remarkable school system, is industrializing rapidly. Growth stands at over 5.5% per year, relying heavily on cocoa production and gold mining.¹⁸ Under the "Highly Indebted Poor Countries" agreement of 2004, Ghana will have money for public investment, which will go to increasing energy reliability, one of the major infrastructure crises Ghana faces (the other being corruption, which cannot be solved with more funding).¹⁹ With a combination of increased cocoa production, mining, and infrastructure development, Ghana's GDP is expected to grow at 5.9% for 2006.²⁰ Among Ghanaian President John Kufuor's national plans is a major macroeconomic restructuring, including removing utility subsidies and privatizing previously government owned public utilities. Kufuor's hope is that private utilities will encourage more

¹⁸ "Ghana" from Ghana Country Monitor, 2006, page 29.

¹⁹ "Ghana" from Ghana Country Monitor, 2006, page 29.

²⁰ "Ghana" from Ghana Country Monitor, 2006, page 30.



Figure 2: Ghana Physical Map

private investment, making Ghana encourage the growth and development of larger industries, and bolstering government finances.²¹

In early 2005 the government stopped subsidizing petroleum, causing a 50% increase in prices in one month.²² This trend has caused tremendous inflation, reaching double digits annually, in both oil and food, which threatens to stagnate economic growth.²³ February 2006 inflation was expected to top 14%.²⁴

Transportation costs factor into food and beverage prices, and fuel prices alone increased 50% last year.²⁵ Gasoline cost ₵34,850 (Ghanaian cedi) per gallon (4.01 USD) on April 3, 2006.²⁶ Many workers are forced to leave Ghana for periods of several years due to marginalized and failing

business measures, and head for the United Kingdom to save and send money home. In total, Ghana received over \$4.25Billion in 2005 in remittances (funds sent home by expatriated workers).²⁷ A full 41% of Ghanaians sampled by Dalen (et. al) wanted to emigrate, nearly 80% for economic reasons, and ten percent would not emigrate, because they lacked financial means to do so.²⁸ These numbers will only increase with time as prices skyrocket, and until such time

²¹ "Ghana" from Ghana Country Monitor, 2006, page 32.

²² "Ghana" from Ghana Country Monitor, 2006, page 29.

²³ "Ghana" from Ghana Country Monitor, 2006, page 30.

²⁴ The Ghana Review International, Feb. 26, 2006. Online at: <http://ghanareview.com/review/index.php?class=BEF&date=2006-02-23&id=13207>

²⁵ The Ghana Review International, Feb. 26, 2006. Online at: <http://ghanareview.com/review/index.php?class=BEF&date=2006-02-23&id=13207>

²⁶ The Ghana Review International, Feb. 26, 2006. Online at: <http://ghanareview.com/review/index.php?class=BEF&date=2006-02-23&id=13207>
Also, conversion factors April 3, 2006, from: <http://wpp.greenwichmeantime.com/time-zone/africa/ghana/currency.htm>

²⁷ "Ghana" from Ghana Country Monitor, 2006, page 31.

²⁸ Hendrik Dalen & George Groenewold & Jeannette Schoorl, 2005. "Out of Africa: what drives the pressure to emigrate?," Journal of Population Economics, Springer, vol. 18(4), pages 741-778, November Taken from <http://ideas.repec.org/p/dgr/uvatin/20030059.html#provider> on April 3, 2006.

as petroleum prices stabilize. For Ghana to become a truly viable agricultural and manufacturing nation, it will need to find cheaper energy.

2.1.1 Country overview

In 1957, Ghana became the first colony in Sub-Saharan Africa to gain its independence, and for the first 35 years of its existence experienced various levels of political control by military regimes. The cycle of military regimes lasted until 1992 when Ghana held free national elections. Currently Ghana holds elections for its president and vice president every four years with a two term limit, and has a unicameral legislative body.²⁹

Ghana has a national population of 21 million people is currently ranked as the 52nd largest country in the world. Its land area is comparable to that of Oregon³⁰.

2.1.2 Current electrical infrastructure

Historically the electricity sector in Ghana has been entirely government funded. The Volta River Authority (VRA) is responsible for generation and transmission of electricity, while the Electricity Company of Ghana (ECG) and the Northern Electrification Department (NED), a subsidiary of the VRA, are responsible for the power distribution.³¹ The VRA own and operate two hydroelectric plants, the Akosombo plant and the Kpong plant. Along with the two hydroelectric plants there are four thermal plants (meaning that they burn fossil fuels) in operation, all in the Southern portion of Ghana (Figure 3).

²⁹ CIA Factbook, Ghana: <http://www.cia.gov/cia/publications/factbook/geos/gh.html#People>

³⁰ CIA Factbook, Ghana: <http://www.cia.gov/cia/publications/factbook/rankorder/2119rank.html>

³¹ Guide to Electric Power in Ghana, pg. 1

Generation Source	Effective Capacity (MW)	Percent of Total Available Effective Capacity	Installed Capacity (MW)	percent of Installed Capacity
Hydro:				
Akosombo	850		1020	
Kpong	120		160	
Total Hydro	970	56	1180	55
Thermal:				
TAPCO	320		330	
TICO	220		220	
TDS	15		35	
OECF Barge	0		125	
Total Thermal	555	32	710	33
Imports	200	12	250	12
Total Installed Capacity Including Imports			2140	100
Total Available Effective Capacity	1725	100		81
System Coincident Peak Demand*	1200	70		56
Reserve Margin	525	30		25

Figure 3: Generating Capacity of Ghana

Ghana’s electrical infrastructure is currently in a restructuring phase. With the “World Bank no longer offering assistance for developing countries in the electricity sector”³² Ghana was forced to restructure and invite private development. The hope is to make the electrical sector safe for investors and thus create competition which will make the electricity industry stable. With only 45-47% of Ghanaians on grid electricity there is still room for expansion in the market, especially in rural areas where only 15-17% of the population has grid electricity.³³ With more private development the competition created may drive expansion into the more rural areas

2.1.2.1 Current capacity for growth

Ghana’s electrical consumption is ever growing. “Over the past two decades it has grown at 10-15% a year and is expected to grow at 6% a year over the next ten years.”³⁴ This growth is mainly attributed to urbanization, projected to grow from “40% in 2000, to 55% by 2012 and 60% in 2020.”³⁵ Coupled with the current economic growth (4-5% a year)³⁶ the ever increasing urban population will consume more electricity. “In 2004 energy consumption was 6,004 GWh,

³² Guide to Electric Power in Ghana pg.28

³³ Ibid pg. 1

³⁴ Guide to Electric Power in Ghana pg. 2

³⁵ Ibid pg. 2

³⁶ Ibid pg. 2

with an expected load growth of 6% over the next decade the load will reach 9,300 GWh by 2010.” “Residential needs will reach anywhere between 7000-13000 GWh by 2020 with commercial and industrial sectors to reach anywhere from 3000-10000 GWh.”³⁷ Currently expansions to thermal plants are being planned, along with new plants such as the Bui Hydroelectric plant, and combined cycle thermal power plant in Tema. Along with this Ghana is involved in the West African Power Pool (WAPP), an agreement between 14 West African countries “dedicated to connecting their electrical grids in order to boost power supply in the region.”³⁸ The West African Gas Pipeline (WAGP) is also expected to come online later this year and provide natural gas to the region. This steady supply of natural gas will significantly reduce the cost of natural gas in Ghana and will also be used to bring the OECF Barge online, increasing the effective capacity of Ghana by approximately 125 MW.

2.1.2.2 Typical Usage of Electricity in Ghana

Electrical usage is usually separated into three sectors: residential, commercial, and industrial. Approximately 50% of Ghana electrical usage is associated with residential usage, and this percentage is expected to grow with continuing urbanization. “The uses include lighting, ironing, refrigeration, air conditioning, television, radio, etc.” “Residential consumers are usually comprised of middle and high income urban users who often own a few high-energy consumption items while the rest of the residential users mainly just use electricity for lighting.” Often many homes are grouped together on one electrical system and share their basic amenities. “Commercial users are usually comprised of banks, offices, and other small businesses” while “industrial users are comprised of mines and aluminum companies.”³⁹ “Industrial use is usually constant regardless of season or time of day, while commercial use is considered less constant and can vary depending on the season, and residential use is not considered constant and can vary seasonally and also throughout the day depending on user needs.”⁴⁰

³⁷ Ibid pg. 23

³⁸ Ibid pg. 51

³⁹ Guide to Electric Power in Ghana pg. 1

⁴⁰ Ibid pg. 5

2.1.2.3 Obstacles to electrification in Rural Ghana

Electrification of rural Ghana has been hindered mainly by the lack of financial stability in the electrical sector. “Despite government financing the VRA and the ECG both incur major debts which in turn slow their operational capability.”⁴¹ The main reason this debt exists is not clear but is expectedly due to “inefficiencies, inability to collect bills and/or charge cost-reflective tariffs.”⁴²

Year	1997	1998	1999	2000	2001	2002
Operating Profit/(Loss)	61.2	18.7	79.2	(257.9)	(220.0)	(582.5)
Net Profit/(Loss)	(58.6)	(105.2)	(283.2)	(983.3)	(329.7)	(1,269.1)

Figure 4: Profit and loss figures for the VRA (Billion cedi)

Year	1997	1998	1999	2000	2001	2002
Operating Profit/(Loss)	(33.9)	6.0	17.3	(13.6)	152.9	(85.3)
Net Profit/(Loss)	(80.9)	(27.5)	(79.2)	(394.0)	110.1	(380.5)

Figure 5: Profit and loss figures for the ECG (Billion cedi)

On top of the major debt (Figure 4 and Figure 5) it is even less lucrative to extend power lines out to rural areas. “It is very expensive to build long distance lines just to serve a small community because those in the community can not usually afford to pay rates high enough to cover the cost of getting the lines there.”⁴³ “Also there is evidence showing that there is no noticeable increase in economic activity in those communities that have benefited from getting grid power.”⁴⁴ Though it is not known necessarily why this is the case, the cause may stem from the tariffs placed on the consumers which may make economic expansion not possible.

“Smaller, locally installed alternative energy sources can be more affordable, such as solar power, etc,”⁴⁵ thus creating a case for a decentralized power solution. By eliminating the cost of sending lines over large areas the only fee is startup and maintenance. Though these fees

⁴¹ Ibid pg. 37

⁴² Ibid pg. 36

⁴³ Ibid pg. 2

⁴⁴ Guide to Electric Power in Ghana pg. 2

⁴⁵ Ibid pg. 2

can be large, there is no cost of fuel for energies such as wind or solar. Decentralized power in rural Ghana there becomes a more affordable and more economically friendly alternative.

2.1.3 Climate and Resources

To implement renewable power, one must utilize available resources. Ghana claims 540 kilometers of coastline, and its northern regions are dry grassland. As a result its climate is widely varied, from tropical in the southwest corner of the nation to very hot and arid in the north. The north suffers from recurrent droughts which have become an environmental concern, and there are strong northeast winds through the first three months of the year. The southern coastline is relatively dry, and the nation as a whole is hot, as it sits close to the equator at latitude of about 8° north.⁴⁶

2.2 The Borough of Merton

The Borough of Merton is a section of southwest London and is committed to promoting environmental responsibility. Located in the southwestern part of the city, the borough is home to a large number of wards, smaller neighborhoods with their own elected councilors. The Pollards Hill ward is home to a large number of Ghanaians, among a large minority population which accounts for 39.8% of the general population.⁴⁷ Assuming Pollard's Hill is an accurate cross section of the all of Merton, the top ten personal concerns of the population include environmental pollution, poor public transportation, and littered streets.⁴⁸ The borough as a whole takes environmental reform very seriously and has enacted plans, including 10% Renewable Plan, outlined in the introduction, to reduce its emissions in order to attain or exceed its Kyoto Protocol commitments.

2.2.1 Demographics and Ghanaians in Merton

While specific data on nation of origin is not available from the 2001 census, London as a whole boasts almost 400,000 Black Africans living within its borders, as compared to a total population of about 7.2 million. Blacks from the Caribbean comprise a similar portion of the

⁴⁶ CIA Factbook, Ghana: <http://www.cia.gov/cia/publications/factbook/geos/gh.html>

⁴⁷ From Merton's Ward Profile of Pollards Hill, page 3: http://www.merton.gov.uk/pdf-ward_profile-pollards_hill.pdf

⁴⁸ From Merton's Ward Profile of Pollards Hill, page 4: http://www.merton.gov.uk/pdf-ward_profile-pollards_hill.pdf

population, and Indians slightly higher. Whites include over 5 million people.⁴⁹ Merton has sections with much higher minority populations, notably in the Pollards Hill (39.8%) and Longthornton (49.7%) wards.⁵⁰

The largest gathering of Ghanaians in Merton is in the Pollards Hill ward. Pollards Hill claims a population of about 40% minority.⁵¹ While specific data on nation of origin for these people is not available, the largest minorities in the census are blacks, African and Caribbean, and Indians, comprising approximately equal numbers.⁵²

2.3 Kyoto Protocols

Worldwide, there has been growing concern about CO₂ emissions. Global warming has led to a series of initiatives worldwide to limit industrial pollution and curb a dangerously rapid warming trend. In 1997, 141 nations joined a collective agreement called the Kyoto Protocols, wherein they established a system of reductions in greenhouse emissions involving members' pledges to reduce emissions by a certain year to a percentage of a base year (e.g. 92% of a nation's 1990 emissions).⁵³ England and Ghana are both members of the agreement, which also provides for carbon swapping- whereby a nation which exceeds its requirement must buy (at market value) credits for its remaining carbon balance, from a nation which has not exceeded its requirement. The nations who reduce emissions stand to profit financially, and the entire world benefits from reduced carbon output.

England has a strong dependence on coal. Cheap coal power fueled the Industrial Revolution, and has remained a vital part of British energy; to this day, coal is the source for 29% of Europe's electricity.⁵⁴ Coal is also among the worst culprits in the growing issue of global warming. Until the British reduce their dependence on coal power, they must buy carbon credits to meet their commitments to the Kyoto accord. Ghana has widespread hydroelectric

⁴⁹ 2001 London census data, available at: <http://www.statistics.gov.uk/census2001/profiles/h.asp>

⁵⁰ From Merton's Ward Profile of Longthornton, page 3: http://www.merton.gov.uk/pdf-ward_profile-longthornton.pdf

⁵¹ From Merton's Ward Profile of Longthornton, page 3: http://www.merton.gov.uk/pdf-ward_profile-longthornton.pdf

⁵² 2001 London census data, available at: <http://www.statistics.gov.uk/census2001/profiles/h.asp>

⁵³ Fletcher, Susan R "Global climate change: The Kyoto Protocol" Congressional Research Service January 15, 2003, Copyright 2003 Congressional Information Service, Inc. Policy

⁵⁴ Fletcher, Susan R "Global climate change: The Kyoto Protocol" Congressional Research Service January 15, 2003, Copyright 2003 Congressional Information Service, Inc. Policy

power⁵⁵, and has little development of power north of the capital city, Accra.⁵⁶ Ghana has the potential to develop a power base of almost entirely renewable energy, and to then sell its carbon credits to England so the British can meet their Kyoto Protocol obligations. Such a situation merits London's interest as well as Ghana's, and creates in London an incentive to develop renewable energy solutions with Ghana.

2.4 Energy alternatives

A number of different energy sources have emerged in recent years (and some have existed even decades) to combat carbon dioxide emissions and provide reliable power for either single term implementation costs or very low upkeep costs. While most of these initiatives are still more expensive than fossil fuel extraction, more research and development, driven by increased interest and demand, can lead to more efficient and lower costing measures (as was the case with the computers of the last decade.) Thus, increased reliance on alternative energy sources will make them viable. Sources include, but are not limited to, auto fuels such as ethanol, biodiesel, and straight vegetable oil (SVO), methane captured from biomass decomposition (or "sewer gas") and turbines powered by wind or flowing water in place of steam power from standard thermal and nuclear power plants.

2.4.1 Bio Fuels

Fuel emissions are a major source of carbon emissions, accounting for 32.4% of the United States' carbon dioxide emissions in 2003.⁵⁷ Concern about the emissions from standard petroleum (which also include emissions involved in acquisition of fuels) has led to a movement toward cleaner fuels. Ranchers and farmers use approximately 3 billion gallons of biodiesel nationwide⁵⁸, an example of the growing use of biofuels, organic compounds made from food stocks such as corn, which are approximately negligible in their carbon output. The stocks are replanted after harvest, and the new crop consumes much of the CO₂ emitted by the burning of

⁵⁵ Guide to Electric Power in Ghana pg. 10

⁵⁶ Ibid pg. 1

⁵⁷ Department of Energy: Emissions of Greenhouse Gases in the United States 2003, <http://www.eia.doe.gov/oiaf/1605/gg04rpt/carbon.html>

⁵⁸ Greg Anderson, United Soybean Board chairman, available through European Biodiesel Board website, http://www.ebb-eu.org/pressdl/Bush_visit_biodiesel_plant.htm

the fuels.⁵⁹ The most common forms of biofuels are biodiesel, a diesel substitute produced from vegetable oil, straight vegetable oil (which can be used in a conventional diesel engine), and ethanol and methanol, grain alcohols which are relatively cheap and easy to produce, and can be used as gasoline additives.

2.4.1.1 Ethanol

Ethanol and methanol are standard alcohols, and have for years been used to power drag racers (which require very fast acceleration and tremendous power.) They are usable in small volumes as gasoline additives in standard automobiles, but they often do not stand alone in this use. Burning either of these fuels requires a change of engine timing and certain engine parameters, as they burn about 15% more efficiently and also produce less heat per unit volume than standard gasoline.⁶⁰ Chevrolet has a number of vehicles in production as part of its “Live green, go yellow” campaign which can run on pure gasoline or up to 85% ethanol.⁶¹ Other automakers will likely soon follow this trend, as ethanol research is rapidly making production cheaper and more efficient.

2.4.1.2 Biodiesel

In recent years the demand for alkyl esters / methyl esters or Biodiesel has been an increasingly lucrative. This is in large part to an increasing concern of fossil fuel emissions and increasing fuel costs. Biodiesel can be made from vegetable oil and animal fats in three different methods, the most popular of which is Transesterification of vegetable oil, using methanol as a catalyst. The process of making Biodiesel yields glycerin and methyl esters; the methyl esters are used as fuel and the glycerin is sold and recycled into soap and other products. Biodiesel is attractive as a fuel oil as it is much cleaner than petrodiesel, and it can be produced from virtually any plant or vegetable oil, and can be mixed with petrodiesel in any ratio. Grades of biodiesel are named based on the percentage of the fuel that is biodiesel, B##. For example, a fuel blend that is 20% biodiesel and 80% petrodiesel would be labeled B20 whereas 100% biodiesel would be labeled B100

⁵⁹ Klass, 30-32

⁶⁰ Poulton, 53-56

⁶¹ From Chevrolet’s website: http://www.gm.com/company/onlygm/energy_flexfuel.html

2.4.1.2.1 Properties

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AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA		
Emission Type	B100	B20
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
Nox	+10%	+2%
Non-Regulated		
Sulfates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

* Estimated from B100 result
 ** Average reduction across all compounds measured
 *** 2-nitrofluorine results were within test method variability

liesel, a fuel oil
Biodiesel is the

Figure 6 Biodiesel vs. Diesel ⁶²

only bio fuel oil to be tested by the Environmental Protection Agency. That testing has helped to prove the substantial environmental benefits that Biodiesel has as a fuel oil. Compared to petrodiesel, biodiesel is a much cleaner alternative. According to the EPA B100 produces 67% fewer unburned hydrocarbons, 48% less Carbon Monoxide and 47% less particulate matter. In addition it produces significantly fewer Sulfates, Polycyclic Aromatic Hydrocarbons (PAH), and nitrated PAH's. With the exception of Nitrous Oxide, biodiesel exceeds the emissions of regular diesel fuel. These figures can be seen in Figure 6 and they clearly show the environmental benefits of Biodiesel.

2.4.1.2.2 Production

The most common means of making biodiesel is transesterification using methanol as a catalyst. For this process, methanol and lye are mixed together in proportions based on the pH and quantity of the oil. The resulting solvent, known as methoxide is then mixed with the oil, heated and mixed vigorously until the oil and methoxide have been thoroughly mixed. After this point the mixture must sit so that the glycerin can separate from the methyl esters. The glycerin,

⁶² http://www.biodiesel.org/pdf_files/fuelfactsheets/emissions.pdf

which settles to the bottom of the mixture, is then removed. The methyl esters are then “washed” and “dried” to remove any soaps that were created from an excess of lye in the methoxide mixture. The biodiesel is now ready for use in any diesel engine without modification.

Biodiesel is relatively simple to make, and can be made in a two liter soda bottle, or in much large quantities and with much more complex, automated setups. Since the biodiesel movement in the United States, until recently, has been a largely grass roots effort, there are several different methods that people have employed to build their own biodiesel reactors which range from 5 gallon buckets with a drill and a paint mixer, to setups that are nearly automated.

2.4.1.3 Straight Vegetable Oil (SVO)

Along with the grass roots effort that have popularized biodiesel, Straight Vegetable Oil (SVO) conversions for diesel engines have popularized in recent years. Any diesel engine can be converted to run on virtually any vegetable oil. The original Diesel engine ran off of Peanut oil, and, in the words of inventor Rudolf Diesel, "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it. The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time."⁶³ Unlike biodiesel, SVO requires more initial setup and modification to the engine, however, long term it is easier to sustain than making biodiesel.

There are many initial modifications that must be made to the diesel engine before it can burn SVO. There must be two fuel tanks, one for vegetable oil, and one for diesel/biodiesel. In addition, unlike Biodiesel, SVO must be heated to 160F in order for the fuel to burn properly in the diesel engine.⁶⁴ The diesel engine must also be turned on and shut off running on diesel fuel. If the engine is turned off with the car still burning vegetable oil, polymerization of the oil can occur if the engine is allowed to cool down with vegetable oil in the cylinders. This can turn the normally slippery oil into a sticky glue rendering the engine useless. In automobile applications, hot coolant is pumped from the engine to a heat exchanger in the fuel tank. When the temperature gauge on the car reaches its normal operating temperature, the car can be switched to run on vegetable oil, and back to diesel fuel. It is harder to set up initially to run an engine on

⁶³ <http://www.biodieselwarehouse.com/>

⁶⁴ “Theory,” Frybrid, <http://www.frybrid.com/svo.htm> (accessed Apr. 17, 2006).

SVO, but long term it is easier to sustain, and less costly than the constant manufacture of biodiesel.

Due to the fact that SVO conversions are not as widespread as the manufacture of biodiesel there has not been the same investigation into the emissions of vegetable oil as a fuel oil. It is assumed that since biodiesel is a derivative of vegetable oil, that the two must have similar statistics in emissions and cleanliness. While biodiesel requires less engine conversion, SVO presents more opportunities for developing countries with an agrarian base. For machinists it presents an opportunity to manufacture their own conversion kits to sell, and for farmers it presents the opportunity to cultivate their fields with crops that will provide fuel oil.

2.4.2 Bio Mass

One organic fuel particularly applicable to rural areas is biomass, a method of composting which produces methane gas. Methane is commonly used as a burnable fuel and is produced in great quantities by landfills and organic decomposition. It is the majority of natural gas (with other gases added to and naturally occurring with it) with which many people heat their homes. Natural gas is considered a fossil fuel, meaning it is extracted from the ground and composed of decayed organic material from long ago. However, in more self sufficient areas people can extract methane from their own compost heaps. By creating a chamber in which to trap one's waste- garbage, organic materials, and even human and animal waste- one can control the outflow of products of decomposition- including methane. The process results in methane, as well as nutrient rich slurry, which can be useful in fertilizer, and it is an anaerobic process, so it does not allow for the survival of waste-ridden bacteria.⁶⁵ In the simplest sense, one builds a tank with a one way entry valve, and loads the chamber with compost and water as needed. Out of the top one attaches a piping mechanism which functions as the same sort of inlet pipe as goes to American homes powered by natural gas. The slurry is periodically removed via a third outlet, to be used and to make room for more compost. The figure shows a sketch of a normal biomass reactor with an agitator in the center.

⁶⁵ Biomass and Liquid Biofuels, 1-3 from:
http://www.itdg.org/html/technical_enquiries/docs/biogas_liquid_fuels.pdf

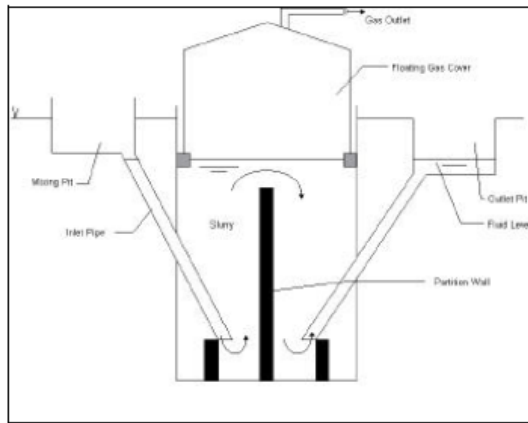


Figure 7: A Biomass Reactor⁶⁶

2.4.3 Wind and Hydroelectric Power

The concept of wind turbines is a marriage of two concepts which have long been used in power applications. Windmills have existed for centuries, and have harnessed the wind to drive irrigation and milling operations more efficiently than human power could drive them. The turbine is used in fossil fuel burning power plants by burning fuel of some kind to heat water into steam, and using steam to drive a turbine.⁶⁷ The spinning turbine is responsible for electric power, driving a magnetic coil and inducing current. The wind turbine uses wind instead of steam to directly spin a turbine and produce power. It spares the infrastructure and emissions of a fossil fuel plant, but carries the risk of unreliability- the turbine does not spin without wind, and in times of still breezes it operates with little output. Hydroelectric dams operate on a similar principle, using water to drive turbines, and are more reliable, as most rivers do not simply dry up. Water constantly flows through the turbine and thus the dam provides a consistent source of power. The advantages of these systems are that they have no emissions and after implementation are inexpensive and require no fuel. The disadvantage, however, lies in the building process and continued use. They must be built in the correct location (where there is reliable wind or a river will not dry up) and even then may not provide consistent output. Wind requires a battery system to be more consistent, which drives up its cost. Also, costs of upkeep

⁶⁶ Biomass and Liquid Biofuels, 4. from: http://www.itdg.org/html/technical_enquiries/docs/biogas_liquid_fuels.pdf

⁶⁷ From NOW with Bill Moyers: <http://www.pbs.org/now/science/wind.html>

can be high, and these machines require a high degree of skill to repair, which may make them less applicable to a rural area.⁶⁸

2.4.4 Solar power

Areas of intense sunlight are employing the sun for energy through the use of solar power. Solar power harnesses sunlight through one of two mechanisms; solar thermal generation involves heating plates of glass which heat a transfer liquid (such as water or oil), which is harnessed directly for heat through a heating system, or in the same fashion as standard turbine power plants.⁶⁹ Photovoltaic cells use sunlight to bounce off of and excite electrons, causing electron flow, and electric current.⁷⁰ In areas of intense sunlight, such as the American southwest, solar energy can be a tremendously powerful resource. A plant going into service in 2007 in Boulder City, Nevada, is expected to produce 64 megawatts, enough power for 40,000 homes, and the equivalent greenhouse gas reduction of removing approximately one million cars from the nation's roads.⁷¹ Solar power has potential for expansion as renewable power demand grows. The principle reason it is not yet extremely common is that it is not yet cheaper than grid power. However, the price has come down tremendously from its original price, and efficiency has improved dramatically. The first laboratory production of photovoltaic solar energy had 6% efficiency and cost about \$600 per watt.⁷² Through research and development, the price has fallen drastically (to under \$0.25 per kilowatt-hour in an industrial system in sunny climate today⁷³). While not yet cheaper than coal, with increasing demand raising research in renewable power, solar power has potential to become viable in coming years.

2.5 Current Implementation in Sub Saharan Africa

The UN has taken up the cause of renewable energy, both as a means to combat global warming and to uplift poor areas and promote economic development.⁷⁴ The use of electricity is extremely important to economic development, and as a result some organizations devote

⁶⁸ From NOW with Bill Moyers: <http://www.pbs.org/now/science/wind.html>

⁶⁹ Winter, C.-J., 199-201.

⁷⁰ Winter, C.-J., 54-56.

⁷¹ New solar receiver tubes unveiled. (Conservation & Renewables). *Bulletin (Northwest Public Power Association)* 60.3 (March 2006): p11(1). Retrieved by Thompson Gale Power Search, <http://find.galegroup.com>

⁷² REPP-CREST Solar Power FAQs: http://www.crest.org/articles/static/1/995469913_2.html

⁷³ Price taken from <http://www.solarbuzz.com/SolarIndices.htm>, April 9, 2006, using System III

⁷⁴ UN Press release, April 11, 2006:

<http://www.un.org/apps/news/story.asp?NewsID=18122&Cr=climate&Cr1=change>

themselves to renewable and reliable power installation. Organizations like AREED (African Rural Energy Enterprise Development), a UN initiative in developing parts of Africa, pride themselves on offering “rural energy entrepreneurs in Mali, Ghana, Tanzania, Senegal and Zambia a combination of enterprise development services and start-up financing” to begin businesses producing sustainable renewable energy.⁷⁵ USAID, a federal government agency which does charitable foreign aid work world-wide, notes that the majority of the world’s unelectrified population lives in impoverished rural areas, and critical to raising them out of poverty is the need to provide power.⁷⁶ Other organizations, including Mali-Folkecenter (an extension of Danish Folkecenter for Renewable Energy)⁷⁷ represent aid from other nations in African nations. Many of these organizations take up rural power as a major issue but also give way to other needs- the more pressing life threatening issues of hunger and AIDS, for example- as priorities. In areas of extreme poverty, electrification is often a major need, but requires more attention and effort and is only starting to be remedied.

2.6 Conclusions

Ghana is a nation with peace and stability, an uncommon situation in West Africa. However, while rapidly growing and expanding its technological base, it still relies heavily on outside aid. Many people are forced to leave due to high costs of living, and double-digit inflation driven by, among other causes, high energy costs. The national power grid is expanding, but still not reaching far across the nation, and in order to power rural areas, petroleum is an expensive but necessary fuel. Increased reliance on renewable energy would help to ease the country’s fuel uses, lowering costs and raising standards of living, especially as fuel costs continue to rise. The Borough of Merton is home to a large number of Ghanaian expatriates, and has taken up the charge of helping to solve Ghana’s energy problems. Through an examination of renewable energy solutions as they can apply to various areas of Ghana, it may be possible to power the nation cleanly (in accordance with the Kyoto Protocols) and cheaply in the coming years, creating a model for industrialization in West Africa.

⁷⁵ From AREED’s home page: www.areed.org

⁷⁶ USAID’s Sub Saharan African energy development:
http://www.usaid.gov/our_work/economic_growth_and_trade/energy/rural_energy/index.html

⁷⁷ Available online at <http://www.malifolkecenter.org/>

3. Methodology

Given the previously mentioned topics, there is a tremendous need for functional, inexpensive power in the rural sections of Ghana which lack grid access. In order to present a widespread solution, we created a model based on practical examples- a mechanism which will allow philanthropic organizations and individuals to achieve maximum effectiveness in their aims. By providing a solution for Kofi Amofo and his particular village, this project presented methods for determining power needs and acceptable responses, cost analysis, and implementation of power in remote areas.

Our mission was to identify energy alternatives that would be compatible with Mr. Amofo's shop, and to create a model for the implementation of such systems such that any individual will be able to easily reproduce the process we underwent to help Mr. Amofo.

In order to achieve this mission, we accomplished four main objectives:

1. Identified energy related requirements for Kofi Amofo to return to his home.
2. Identified power options to meet his needs with reasonable maintenance and repair, and recommended an energy system to reduce his dependence on diesel power.
3. Developed processes and tools for system implementation based on prior successes in rural energy development.
4. Developed a system to evaluate processes and tools for effectiveness.

Our case involved developing a framework to fund and manage installation of a renewable power source for Mr. Kofi Amofo's shop, and this case may eventually lead to other test cases. Funding for Kofi Amofo's power source came from a source defined in objective 3, which contains information for petitioning Non Governmental Organizations for funding. There were two ultimate deliverables of this project: a recommendation for a system of electrical generation for Mr. Amofo's shop, and a guide for other Ghanaians hoping to return to their homes to determine the type of solution and aid associations necessary for them to do so. We were unable to witness the conclusion of Kofi's individual story, since the system did not come to fruition in the seven week period. However, by identifying NGOs and finding funding for projects, we believe that we have built a set of tools to allow individuals like Kofi to return to Ghana and lead prosperous lives.

3.1 Identifying energy requirements for Kofi Amofo to return home

Kofi Amofo left Ghana three years ago because his energy costs were too high to maintain his business. Without a solution to his energy problem, he is unable to return home. The goal of this project was, first and foremost, to name a solution to his energy problem, and find a means to fund and implement it. The first issue was his exact power need. Before we could solve his energy problem, we had to know the scope of his energy requirements. We knew from his answers to a prior questionnaire (see Appendix F: Kofi Amofo's Answers to Previously Posed Questions), that among other machines, Mr. Amofo owns and operates five welding machines. In order to attempt to understand the associated power requirements for the workshop, we searched for information about different types of welding machines. Depending on the nature of these machines, our research indicated that they could require up to (or if he uses older models, more than) 12kW of power during operation. If his largest power draw were actually only a 6kW machine and he only operated one at a time, there would be a much easier solution than there would be with 5 of the 10-12kW machines operating simultaneously. To determine exactly what he needed for power, we asked him directly during an interview, as he knew more specifics (such as brand and model names, year of purchase, etc.) about the machines he uses than he presented in the initial questionnaire's overview list of machines.

We interviewed Mr. Amofo on May 31, 2006, along with his cousin Philip, in the Merton government building and discussed a number of topics. We wrote an interview script (see Appendix A: Script for interview with Kofi Amofo) with a list of pertinent topics and questions we wanted to discuss with him. Our goal was to ask questions about as many pertinent topics as possible so that we would not require a second interview, since Mr. Amofo is a worker in London and did not have a lot of free time. Most important were those of his business practices- how many and which machines he operates simultaneously, how much fuel he uses on a regular basis, etc- and available resources and local topography. In order to develop renewable power, he needed some sort of resource, such as wind, sunlight, a river, or available biomass which could be harnessed for energy. These questions allowed us to build a framework for the scope of the energy need (how much power we should attempt to provide him with), the possible energy solutions, the extent of his energy problems (as they relate to the high costs of petroleum), and what kind of area his home town, Abetifi, is in. We also asked questions about local power and whether his generator was his only power source.

Our research along with the *Guide to Electric Power in Ghana* indicated that Ghana's power grid extends north from Accra, the capital which is on the coast, up to the interior of the country, but was unclear about how far the electrical grid extends into the northern regions of the country. We were not certain as to whether Mr. Amofo had access to the grid and used his generator to supplement the electricity he purchased from the electrical grid, or if he depended solely on his generator for electrical power.

With questions about local topography and resources, we were looking for a few key types of information, the first being temperature. We were particularly interested in an average yearly profile of high and low temperatures. In order for biomass reactors to work properly, the region must have fairly consistent average temperatures, with few extremes between high and low temperatures. The next piece of climate information that was crucial to helping identify a potential energy source is average wind speed and altitude. Altitude and wind speeds are vital to wind power since wind turbines require a minimum wind speed to produce electricity. Proximity to a body of water, in this case Lake Volta, can cause lake effect winds which could produce winds strong enough to power a wind turbine. The next vitally important piece of climatological data is sunlight duration, as this could help to determine if Abetifi would be a suitable region for solar power generation. The general geography of the region is also vitally important; for example if Mr. Amofo's workshop were near a river, micro-hydroelectric power could be a potential candidate. With knowledge of the available resources, we would be able to make the most informed recommendation for a feasible power source.

The questionnaire also contained questions about his business in Abetifi to gain a better understanding of his abilities as a skilled craftsman. Our research led us to a company that specialized in developing plans, and teaching classes in the construction and installation of homemade wind turbines⁷⁸. These plans and courses could potentially allow Mr. Amofo to supplement his energy generation with renewable sources, and also as a means to extend the realm of his business through the manufacture and sale of wind turbines. If he were to build his own windmill, he could prove their usefulness, and then market them to other people in the region who wanted a small amount of power for their homes. We asked him about this idea so that he could decide if he was willing to undertake the process of solving the problem for himself, and for his community.

⁷⁸ www.scoraigwind.com

In short, we met this objective by interviewing Kofi Amofo with emphasis on his power needs, his grid access, and the available resources in his hometown.

3.2 Identifying power options to meet needs, maintenance and repairs

To make a power system recommendation, one must determine which systems will actually work and will be feasible to install and maintain. A windmill in an area without wind will not produce power, and an extremely expensive or failure-prone system can require too much continued maintenance to justify its use. Installation and repair costs, as well as probability, frequency and cost of failure, are major concerns in a rural area where access to the materials and equipment required may be limited. These are factors we considered when deciding on available power options.

The cost of implementation and maintenance of renewable energy sources is of primary importance to their economic sustainability. In order to identify options that will have reasonable implementation costs and low maintenance we looked at prices set by vendors for various renewable energy systems. These included wind turbines, micro hydro turbines, photovoltaic systems, and their required electrical components, to attempt to establish a price range for each of these systems, using a base estimate of a 30kW power system. We came to this estimate based on the assumption that Mr. Amofo would operate simultaneously, in peak business times, three arc welders (each at approximately 10kw), since they require the most electricity, or several smaller machines. The questions relating to Mr. Amofo's power usage in the interview were used to develop a more accurate estimate, but with even a base estimate, implementation costs could be adjusted to meet the actual values at a later time. Working with the 30kW estimate, we searched for photovoltaic systems, wind turbines, new, used, and handmade, and micro hydroelectric turbines and created a price per watt for the base components. These systems have direct current outputs, which require conversion to alternating current for most uses, but the estimate was based strictly on the components generating the energy. We then developed an estimate for a 30 kW system, so we would have a rough idea of the most expensive and most cost effective systems. After completing the interview with Mr. Amofo, we revised our estimate of his energy consumption based on the data he provided us pertaining to his machinery.

We also spent time in the British Library looking for case studies of power implementation. Among other things, we looked for problems associated with power systems in

remote areas, the relative success rates of different systems and any major concerns, such as fires, floods due to hydroelectric dams etc. for the different systems. As Mr. Amofo relies heavily on having consistent electrical energy, we wanted to minimize the amount of upkeep required for his energy system so he would not have to interrupt work to perform repairs. The number, type, extent, and cost of repairs become a major concern which we wanted to minimize.

This objective was primarily achieved through research, which allowed us to make an informed decision with regard to power choices when we had to make a final recommendation. Armed with figures on approximate costs for various renewable energy systems, maintenance and any major concerns of failure, we were able to make the most cost-effective decision. With the climate data and local topography information, we were able to decide which of the reasonably affordable options would be the most effective. With both of these kinds of information available, we were able to determine what would be the most practical energy solution for Mr. Amofo's shop.

3.3 Developing Processes and Tools to Aid in System Implementation

The project had further-reaching consequences than those strictly affecting Mr. Amofo. Our research yielded a very large number of organizations working in Ghana, often on projects involving rural development. Given the small grid capacity in Ghana, other workers could benefit from similar power solutions. For these reasons, we decided to try to organize a framework by which other persons could determine their own power needs, and the means by which they could receive funding to bring the project to fruition.

In order to achieve this objective, we determined that we needed to take a similar approach to the one which we took for Mr. Amofo. The implementation steps for a power system in this project were:

1. Determine actual power needs
2. Determine a system capable of meeting those power needs
3. Find a means to finance the system, using Non Governmental Organizations or governmental aid, and the qualified workers to supply and install the system

As a result, we needed to design tools to guide others through each of these steps, in a similar fashion to those steps we took for Mr. Amofo. The tools we designed were a

questionnaire to point to power needs, a flow chart of system decisions, and a database of NGOs and operating in Ghana.

3.3.1 Questionnaire for Power Needs

The Borough of Merton has continuing contact (albeit somewhat limited) with the local Ghanaian community. A number of workers in the building are of Ghanaian descent or immigrants themselves. Kofi Amofo himself worked in the Merton Civic Centre, alongside his cousin Phillip. We decided that our wider goal for the project could be achieved, in part, by creating a questionnaire focused on similar questions to those we asked Mr. Amofo and those of the initial questionnaire, and leaving it with the Borough of Merton. They could then apply our research and data analysis techniques to other people in similar situations. While each case is different, if we broadened our tools enough, we could lay the groundwork for other energy-related cases. This would save resources and time required to handle other cases, and turn our work with Mr. Amofo's case into a model for other rural electrification implementation. This questionnaire is contained in Appendix B: Questionnaire.

The questionnaire contains questions broken into three general areas. They pertain generally to an individual's background and emigration to Merton, to energy issues, and to natural resources available for possible solutions. These questions are intended to investigate social problems, energy concerns, and possible solutions to such problems. The emigration questions include ones about reasons for departure, because there are a large number of different reasons people may have left Ghana. Food is expensive, petroleum prices are skyrocketing, and health problems are common and severe enough that the CIA Factbook describes Ghana as very high risk for disease transmission.⁷⁹ By asking for the major reasons, there is potential for other work exploring solutions to various other problems. Energy concerns are the primary focus of this project's work, so the questionnaire is specifically tailored to power problems. Other projects could be designed later to address other social problems. The resources and topography are also a concern, because available resources, climate and location guide possible energy solutions.

In order to determine the effectiveness of the questionnaire, we interviewed several workers in the Merton Civic Centre. These people had very different backgrounds from Mr.

⁷⁹ <http://www.cia.gov/cia/publications/factbook/geos/gh.html#People>

Amofo, working in white collar jobs and living in London permanently, rather than as temporary workers. However, they provided us with useful insight into potential problems with the wording of several questions, and helped us to refine our tools and determine effective means of dissemination of our work. We left a final version of this questionnaire with the Merton government. The Borough of Merton could then use the questionnaire and other tools we developed as a means to undertake other case studies, and the tools we have developed from Mr. Amofo's case could help to determine power needs for other Ghanaians.

3.3.2 Flow Chart of Power Options

In order to determine available power options, we developed a system to evaluate available resources and costs. From the questions relating to available resources, we designed a flow chart to determine feasible power applications. This flow chart is contained in Appendix C: Flow Chart for Power Solutions. Our research (see Energy alternatives) led us to the requirements for a number of renewable energy systems, and we were able to determine necessary resources and equipment to install them. From the energy estimations we did prior to our interview with Mr. Amofo, we were able to develop cost estimates for the various sorts of power systems. As cost is a major concern for energy systems, we listed both equipment required to utilize resources, and expected prices for full systems. We began with the available resources at the top of the page, so that systems would be chosen based on the most appropriate resources. By using this flow chart, other people considering power systems can easily determine (if they have the proper data) which power system is the most useful for their particular need.

3.3.3 Databases of NGOs and Renewable Energy Projects

Once a person decides what system is the correct one for his needs, he then must find a way to implement the system. There are several different ways this can be done, one of which involves petitioning for aid from an NGO. In order to implement a rural electrical system, one must know which organizations are most applicable to one's particular case. As a result, we have set up a database of the NGOs operating in Ghana which catalogs their contact information and the types of work that they do. Also, for the purpose of reference we have found a website that documented 147 separate renewable energy projects that were previously and are currently being implemented.

There were several types of information that had to be documented for the NGO database. In order to record this information we navigated Ghana's government website and were able to locate two lists of NGOs operating in Ghana. One list was for those NGO's headquartered internationally and the other was those which are headquartered within Ghana. We cataloged each of these organizations and documented their contact information and specialties using Microsoft Access, and Microsoft Excel. Contact information was often easy to find (usually located in a "Contact Us" section). This information included international address, phone number, email address, and website along with the same such information of their Ghanaian branch. Their specialty was less straightforward to find than the contact information.

Through research we discovered there was a multitude of aid types entering Ghana. From reading through mission statements, vision statements, objectives, and current and past projects we were able to ascertain the type of aid each organization provided. The types which we documented were rural development, electrification, micro-lending (small loans), health care, education, and food. The aid we were most interested in was that which pertained to rural development, electrification, and micro-lending as we felt these would be most helpful in getting our project, and future projects funded. We included the other forms of aid because we saw them as major trends in the aid not only going to Ghana but around the world. Also, we wanted to discover what percentage of aid in Ghana was relevant to our work. After scouring each NGO's webpage for pertinent information we then had to record it in our database.

Recording and using the information is done using Excel and exported to Access. Contact information was straightforward. This was done by just copying and pasting or transcribing the pertinent data. For recording the type of aid each NGO specialized in we created six data fields (rural development, electrification, micro-lending, health care, education, and food aid). When documenting in Excel, if an NGO specialized in a certain area the word "True" would be placed in the corresponding data field, and a "False" placed if they did not specialize in said area. When documenting in Access you must click on the "checkbox" underneath the category the NGO specializes in. It should be noted that an NGO can specialize in more than one form of aid. In order to better understand exactly how each NGO worked we created another data field called "Other." In this field we would compile all the information from the mission statement, vision statement, etc., into a comprehensive text summary. Using Access you can create reports that show only the NGO's which specialize in a certain area and organize that data so it only shows

information that you require. There are also many features in Access which can be used to manipulate the data, but experience in Access is necessary. In order to best use our NGO database, we needed to see how others have used aid to get renewable energy projects done.

A renewable energy project database was to be created by searching for other renewable energy projects and compiling important information about each. The main purpose was to develop a reference, a way to see how others have gone about getting similar work completed. While searching for projects we stumbled upon a website that documented 147 renewable energy projects. The website is maintained by the National Renewable Energies Laboratory (NREL), and the projects are listed in the Village Power Project database (<http://www.rsvp.nrel.gov/asp/logon.asp>). The database can be searched by country, region (of the world), technology (energy technology), application (type of energy use), and year last updated. Contained within each entry is a multitude of information pertaining to when and where the project takes place, how much money was spent, what the project did, and what was learned from the project. In order for these and other tools to be useful though, we needed to make sure they worked properly.

3.4 Designing the Means to Evaluate Processes and Tools

An important concern was that we needed a means to evaluate any of our work which did not pertain specifically to Mr. Amofo. Our energy system estimate could be evaluated and our approach could be evaluated based on the success of the system. Any system we would recommend would be environmentally friendly, but for a system to be truly successful, there must be an economic benefit as well. After the system is in place, its success can be evaluated as a success or failure by whether or not it can save Mr. Amofo money in addition to reducing pollution and carbon emissions. However, our other tools did not have the same testing procedure. As a result, we developed a system to evaluate our tools. To do this we attempted to locate and establish another case study. We were unable to find one, but instead created a case to show the thought process involved with our tools. Using the tools we have created, and the process example we have created, someone else will be able to attempt to solve a similar problem to ours, and evaluate the usefulness of our tools in another person's case. The evaluation of our tools can then be based on how much additional work beyond the original set of questions and processes must be done. If our work is successful, it will make the process of

establishing renewable energy solutions for other Ghanaians much easier and faster, and expedite the process of allowing other workers to return home as they need.

4. Data and Analysis

4.1 Problems and Changes

The finalized methodology in this report was the result of numerous revisions and changed many times throughout the course of the project. We encountered several major setbacks, which required us to work around our problems and rethink our approach. These are the major issues we encountered in the course of our work:

Many resources and background works were extremely difficult to obtain. We searched the map library at Clark University in Worcester Massachusetts, and the British Library in London, but were unable to obtain topographical maps of Ghana. The lack of good maps made our initial assessment of Mr. Amofo's power options more difficult. Unaware of the land characteristics around Abetifi, we could not even speculate at which options might be possible for Mr. Amofo's power system. Thankfully though, Mr. Amofo provided us with detailed maps of his town, and the immediate surroundings, but we could still not locate a topographical map of the entire nation. While geographical information was difficult to locate, there is a very strong network of meteorological services in Ghana. We attempted to find detailed geographical data using Google Earth Professional edition, however the information that we retrieved from this source was insufficient for our purpose of identifying potential renewable energy sources. It was insufficient as the satellite imaging was not nearly detailed enough for proper analysis of the region.

Detailed climate information was extremely difficult to locate at first, but Mr. Amofo was able to provide us with the information that we required. To attempt to locate this information we researched at the British Library, but found no information pertaining specifically to the climate. We later learned that Ghana has a well developed, functioning Meteorological Agency which keeps detailed weather data for much of the country.

Another problem we had was the availability of aid. This project places an emphasis on micro-lending, because aid from larger organizations will not likely reach out to a workshop with grid access. Large aid organizations undertake large projects. USAID, the foreign development wing of the United States' government, is drafting energy policy for a gas line set to begin operating in Ghana in December 2006. Other aid groups work to develop entire villages. This report recommends that Abetifi work on a village-wide solution, because that may attract the

efforts of an aid organization. However, understanding that one man would be unlikely to attract funding for his private business, we pursued micro-lending as an option.

The first plan we had developed involved interviewing the Ghanaian population in Merton, and attempting to create a large database of social problems, which would catalog answers to similar questions to the final questionnaire presented in this report. This approach was flawed, in the sense that surveying businesses in Merton is generally unsuccessful. Some of the immigrants residing in Merton are not there legally, and will not speak with anyone working with the government. We were forced to change our approach, and took a more passive approach, devising the tools to aid people who approach the government, rather than bringing our work to the larger community.

Our evaluation process for the tools we created was a result of numerous revisions. While still operating under our original methodology, we believed we would locate another case study with background similar to Mr. Amofo's. However, when we changed our approach from one of widespread surveying, we found that locating another test case was difficult. We asked the other Ghanaians for any similar cases during our interviews, but only received one lead. One interviewee was familiar with business owners who had left Ghana because of business concerns, but not necessarily because of energy. Without a test case to illustrate the uses and necessary revisions to our tools, we created an example. From the example case we developed, other cases can follow and evaluate the ease with which our tools can be used, and make any necessary changes to make them more effective.

4.2 Interview Results From Mr. Amofo

As stated in the Methodology, we interviewed Mr. Amofo on May 31, 2006 in the Merton Civic Centre, where he gave us detailed information on his machines, generator, previous work, climate, and hometown. He also gave us information on local geology, topographical maps, and a detailed map of his area of Abetifi, as well as detailed daily climate information compiled by the district meteorological officer from 2001 to 2005. The transcript of the interview is located in Appendix E: Results of interview with Kofi Amofo.

The first major subject of interest to us was his generator, which he said that he operates at full power, for generally between 8 and 10 hours a day, burning 8-9 gallons of diesel fuel. He was unable to tell us what his full power output was, but was able to say that with no other

machines running in the shop, he is able to run up to four of his arc welders at one time, each at 12-14kW of power. He informed us that he builds his own machines, and gave us examples of several that he had built (including his arc welders) and several he planned to build when he returned (including a fan system, a planer, and a small forge). He was extremely interested in the possibility of manufacturing his own homemade windmills, as he felt he could build them with relative ease, and increase the scope of his business while providing power to an area with inconsistent grid access.

Upon evaluation of the anecdotal data Mr. Amofao provided us, we revised our estimate of Mr. Amofo's power usage. Since he can run up to four arc welders simultaneously if they are the only machines running, and each has a power draw of 12-14kW, we expect his generator to have an output of 50kW. He did not know the exact power output, but was aware that the limiting factor for his machine usage is the electrical output of the generator. This changed the approach that we took for his problem. Since his volume of work is limited by his power consumption, our objective is not to meet his current output, but to provide as much power as possible so as to decrease his dependency on fossil fuels for electrical generation. This approach can either reduce his diesel consumption, or allow him to run more machines and thus increase his productivity and profitability. Instead of designing a system with a target power output, we instead designed a system with a high power output which would not replace his diesel generator, but would allow Mr. Amafo to expand his business without increasing his diesel consumption, and would power additional shop operations.

4.3 Abetifi's Climate Profile

During our research period, we experienced a great deal of difficulty obtaining detailed climate data for the region in Ghana while in the United States as well as the United Kingdom. During our interview with Mr. Amofo we learned that Ghana has an active and extensive meteorological agency which keeps detailed information of weather data within Ghana. Abetifi is a town with a population between 10,000 and 15,000 people. It is assumed that towns of similar size would have similar data readily available, and future groups seeking to identify energy sources should first contact the Ghana Meteorological Agency to receive extensive climate data before proceeding to identify potential solutions.

Mr. Amofo was able to provide us with daily observations of high and low temperatures, wind speeds, and hours of daily sunlight exposure. This daily climate information spanning from January 1, 2001 to December 31, 2005, and was compiled by the meteorological agency of Ghana. This information extends onto sixty pages, and is too much to display to be understood effectively, however average monthly data is available in Appendix H: Abetifi Climate Data. One area of observation titled “sunshine direction duration,” is interpreted as hours of direct sunlight. Daily high and low temperatures are given in Celsius. Wind run is a measure of the amount of wind to pass a given point in a day. The greater a day’s wind run is, the higher its average wind speed is. “Synoptic Observations,” simultaneous measurements from several different locations, is the method through which wind data was collected. Each of these areas of observation is useful for a type of renewable energy, and has been transcribed into a spreadsheet, and will be presented graphically for easier analysis and interpretation.

To better understand the climate of Abetifi and to obtain a better understanding of yearly weather patterns, we grouped the data by month, and then performed averages of all of the data. From this we were able to develop good summaries of typical weather for Abetifi which has allowed us to better determine the energy alternatives that will work best in Abetifi. Abetifi is located in the Eastern Region of Ghana, near the western bank of Lake Volta. Abetifi has a warm climate with daily average high and low temperatures of 28.7°C and 21.1°C (83.7°F, 69.98°F) respectively. High temperatures peak in the month of February at 31.7°C and reach their lowest in August at 19.8°C which corresponds with the region’s rainy season.

To show an average year, we averaged all of the temperatures recorded over the 2001-2005 time span by month, allowing us to determine the average high and low for each individual month. Figure 8: Average Monthly Temperatures for Abetifi, Ghana gives the general trend of yearly temperatures. These temperatures reach a maximum in February and a minimum in August, and demonstrate little shift for the low temperatures, and a slight (6°C) but defined shift in high temperatures through the year.

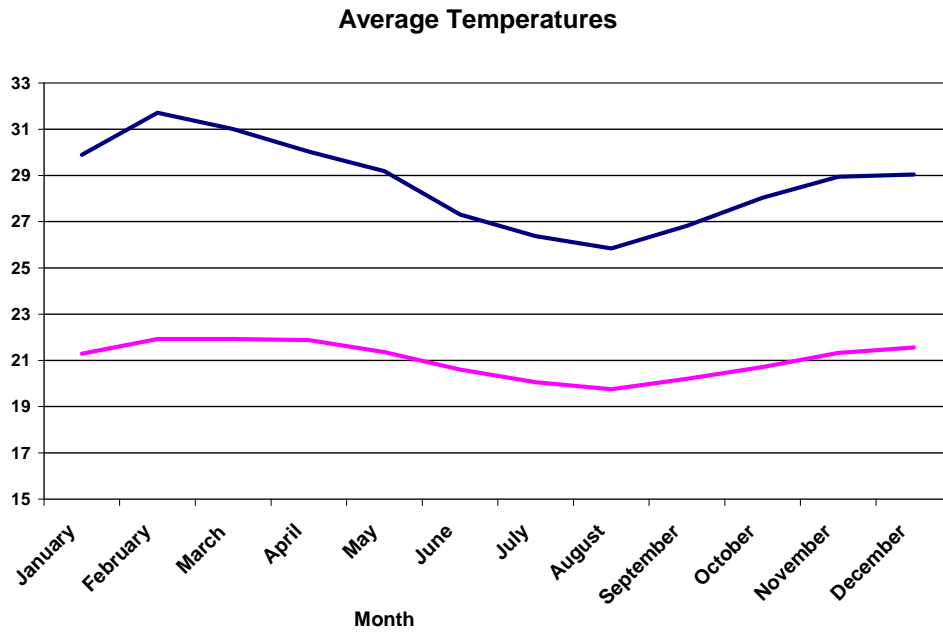


Figure 8: Average Monthly Temperatures for Abetifi, Ghana

Wind speed readings for Abetifi are taken at a height of ten meters. From the climate data we obtained the yearly average wind speed at ten meters is 4.39 knots, with a high monthly average of 5.22 knots in August and a low monthly average of 3.35 knots occurring in January. Figure 9: Average Monthly Wind Speed, Abetifi, Ghana presents average monthly wind speeds for Abetifi.

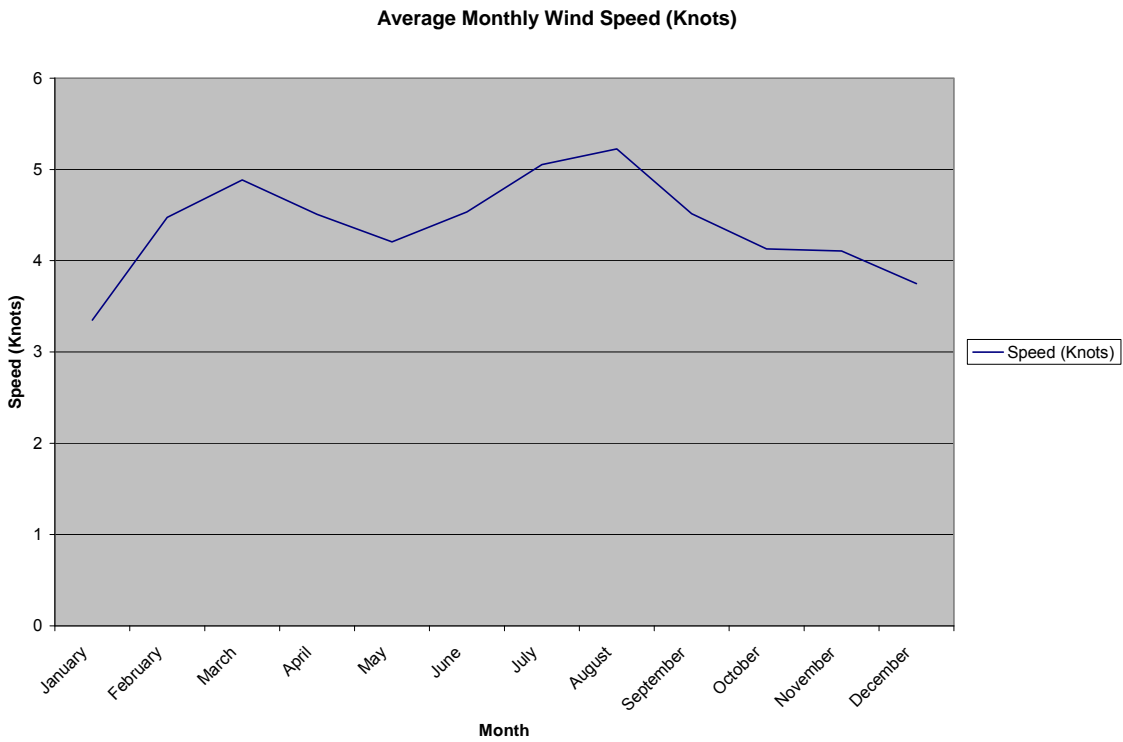


Figure 9: Average Monthly Wind Speed, Abetifi, Ghana

The average speed of wind is important to wind power, but also important is the notion of wind run. Wind run is defined as the amount of wind to pass a point in the course of a given time span. The wind run is important because the higher the run value is, the more wind passes a

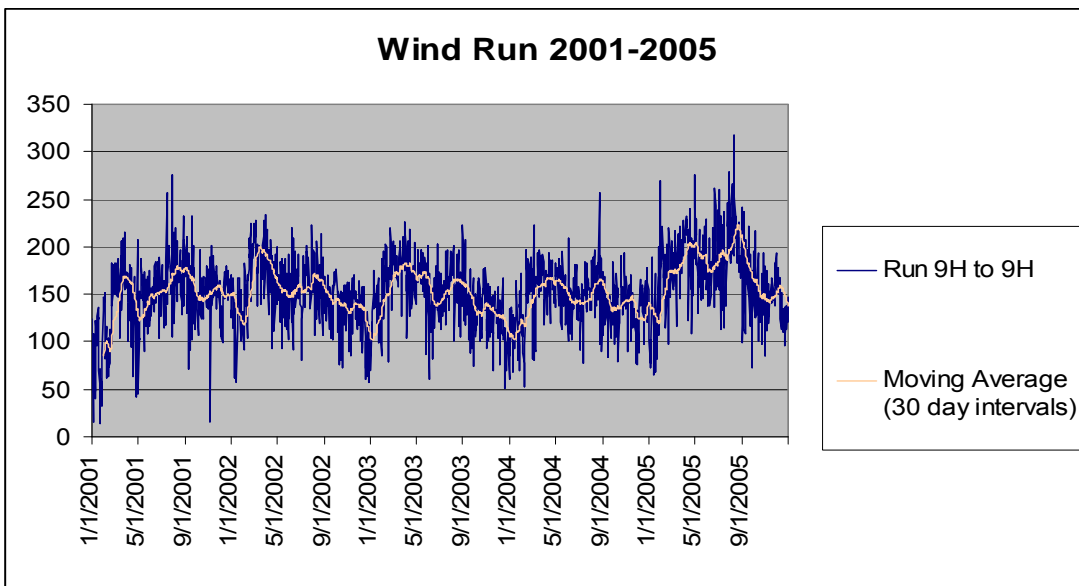


Figure 10: Wind Run for 2001-2005

point in one day, and thus the more wind can be harnessed for power. Figure 10: Wind Run for 2001-2005 shows the wind run for Abetifi over the same time interval as is the basis for the average speeds.

As the moving average (denoted as a tan line) shows, there is a lull in wind run in January each year, followed by a high point in March and April, with a secondary high point in August and September. While the heights of the peaks and troughs vary from year to year, these trends are consistent, and coincide with the storm seasons in Ghana. In addition to the climatology data, Mr. Amofo included a document with other pertinent information, which includes the existence of strong storms in late March and late August which include extremely strong winds. These periods also have some of the highest variations from the trend, with runs in excess of 250 per day on several occasions.

Abetifi also averages 6.8 hours of direct sunlight duration per day. The direct sunlight duration reaches its lowest average amount in August. Figure 11: Daily Sunlight Hours shows sunlight duration through the 5 year period, as well as its associated trend. As opposed to the wind run trends, which tend to be much higher in March and August, sunlight reaches a relative low in these times, and is much higher in January and October, as the winds wane. This phenomenon is related to the rainy season of the area. When there is more rain and cloud cover, there is also much stronger wind, and in the months of sunny weather, there is much less wind.

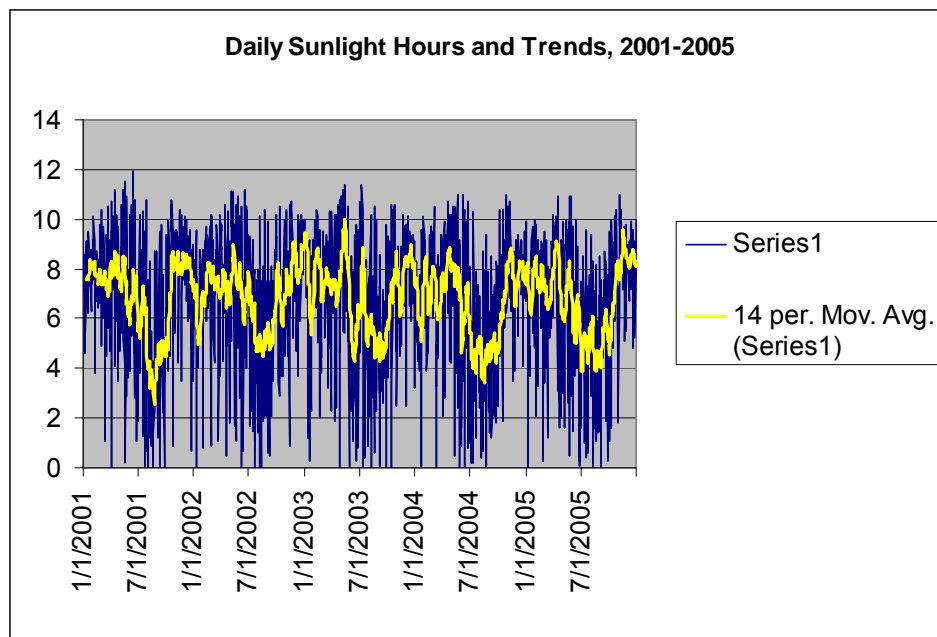


Figure 11: Daily Sunlight Hours

To make this data easier to comprehend, we also grouped sunlight by the number of hours per day measured. “Sunlight direction duration,” the label applied to our climate data, measures the number of hours per day during which the sun shines directly on the observation point. The sunlight direction duration distribution figure below groups the number of sunlight hours per day by frequency.

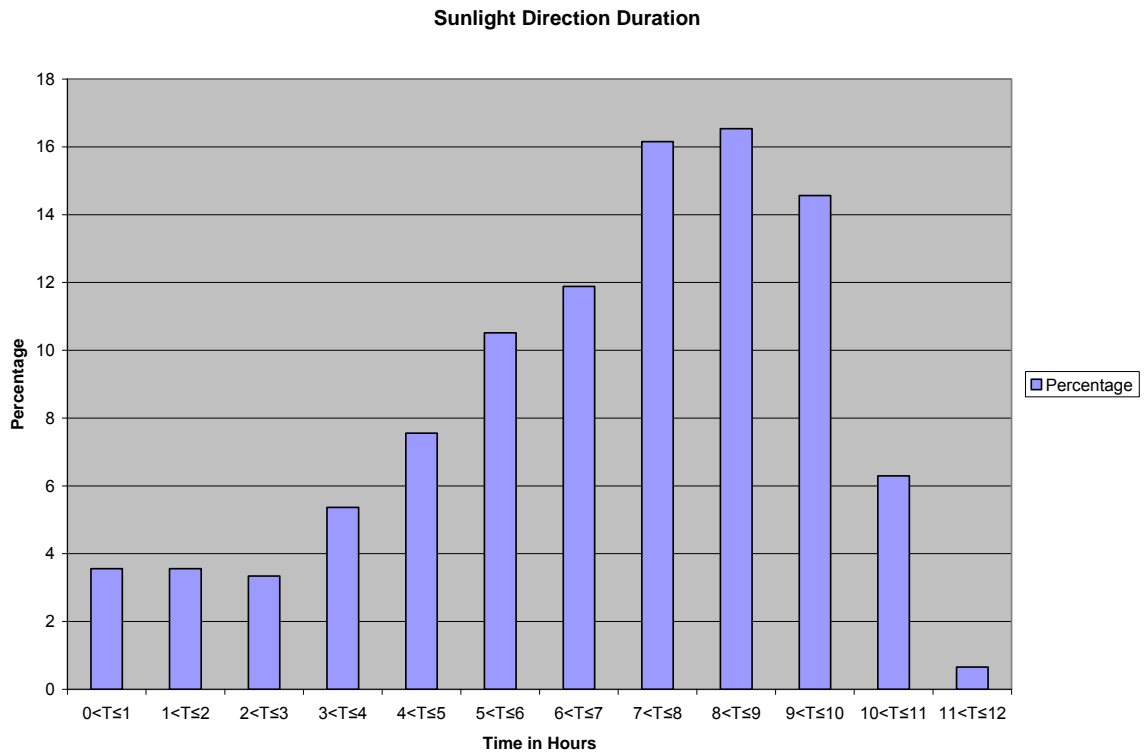


Figure 12: Sunlight Direction Duration Distribution

As the figure shows, 76% of the time, Abetifi has over 5 hours of daily sunlight. The average sunshine per day is 6.8 hours, yielding an extremely high amount of daily sun which can be harnessed for solar power.

Abetifi has very consistent daily temperatures. The average temperatures change by only about 5 degrees over the course of the year. There is a tremendous amount of sunlight there, averaging about 6.8 hours per day, and at the times of year with fewer hours of sunlight, there tends to be much stronger wind. This makes the possibility of a hybrid power system, combining wind and photovoltaic options much more feasible. Estimated implementation cost, and return of investment will be explored in the sections to follow.

4.4 Cost Analysis

The best choice for a power system is one which is both cost-effective and environmentally sound. Our original goal was to improve the economic viability of Mr. Amofao's business, so the energy system would have to be affordable to satisfy its original objective, and the more cost-effective system would be the better choice in this regard. While environmental effects are not explicitly mentioned in the sections to follow, all of the system options are an environmental improvement over Mr. Amofo's diesel power use. Emissions and other environmental concerns would be much improved with either choice. At this point, the feasibility and cost of the different systems becomes the major concern.

We began with five power options for Mr. Amofo's shop. These were wind, solar, micro hydroelectric, biomass, and biofuels. From these, our interview made it clear that the last three options were not as feasible. Mr. Amofo's shop is not close by a river, so micro-hydroelectric power is not feasible. There is available wood for biomass, but no other sources were named, and wood is more difficult to break down than grass or cornstalks, and conversion of biomass to electricity is much more difficult than gas lighting or heat. Vegetable oil is more expensive than diesel fuel, so any biofuel setup would be more expensive than his current power system, unless he were able to buy, produce or otherwise obtain vast amounts of vegetable oils at a deep discount. At this point it becomes important to determine which of the two remaining options will be best for helping to supplement his power problem.

To run a cost analysis, one determines what it costs to implement a power system, and given the cost of the alternative (in this case his diesel generated power), the time that it would take for the system to pay for itself. If, for example, a one kilowatt system costs \$1000 to build and the cost of the existing grid power is \$0.04 per kilowatt-hour, the system would have to operate for 25,000 hours before it paid for itself. If it runs every hour of every day, that system would take about three years to pay for itself, and if its expected life is over three years, it is a good economic choice to build the system. This is the logic we employed, which we have adjusted appropriately to Mr. Amofo's power needs.

Through the interview we learned that Mr. Amofo burns approximately 1 gallon of diesel fuel every hour he works, and that his total generating capacity is approximately 50 kilowatts. As such, every 50 kilowatt hours generated with renewable energy replace a gallon of diesel fuel, which costs Mr. Amofo £2.80, or approximately \$5.50 US (see Appendix E: Results

of interview with Kofi Amofo). For the solar photovoltaic system, 1kw of generating capacity costs about \$4,500US, and batteries to store energy over weekends add an additional \$1,000, raising the total cost to \$5,500 US. This means that the total energy generated over the lifetime of the system must exceed 1,000 gallons of diesel fuel, or 50,000 kilowatt-hours. Mr. Amofo's region, according to the climate data he gave us, averages almost 50 hours per week of direct sunlight. Assuming that 1 hour of direct sunlight on the 1kw solar array yields a full kilowatt hour, this one can expect an average of 50 kilowatt-hours of energy, or the equivalent of one gallon of diesel fuel, generated per week. This means that, with diesel fuel prices standing at today's rates, the system will pay for itself in 1,000 weeks, or slightly over 19 years.

The wind turbine analysis is much more difficult to complete. The individual from whom we purchased the plans, Hugh Piggott of Scoraig Wind, sells pre-made 1kw turbines for £650, or about \$1,300 US. The battery capacity costs an additional \$1,000, raising the total price for the system to \$2300 US. This assumes no price increase for the labor cost of the construction, meaning that the materials alone will likely cost less than the assumed price, which allows for the additional costs of larger capacity construction projects. This system requires an average wind speed of 11mph or 5 m/s, which is much higher than the average recorded wind speeds in Abetifi. However, some adjustment is needed. The wind speeds are recorded at a height of 10m, which is only about half of the height of the actual windmill. Wind speeds are thoroughly dependent on both the altitude and the ground over which the wind blows. The adjustment for wind speed is available from the Danish Wind Energy Association,⁸⁰ and for a 20m windmill height, the applied wind speed is estimated to be about 1.2 times the recorded wind speed, or 5.5 knots (2.9m/s).

In How to Build a Wind Turbine, Hugh Piggott presents a model for small wind turbine output. Power from wind is proportional to the cube of wind velocity and square of diameter (which is the area covered by the rotor blades), as well as a coefficient which quantifies losses of the system.⁸¹ Mathematically, this model is: $P = 0.15v^3d^2$

For a system with 4m (13') blades, and a diameter of 8m (26'), turbine output in "average" wind is about 230W. This is a small amount of power, but is still enough to power several lights, and could charge batteries overnight. With consistent wind, this system would

⁸⁰ <http://www.windpower.org/en/tou>

⁸¹ How to Build a Wind Turbine: The Axial Flux Plans, Hugh Piggott, page 11

provide 6 kilowatt-hours per day, and provide equivalence with a gallon of diesel fuel approximately every 8 days, which allows the system to pay for itself in approximately 9 years.

It is important to note that the estimate of 2.9m/s for wind is a synoptic observation, meaning that it is the average of a number of observations taken at the same time. The wind at Mr. Amofo's shop may be far greater or less than this value. Additionally, 2.9m/s is an average of daily winds. If, at different times, the wind is either 4m/s or 1.8m/s, the power produced at those times will be 650W and 60W respectively. If both of those speeds occur for the same length of time, the output will average about 340W, which is almost 50% greater than the estimate based on consistent wind speeds. Depending on the variation in wind speeds, the power estimate may be grossly inaccurate, and could easily produce far greater outputs and return investment far sooner.

In short, solar power will be cost-effective, but only as a very long-term solution. Solar photovoltaic cells are expensive, and unless the price drops significantly, power generation using them will have an extremely high price. Wind power is much cheaper, but in Mr. Amofo's town it may not provide a very high output, and will not replace a large amount of his dependence on diesel fuel. This option requires much more specific data, and merits further study. Another important factor to remember in cost analysis is that the price of diesel is not simply a burden for Mr. Amofo, but has marginalized the profits of his business. Therefore, it is unsafe to assume that he can afford an expensive power system. Currently, Mr. Amofo's workshop is in operation in Ghana under the direction of his employees. If his shop operations depend very heavily on every pound he is able to send back to Ghana, he may be unable to invest in a solar array on the side. Funding from a third party will be very important to the solution to Mr. Amofo's energy problems.

4.5 Risk Analysis

Every machine carries a risk of failure. Some systems are likely to fail due to a high number of moving parts, poor materials, or poor design. Some machines can be overstressed or fatigued and fail over time. Any sort of failure in the power system would be extremely problematic for Mr. Amofo, as it would result in unwanted dependence upon his generator and require maintenance which would take time away from his work. The power systems we have

considered have the potential to fail for a number of reasons, and considering the risk of failure is important to the proper recommendation.

Fire hazards are a major concern. With a large number of batteries and wires to install such a system, there is the possibility of an electrical fire. It is safe to assume that Mr. Amofo's existing electric system can handle the added capacity, but the additional equipment carries a risk with it. We assume that Mr. Amofo is capable with electronics, since he has built many of the machines in his workshop, and we feel that fire hazards will not pose an extreme risk for his shop.

The windmill, being handmade partially from inexpensive car parts, carries a risk of mechanical failure. This means that a part may break, and require that the windmill be taken down and fixed, at a potential cost of considerable time and materials. This is a minor concern, however, given the previously stated inexpensive nature of the windmill. The design is cheap enough to be rebuilt entirely and still have a relatively quick return of investment (under five years). The other risk is high stress. In order to produce the maximum power, the winds must be very strong, and the windmill must be very high in the air. This carries a risk for the tower, as heavy loading can break it. The tower must be built to withstand high loads, especially due to the rainy season, which carries with it extremely fast wind speeds. The tower is held in place with guy wires, so it should be capable of withstanding fast speeds, but there is still reason for concern, and it may be a good decision, should Mr. Amofo employ a windmill, to design a means to drop the windmill to the ground in strong storms, so that he does not experience unnecessary failure.

As a solar array is very expensive, risk of mechanical failure is a very important concern. Since the system will take about 20 years of uninterrupted service to pay for itself, any downtime can make it an unreasonable system to install. The technology of modern solar photovoltaic panels is simple, in the sense that one places the array on the roof, and simply plugs them in (either to a battery, or in series to generate higher voltages), and at the end of the series, if using it directly, into the transformer. There are no moving parts in the panels, so there is little possibility of failure. Overpowering the system may cause problems, but as long as the parts are designed to handle the load, there should not be a high risk of failure in the system.

4.6 Tool Data and Analysis

In order to test the questionnaire, we spoke with 3 Ghanaians working in the Merton Civic Centre. We attempted to address any concerns of wording, as well as learning of any other relevant issues of concern. Notes from these interviews are contained in Appendix I: Notes from Interviews with Civic Centre Employees. In addition to the questionnaire, we asked about a number of other topics. We attempted to discern how many, if any, individuals were in similar situations to Mr. Amofo, how to make our tools for identifying potential renewable energy sources as effective as possible, and whether the approach we had taken would be the most effective, or if later projects would have greater success in different ways. A number of interesting and important trends emerged among the people with whom we spoke.

Each of the interviewees identified energy as a major concern for all of Ghana, not only industry. When we asked about how to solve the problem, the notion of a “seed project” appeared to be the consensus for the best approach. The interviewees all believed that one very successful project could lay the ground work for later successes and allow for widespread success throughout the country. Each encouraged us to develop a reproducible method for system installation, which could allow others to imitate the process we have used for Mr. Amofo.

The interviewees also had similar connections to Ghana. Each of them also contributes to Ghana from abroad in some way, including remittances or child education sponsorship, and has an interest in the outcome of the project. Each seemed willing to take part in future work to continue this project.

Another goal of our interviews was to locate a second case study with which our tools could be evaluated. One of our interviewees told us that she knows former business owners who have emigrated from Ghana to London, but was uncertain of energy’s role in the decision. This gives evidence that Kofi Amafo may not be in an entirely unique situation, and there may be other similar seed projects which can be undertaken in the future, for other individuals and possibly other areas of Ghana.

From the interviews it became clear that among the ongoing works to follow this project, there is tremendous potential to link the Ghanaian community of Merton, with its resources and finances, to Ghana and develop a potent aid network. Other ideas the interviewees gave us included attempting to involve the Ghanaian government, as well as universities, secondary

schools, and technical institutions, in later projects. One prevailing opinion is that management and collaboration between the necessary groups is lacking in Ghana. One interviewee told us that one of the biggest problems is an issue of poor resource management. The government “lacks a sense of urgency” found in first-world governments. While the government has recognized energy as a major issue, until recently, it has been slow to promote new technology and electrical expansion. Ghana also has ample resources for energy, but still relies on old technology.

Another interviewee added that one major problem is that skilled workers like Mr. Amofo, while tremendously talented, go unrecognized because they do not write textbooks, and the universities have little interest in their knowledge, which slows technical learning. Some form of collaboration between the British and Ghanaian authorities and universities, as well as management assistance from a developed, first world nation, could prove immensely helpful to Ghana’s energy growth.

4.7 Database Data and Analysis

Two databases were to be created as reference material that we knew could be used in the future. The first of which is a renewable energy project database, and the other a database of NGO’s working in Ghana. A renewable energy project database had been designed by us but during our research we discovered one that was previously made (<http://www.rsvp.nrel.gov/asp/logon.asp>). In this database we found over 140 past and current energy projects. The information contained in each project is extensive, and example of what is contained in each entry is in **Error! Reference source not found.** The data will be useful to future projects in that it will provide a layout of exactly how others have gone about getting renewable energy projects completed. There are many examples to search through with a variety of types of energy options. The NGO database is a similar case, it was useful to us as it gave us an idea of what can be done and what is being done, but its real use will come with future projects.

With many NGO's working in Ghana there is a great opportunity to get many different types of projects funded. On the Ghanaweb website (www.ghanaweb.com), there is a list of both foreign and local NGO's working in Ghana. In order to comprehend the type of aid going into Ghana and to help us find NGO's that may be able to help in aiding Mr. Amofo's project, we visited each individual NGO's website and documented some necessary info about them. This data included the name of NGO, its country of origin, what areas it specialized in (Rural development, Electrification, Micro-lending, Health care, Education, and Food Aid), a description of the work they are doing, and their address and contact info. This full database is available on the CD. **Error! Reference source not found.** is a screenshot of what the NGO form looks in Access.

ID	NGO Name	Country of Origin
	Africatrust Trust	United Kingdom
<input checked="" type="checkbox"/> Rural Development <input type="checkbox"/> Electrification <input type="checkbox"/> Micro Lending <input type="checkbox"/> Health Care <input checked="" type="checkbox"/> Education <input type="checkbox"/> Food Aid		
Other		
Organize Volunteers from Europe and North America to work in rural West Africa in schools a		
Headquarters		
Street Address		
P. O. Box 551		
Additional		
City		State
Portsmouth		Hampshire
Post Code	Phone Number	
PO5 1ZN	01873 812 453	
Email	Website	
wales@afriatrust.gi	www.afriatrust.gi	
Ghana Headquarters		
Street Address (GH)		
Africatrust Bureau		
Additional (GH)		
P.O.Box 1371		
City (GH)		
Cape Coast		
County/Region (GH)		
Ghana, West Africa		
Post Code (GH)	Phone Number (GH)	
#Name?		
Email (GH)	Website (GH)	
ghana@afriatrust.gi		

Figure 13: NGO Form in Access

In order to best understand the data from this database, we used Excel to create a graphical representation. We wanted to know how much of each type of aid was going into Ghana. From Figure 14 we can see that a majority of aid is going into education. Education itself encompasses many aspects of aid, including building schools and providing monetary aid. It also includes aid in the form of volunteer teachers from abroad, and job training and skills training. It was also noticed that a lot of job and skill training was directed specifically for women; the reason for this was not discovered and may be a point of interest for future projects. The second most prevalent type of aid going to Ghana is health care. The main type of health aid going to

Ghana is in the form of HIV/AIDS awareness, prevention, and treatment. With 3.1% of adults in Ghana living with the disease⁸², it can be seen why a lot of aid is in this area. Rural development is the third most prevalent type of aid, again covering a broad area. Aid of this type goes into general capacity building in rural communities such as building libraries, community centers, hospitals, etc. With rural communities lagging behind the major cities in development not only in Ghana but also worldwide, it can be seen why there would be aid in this area. Electrification is a major advance in development and can be seen as a possible type of rural development.

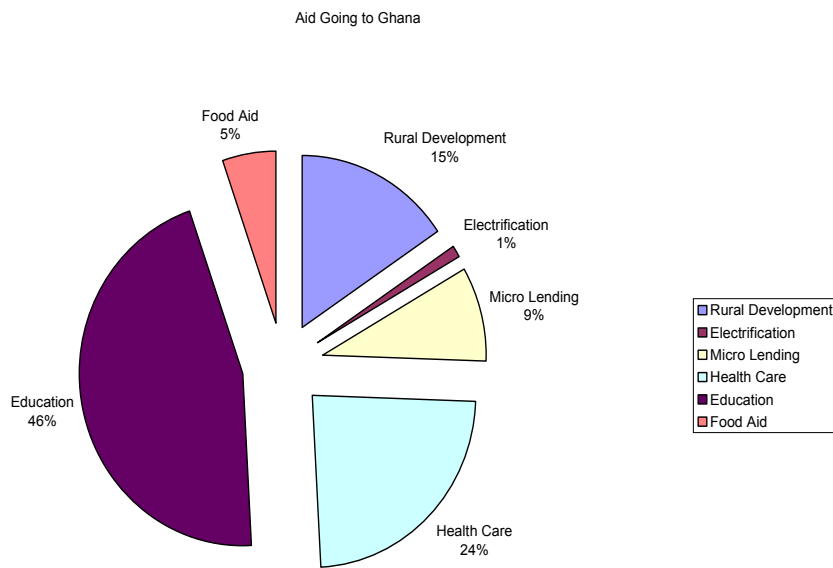


Figure 14: Aid Going into Ghana

The areas in which less aid is supplied are micro-lending, food aid and electrification. First comes micro-lending, which is providing small loans to businesses and individuals in need. Again, as in education aid, a lot of these NGO’s direct this aid toward women. Though aid is not going exclusively to women, NGO’s often make a point to make it known that women can benefit. Micro-lending is also interesting in that it can help Mr. Amofo by supplying him with capital to possibly purchase a renewable energy source. Food aid and electrification are the two least prevalent types of aid going to Ghana. Food aid itself is self-explanatory, while

⁸² CIA Fact book: Ghana

electrification is aid going into extending the electrical grid and also building off-grid power sources (renewable sources most often). With electrification being the most important type of aid to us, it was discouraging to see that there was not a lot of aid directly going into that area (3 NGO's out of 129). We believe this may be a result of where we obtained the list of NGO's.

By investigating what types of aid are going into Ghana we could see opportunities of where our projects could get funding. After reviewing each NGO and summarizing the aid they provide there are now several areas of interest that could possibly be vital to this project. Along with electrification, micro-lending and rural development organizations are extremely interesting to us. More investigation and emphasis should be put into investigating these areas of aid, specifically in how they work Ghana.

4.8 Evaluation of Our Tools

Our interviews did not lead us to another case which we could use to evaluate our tools. In order to evaluate our tools, we created an example case to illustrate their correct use. The example is located in Appendix L: Case Study Example. We attempted to vary the details so that some of the example would be related to our experiences with Mr. Amofo (energy concerns have kept this man from returning home), but the area, weather patterns, and relevant personal experiences differ from those in Mr. Amofo's life. We did this to verify that our tools could still provide answers in case studies where Mr. Amofo's expertise and personal background do not apply.

We filled in answers for a tailor's son whose reason for arrival in London is to support his father, whose business is unable to operate when the power grid does not operate in Kumasi. We chose Kumasi because two of our interviewees were born there, and gave us some details of the weather patterns and land ownership there. Therefore, we felt reasonably confident that we could accurately answer these questions for Kumasi.

For the answers pertaining to available resources, we chose to mention a river on his property so that there would be a clearly feasible option. For the purposes of the flow chart, we chose to have one clear choice to explore. On the flow chart, we outlined the micro-hydroelectric turbine option in red, to denote that it is the system recommendation. For the resource questions, we said that there was a long rainy season, little wind except during strong storms, and no available biomass or vegetable oil. These questions correspond to the top line of the flow chart, which asks if a particular resource is available. Since there is only one definitive

“yes” answer based on the questionnaire, there is only one option to explore. From there, we queried the NGO database, and presented some of the results dealing with micro-lending. Kumasi is a city (which is mentioned in one of the answers) so rural development is not applicable, and thus micro-lending is the most readily applicable aid source for such a business owner. We chose to only show three examples of micro-lending sources, because they display the results of the query, and there would be similar results for the others, and there would be an overwhelming number of them.

We added answers in the questionnaire to say that this man rents his land from the chief in his city, which is a common situation in West Africa. This becomes a concern because if there is some sort of planning procedure required, this will have to be taken into account. We wrote that the man is connected to the grid, but has only intermittent power. This is the actual case in Kumasi, and much of southern Ghana. It also leaves open the option of sales to the power grid, rather than power storage. If people produce excess power, they can often sell it back into the local power system for the same rate that they would buy it from the electric company providing it. Batteries add to the cost of the system, but this method provides a means to earn money when not using power, and to save money in the implementation cost of the system. With this example to follow, other people can readily imitate this system for real cases.

4.9 Summary

At this point, we cannot make a succinct system recommendation for Mr. Amofo. The wind speeds over his workshop require further study, and the solar power system is, with current technology, too expensive. The other option is to wait for cheaper solar technology, which requires more time for research, development, and commercial availability, but whose advances are close along the horizon. The first recommendation we can make is that he purchase an anemometer, with which he can measure his own wind speeds and determine whether or not to pursue wind power.

Alternatively, even if the windmill is not viable for his shop, it is a product which Mr. Amofo can make for sale and increase his business profitability. Much of the work to build the handmade windmills involves hand tools and simple power tools, which means that they may be assembled in his shop without the use of his most powerful machines, and thus without adding significantly to the cost of diesel fuel use. As Abetifi is grid connected, many homes have some

access to power, but their power supplies are inconsistent, so the windmills can power at least some of their appliances in times when the power grid is not available.

5. Conclusions and Recommendations

5.1 Recommendations for Kofi

Based on analysis from climate data and our analysis of energy alternatives we cannot recommend a solution without further data collection. He must do wind studies specific to his workshop area, in order to determine the feasibility of wind. Should wind prove unfeasible, solar power will work well to satisfy his power needs, but will require better technology, which is still in development. Once the proper solution becomes readily apparent, Mr. Amofo or future groups should investigate those NGO's which supply electrification aid and also investigate those that supply micro-loans or rural development aid. Finding the right organization can be done by sorting the database of NGO's by the types of aid they supply and reading exactly what type of work they have done and what they wish to do. If any further information is needed contact addresses are provided.

In order to determine wind feasibility, we have included a chart with wind speeds and windmill blade lengths in Appendix J: Potential Windmill Outputs. Mr. Amofo can compare this chart to the wind speeds he records over his shop and determine whether wind is actually feasible and the windmill will work. The outputs are in kilowatts, and a 1kw output translates to approximately 2% of his power usage.

The homemade windmill, while not necessarily a solution to Mr. Amofo's power problems, is a possible source of income. While Mr. Amofo's shop has an extremely high power draw, and in low wind speeds would not be aided tremendously by a windmill, the output in even standard winds (approximately 3m/s) is enough to power several light bulbs. Homeowners in Abetifi could use the small amount of power generated by the windmills for supplementary power when the power grid does not supply them with any form of power. The windmills are not machine intensive to manufacture and can be easily assembled without the consumption of large amounts of electricity. Mr. Amofo should take the plans provided, attempt to modify them as necessary to increase their power output, and sell them from his shop as a greater source of income with lower overhead cost than many of the other machines and metal works he currently produces.

5.2 Other areas of recommended study

Recommended applications of deliverables

One major issue is that we do not have much experience with the actual ground issues in Ghana. Later project work must involve the Ghanaian government and education system, which can write policies and disseminate information. By including these parties, other project groups can begin to build on the work this project has done, and apply the tools we have created to actually solve energy problems. Working with universities and technical schools in Ghana, future project work could attempt to study available resources and determine a resource profile for the nation for renewable energy implementation, or attempt to improve and generalize renewable energy technology using the methods outlined in this document.

With the number of electrification organizations as low as it is, and with the local interest in energy for Ghana, future work should attempt to organize local Ghanaians to develop an organization focused on renewable energy projects. There are many individuals who give aid (totaling over \$4 billion per year, see 2.1) back to Ghana in forms such as remittances or charity work, and by organizing them into a group, future projects can develop a very focused, potent aid source.

After compiling the data for our NGO and case study databases we have devised a list of other possible uses for the data. The database should be put online for reference and also for future updates. By placing it online it can be made available to anyone looking for aid in Ghana who has access to a computer and internet. It can also be a resource for aid organizations who wish to get funding for their projects. By having an NGO's name in this readily accessible database it gives it more exposure to future stakeholders. This may inspire NGO's currently not in the database to insert their names into it, thus creating a sustainable data-farming system.

Other possible energy alternatives

There were a number of ideas we failed to investigate during the course of our project in order pursue a solution for Mr. Amofo. This project concerned itself with electricity, and ignored alternative energy sources for individual machines. The welding machines Mr. Amafo uses are tremendously energy intensive, and for certain applications, gas welding may be a possible alternative. In terms of other electrical options, this project dedicated itself to the individual case of one workshop. Abetifi is a town of approximately 10,000 people, and is

connected to the grid, but only receives intermittent power. Abetifi as a whole could benefit from a larger scale project, such as a solar thermal facility or a large windmill (with 500kw to 1MW generating capacity, or possibly larger), which would require a larger initial investment, but would result in more widespread aid to the town. Citizens of the town of Hull, Massachusetts, collectively own two windmills, with a combined generating capacity of over 2.4MW. These windmills provide power for the town, and also sell excess power into the local power grid. The citizens receive discounted power, and the windmills pay for themselves over the course of their lifetimes.⁸³ A similar scheme could benefit Abetifi, and to a lesser extent the surrounding towns. If Abetifi can locate ample wind for a large turbine, the town may be able to buy it and provide consistent power for themselves. Additionally, excess power can boost power availability in surrounding towns, while providing Abetifi with a source of revenue.

If possible, Abetifi should attempt to develop a wind profile and determine whether there is a location with strong enough winds to power a large turbine. This should be relatively easy to do, given that the wind measurements in the town are synoptic, meaning that there are already multiple observation points, and there is extensive data collected from them. If one location has winds consistently greater than 15 miles per hour (8m/s or 13 knots), a large-scale wind turbine in that location could potentially power the majority of the town.

⁸³ Hull Wind Power and Alternative Energy, Hullwind.org

Appendix A: Script for interview with Kofi Amofo



Interview Date:

- 1) Could you describe the region of Ghana that you originate from?
- 2) What sorts of agriculture exist in your area?
- 3) What sorts of terrain and natural resources do you have available? (Rivers, grassland, etc)
- 4) What is the climate like year round? Climate information given.
 - a. Is there a long rainy season? YES NO
 - b. Is there consistent wind? YES NO
 - c. Are strong storms (with extremely heavy wind) common? YES NO
- 5) Do you know of any (and if yes, what) energy implementation attempts that have been made in your area?
- 6) What sort of electric power generation do you have (specific model generator if possible)?
- 7) How much diesel fuel do you consume daily?
 - a. At what price?
- 8) Can you give us more specific information on the machines in your shop?
- 9) What machines require the most power?
 - a. What other machines require power?
- 10) How do you run your machines (many at once, only one or two at once, which ones simultaneously, etc.)?
- 11) Would you be interested in learning how to build your own turbine in order to build a power system for yourself or to market to others in Africa?

Additional information:

Appendix B: Questionnaire



DATE:

NAME:

Personal Background

1. What is your objective for your time in London?
 - a. Did you bring family with you? YES NO
 - b. What factors caused you to decide to leave Ghana?

2. Do you intend to return there to live in the future? YES NO
 - a. If so, when and under what circumstances?

 - b. Would you be more likely to return if given job training? YES NO
 - c. If yes, how can we contact you?

3. What do you do for work?
 - a. Do you have experience in metal or woodwork, or similar trade?

Home Background

4. Could you describe the region where you live in Ghana?
 - a. Is there a large amount of local agriculture?
 - b. What is the local topography like (hills, plains, etc)?

5. What is the land ownership situation in your home area? (i.e. Do people own land or rent, is land community-owned, etc)
 - a. Specifically, do you own your land?

6. What sorts of terrain and natural resources do you have available? (Rivers, grassland, etc)
 - a. Is there a lot of available biomass (vegetation)?

7. What is the climate like year round?

a. Is there a long rainy season? YES NO

i. Can you give approximate dates?

b. Is there consistent wind? YES NO

i. If so, how strong?

c. Are strong storms (with extremely strong wind) common? YES NO

Energy Related

8. Are you connected to grid power? YES NO

a. If so, does the grid provide consistent power?

b. If not, is the grid near you at all?

9. Do you know of any (and if yes, what) energy implementation attempts that have been made in your area?

10. What sort of electric power generation (if any) do you have?

a. If running on petroleum generation, how much do you use?

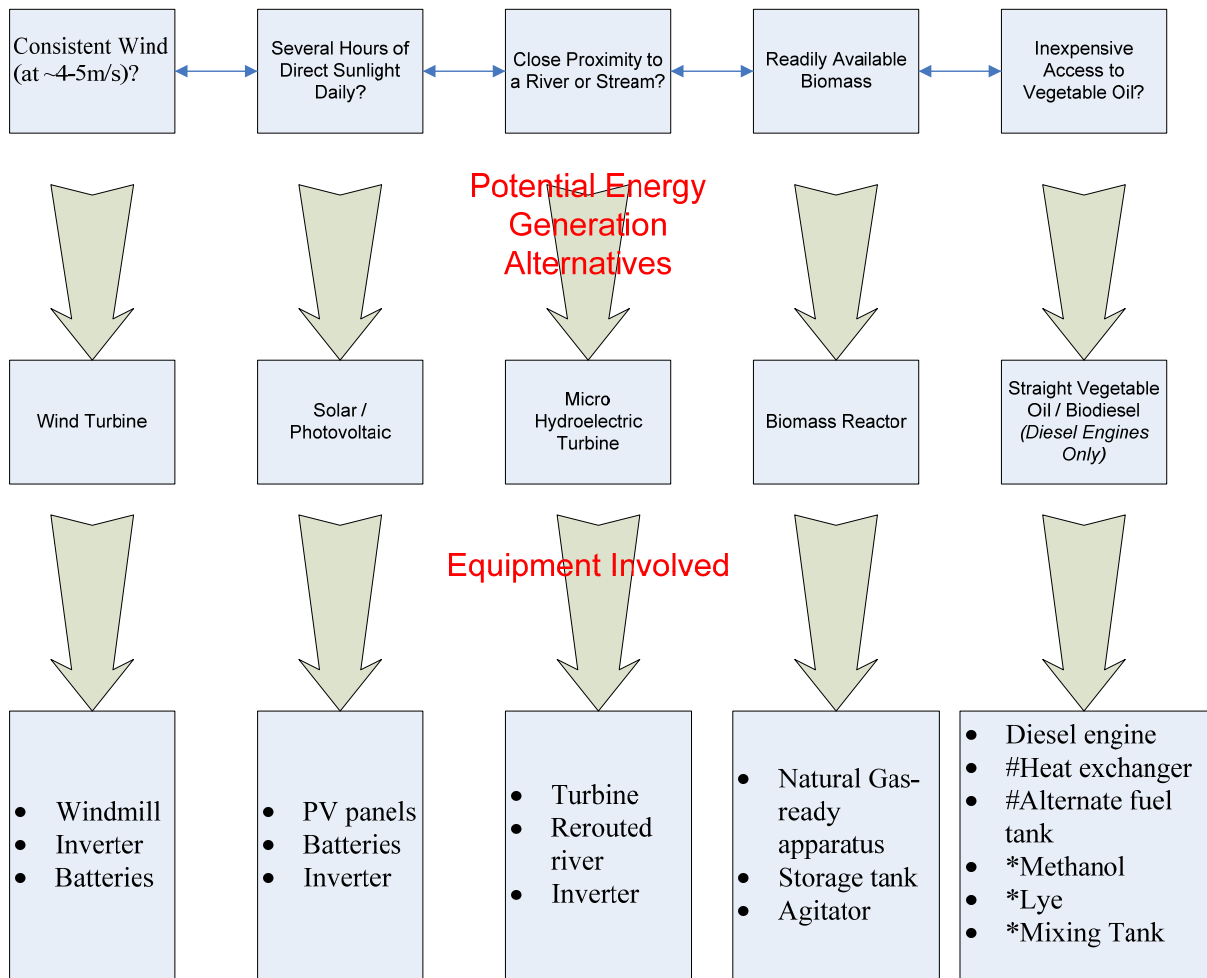
11. What sorts of appliances or electrical uses do you have in your home?

a. Can you tell us about how much electricity you use?

Appendix C: Flow Chart for Power Solutions



Assessing Energy Alternatives



Notes:

Begin with any of the questions in the top row of boxes. Follow any route for which the answer is “yes”. These yield a power source applicable to the area. Following the next arrow yields equipment necessary to make the system function, and the last step provides a cursory cost overview for the system. This does not include labor, or continued upkeep costs (fuel costs or any replacement parts to be installed later).

For grid connected areas, the batteries may not be entirely necessary- if one can contract with the power company to supply power to the grid as needed, excess power can be sold into the grid for income, which may or may not be suitable in place of storage.

The equipment denoted with the pound (#) pertains to Straight Vegetable Oil conversion but is not required for biodiesel use. Equipment denoted with an asterisk (*) pertains strictly to biodiesel and is not necessary for the Straight Vegetable Conversion.

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Appendix E: Results of interview with Kofi Amofo



Interview Date: **May 31, 2006**

- 12) Could you describe the region of Ghana that you originate from?
Maps and climate information given. Abetifi is a village of about 15,000 people in Ghana's Eastern Region.
- 13) What sorts of agriculture exist in your area?
Wood biomass is readily available. Vegetable oil is more expensive than diesel fuel.
- 14) What sorts of terrain and natural resources do you have available? (Rivers, grassland, etc)
No rivers close by (a matter of miles to the nearest large stream). Altitude of 630 Meters
- 15) What is the climate like year round? Climate information given.
- a. Is there a long rainy season? YES [X] NO[]
i. March to July
 - b. Is there consistent wind? YES [X] NO[]
i. Average of 5 knots
 - c. Are strong storms (with extremely heavy wind) common? YES [X] NO[]
i. 28-34 knots late March to early May and late August into September
- 16) Do you know of any (and if yes, what) energy implementation attempts that have been made in your area? **Actually has access to grid power but it is unreliable at best. Power is supplied to schools, municipal buildings, and periodically others, but is often subject to weeks of blackouts. Uses the diesel generator to remove reliance on the grid.**
- 17) What sort of electric power generation do you have (specific model generator if possible)? **India 4 or 6 cylinder diesel generator. Triple phase with 415V output, number of kilowatts not known.**
- a. How much diesel fuel do you consume daily?
8-9 gal. Shop usually open 8 hours, and periodically up to 10-12 hours when trying to meet deadlines.
 - b. At what price? **£2.80 (\$5.30)/gallon. (total usage = aprox. \$45US per day.)**
- 18) Can you give us more specific information on the machines in your shop?
Planning to add forge, ventilation system and planer and computers possibly, as well as other telecommunications in the future. Built many existing machines, so no commercial data exists for them.

19) What machines require the most power?

Welders and grinders. Welders mostly 12-14 kW

- a. What other machines require power? **Wood planer, lighting, fans. Planning to build 12-24V forge, transformer AC-> DC, ventilation system, which will also require electricity.**

20) How do you run your machines (many at once, only one or two at once, which ones simultaneously, etc.)? **Most at once. Sometimes up to 4 welders at once**

21) Would you be interested in learning how to build your own turbine in order to build a power system for yourself or to market to others in Africa? **Most certainly. Builds his own machines, and has shop to sell works in market as well as taking special orders.**

Additional information:

Wind is not tremendously fast, but averages ~5 KTS(which we assume means knots). Hours of direct sunlight also given.

Costs £80-100 to travel to Accra to buy materials and transport them back. Sometimes costs are even higher if rental truck is unavailable, nonrefunded deposit to reserve it for later. Cost of square pipe = £1

Other businesses also run diesels- carpenters operate in the same area.

Possible problems and fears should not be problematic: no local planning regulations to stand in the way. Chief owns the land, but would not have a problem with it- he is coming to London over the summer to hear about energy work. Any step in the right direction should pass by him easily.

Appendix F: Kofi Amofo's Answers to Previously Posed Questions

Immediate information required (*Kofi*)

1	Full name of business Globe Metal Works
2	Description of business activity Manufacture of agricultural imprint machines and processions machines, metal gates, window guides, balustrade,
3	Full contact details of owner (Kofi): UK Kofi A. Amofo 14 Stepheions Close Aylesbury Bucks kanim2020@yahoo.com.au Post code HP 19 7 QU
4	Full contact details of owner (Kofi): Ghana Kofi Anim Amofo P.O. BOX AT 33 Abetifi Kwahu E/R Ghana West Africa
5	Full address of workshop in Ghana Globe Metals Works P. O. Box AT 33 Abetifi Kwahu E/R Ghana West Afrika Phone 00233-81-30070 or 00233 208781241
6	"Google Earth" location coordinates
7	Land ownership details for the area surrounding the workshop Land is rented from one Nana Dakwah of Abetifi Kwahu
8	Number of employees in workshop 10 Workers
9	What machines are in the workshop? 5 welding machines 1 Table top drilling machine 1 big 9" angle grinder , 4 small 4" angle grinders 1 wood lathe 4 vices, 2 hand drilling machines 1 voltage transformer 240-240v 4 voltage transformer 240-110v

	1 wood lathe, 1 wood planing machine, 1 circular saw machine to be complete.

Possible technology options

1	Wind turbines
2	Solar photovoltaic
3	Biomass crop for generator
4	Biogas for generator (anaerobic digestion of biomass)
5	Sewerage gas for generator

Additional comments or observation

Appendix G: Budget and Schedule

Team Name	Merton Ghana Power		
Objective / Task	People in Charge	Budget	Deadline
Complete Background	MJB		16-May
Refined Methodology	SK		20-May
Interviews	DL	\$60	2-Jun
Database Organization	MJB		15-Jun
Presentation			
Organization			18-Jun
Rehearsal			26-Jun
Final Presentation			29-Jun
Final Draft			
Copies		\$40	
Delivery			

Objective / Task	May													
	5/13	5/14	5/15	5/16	5/17	5/18	5/19	5/20	5/21	5/22	5/23	5/24	5/25	5/26
Complete Background	X	X	X	X	X									
Refined Methodology				X	X	X	X	X	X	X	X			
Interviews														
Database Organization														
Presentation														
Organization														
Rehearsal														
Final Presentation														
Final Draft														

Objective / Task	June														
	6/1	6/2	6/3	6/4	6/5	6/6	6/7	6/8	6/9	6/10	6/11	6/12	6/13	6/14	6/15
Complete Background															
Refined Methodology															
Interviews	X													X	X
Database Organization									X	X	X	X	X	X	X
Presentation															
Organization															
Rehearsal															
Final Presentation															
Final Draft															

Objective / Task	6/16	6/17	6/18	6/19	6/20	6/21	6/22	6/23	6/24	6/25	6/26	6/27	6/28
Complete Background													
Refined Methodology													
Interviews													
Database Organization													
Presentation Organization	X	X	X	X	X	X							
Rehearsal							X	X	X	X	X	X	X
Final Presentation													
Final Draft													

Appendix H: Abetifi Climate Data

Date	Maximum Temperature (C)	Minimum Temperature (C)	Run 9H to 9H	Wind Direction 1	Wind Direction 2	Speed (Knots)	Sunshine Direction Duration
1/1/2001	29.8	20.1	124.44	SW		2	7.1
1/2/2001	29.6	20.4	110.83	SW		4	8.5
1/3/2001	30	20.4	15.23	SW		3	8.7
1/4/2001	30.4	21.3	60.29	Calm	SW	1	7.9
1/5/2001	29.1	20.2	47.03	SW		2	8.6
1/6/2001	29.5	21.1	108.66	Variable		2	6.4
1/7/2001	27.9	20.7	48.03	SW		3	4.6
1/8/2001	29.4	20.7	106.5	SW		2	4.9
1/9/2001	29.2	20	39.54	SW		1	6.9
1/10/2001	31.6	20.5	118.67	SW		1	8.9
1/11/2001	30.4	20.5	121.84	SW		3	8.3
1/12/2001	31.5	21.2	101.88	SW		3	9.1
1/13/2001	29.4	21.4	118.83	SW		3	7.9
1/14/2001	31.2	21.5	95.25	SW		2	8.1
1/15/2001	32.1	20.6	127.71	SW		4	9.1
1/16/2001	30.3	21.4	136.37	SW		4	6.2
1/17/2001	31.7	21.9	123.81	SW		4	8.9
1/18/2001	31.2	21.3	125.4	SW		4	9.3
1/19/2001	31.4	21.4	70.36	SW		3	9.5
1/20/2001	30.7	21.6	52.74	SW	NE	4	8.4
1/21/2001	30	20.4	61.11	SW		3	8.3
1/22/2001	30.7	19.7	13.48	SW	NE	3	7.3
1/23/2001	31.8	21.5	70.52	Variable		2	8.3
1/24/2001	30.3	21.2	61.44	Variable		2	8.8
1/25/2001	29.6	21	56.62	Variable		2	8
1/26/2001	30.6	20.8	32.67	Variable		2	6.3
1/27/2001	31	21.5	49.22	NE		2	7.3
1/28/2001	31.6	21.5	87.68	Variable		1	8.8
1/29/2001	32	19.5	132.71	SW		3	8.8
1/30/2001	31.1	20.4	142.77	SW		4	7.4
1/31/2001	31	21	147.27	SW		3	8

Appendix I: Notes from Interviews with Civic Centre Employees

These notes are taken from the interviews conducted with Merton Civic Centre Employees. All of the opinions expressed are those of the interviewee.

Interview 1

Reasons for immigration:

Many people come to UK for economic reasons, job training, or education. During the civil unrest of the 1970s, many intellectuals left. Most emigrants have some desire to return home, or to do something for Ghana. The interviewee himself wants to return home, and says that he “never really felt at home here [in the UK].”

His observations about Ghana:

Ghanaians are hard working people, but they do not have access to many jobs. The people are brilliant, but the standard of living is low. There are many untapped resources, and many available markets, but management and government is lacking. There is no sense of urgency to government work, and the nation would benefit from businessmen in government offices.

Energy concerns:

The energy is available but poorly managed. Due to inefficiency and lack of redundancies, the grid is unreliable. The energy project will be useful and helpful. One advantage is the ability to make goods there, rather than import them.

Kofi’s situation is specific to him, but there are a large number of people with business situations affecting decisions to leave Ghana.

He keeps a very close network with Ghana, and knows of many others who do as well- he reads Ghanaian news, and visits his mother in Kumasi frequently, and these are not uncommon occurrences for many Ghanaians.

Energy needs a seed project (like the one we are doing) because once there is a successful system, others will follow it.

Interview 2

Our project is a good notion for energy not only in Ghana, but in other developing nations as well. High oil prices are impacting cost of living and industry.

Most of Ghana's energy comes from the Akusombo dam, and due to droughts there are questions about its viability. As a result, there has been deforestation for charcoal power.

Some of his friends have solar power, but it is expensive, and does not produce enough power to store energy for days when the grid does not provide power.

On the success of the wider project:

“Once it works, millions will follow suit.” If Kofi can power his business, others will use the technology. Ghana is well developed and western, but there is an imbalance of facilities. Power costs are so high that lights are the extent of powering capacity. If a renewable, small scale power scheme takes off, it will have government support.

Energy concerns:

Nigeria provides oil, but a change of government could dry up supply, so oil is a concern.

Electricity cutouts are a concern to citizens. Droughts and questions about the dam have led to global warming awareness as well.

Typical homes in Accra have electric stoves, TVs, and other standard appliances, but most places only have grid access for schools and municipalities. Hotels and some people have backup generators to handle the rolling blackouts, and some people have PV systems, but most people rely on the grid alone.

Interview 3

Many Ghanaian workers are economic migrants, and 20% of migrants go to the UK (due to Commonwealth history and language). She knows business owners who left businesses to go to the UK, but is unsure of the role energy plays in that decision.

Renewables, particularly solar, biomass, and hydrogen fuel cells are areas of intense interest.

Energy is a household problem as well as a business one, and utilities have become privatized in recent years to combat corruption. Energy is a major concern now because of security concerns, and the science university in Kumasi is researching renewable technology.

Micro-lending is a common occurrence. Solar PV systems will be cheaper soon, because Shell is designing cheaper, more efficient PV technology.

Suggestions:

Involve universities, secondary schools and technical colleges. There is a secondary school (possibly called St. Peter's, but she was not sure) in Abetifi which could help with Kofi's particular situation. Some sort of web-based link to coordinate universities, schools, aid groups and governments would make the project easier.

One major problem is the jump from worker's skill (Kofi's ability to build something without too much thought) to book learning in universities. Literacy is a concern. Look into video or radio transfer of information. The north, which needs development most, has only radio reception.

Appendix J: Potential Windmill Outputs

Wind Speed (m/s)	Blade Length (m)	Power Output (kw)
1	1	0.00
2	1	0.00
3	1	0.02
4	1	0.04
5	1	0.08
6	1	0.13
7	1	0.21
8	1	0.31
9	1	0.44
10	1	0.60
1	2	0.00
2	2	0.02
3	2	0.06
4	2	0.15
5	2	0.30
6	2	0.52
7	2	0.82
8	2	1.23
9	2	1.75
10	2	2.40
1	4	0.01
2	4	0.08
3	4	0.26
4	4	0.61
5	4	1.20
6	4	2.07
7	4	3.29
8	4	4.92
9	4	7.00
10	4	9.60

Explanatory note: this figure is derived from the wind equation presented in How to Build a Wind Turbine: The Axial Flux Windmill Plans by Hugh Piggott. This formula for wind power is:⁸⁴

$$0.15D^2S^3$$

D is the diameter of the windmill (or twice the length of the blade) and S is the wind speed passing the rotor. Using sample wind velocities and blade lengths, one can develop an approximation of the power output which can be harnessed by a small turbine. Small outputs, however may actually be eclipsed by the cut-in phenomenon, so numbers derived from wind speeds below 2m/s may actually be exaggerated.

⁸⁴ How to Build a Wind Turbine: The Axial Flux Windmill Plans by Hugh Piggott, page 11

Appendix K: Renewable Energy Project Entry



Village Power Project

Basic Project Information Goals and Objectives Project Size	Technical Characteristics Resource Profile	Lessons Learned
Institutional Aspects Project Participants Project Organization	Economic/Financial Profile Economics Financing	Contact
Available Documentation	Host Country Information	Photos/Graphics

BASIC PROJECT INFORMATION

Abstract:

Project Name: Morocco, Wind-Diesel

Region: North Africa

Country Name: Morocco

Location within Country:

Technology: Wind, Diesel, Hybrid System(s)

Application: Water Heating, Water Pump, Irrigation, Ice Maker

Sector: Water Supply

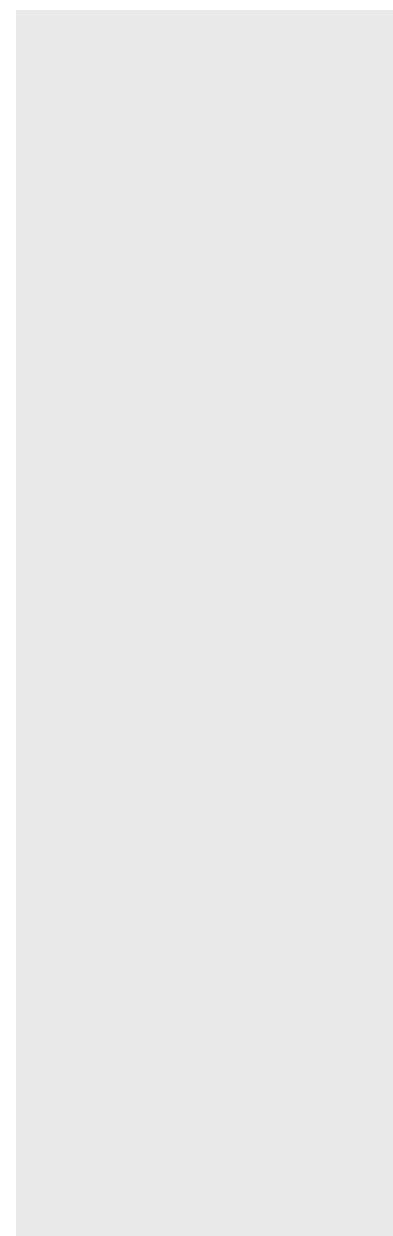
Project Type and Characteristics:

Type of Systems: Centralized Mini Grid

Project Dates: Initiated June 1994.

Project Status: Underway

Lead Organizations: Atlantic Orient Corporation



Last Updated: 5/27/1996

Goals and Objectives

Developmental Objectives: • Provide a stable source of energy to a desert farm in Tiniguir. • Provide ice making capability so that local fishing villages can preserve their catch and ship it to the northern population centers. • Improve the quality of life for the inhabitants.

Environmental Objectives:

Institutional Objectives:

Project Size

Technical: 150kW wind turbine, two 48kW diesels

Cost: <USD\$300,000< font>

Users: 24 inhabitants all yr, 200 for harvest season

INSTITUTIONAL ASPECTS

Project Participants

Government Agencies:

International Bilateral Agencies:

NGOs (Local and International):

Cooperatives:

Private Sector: Private corporation owned by the King.

Others:

Project Organization

Organizational Structure: AOC was retained as a turnkey subcontractor. They are training locals to operate the icemaker and wind turbine. There is a per diem agreement for technical support.

Site Identification:

Technical Design:

Installation:

Training: AOC

Maintenance:

Resource Assessment:

Technical Assistance:

Community Involvement:

Revenue Collection:

Follow Up:

Other:

Links with other projects and programs:

Project origins, history, and development: Customer contacted AWEA who referred them to AOC.

Potential for replication and diffusion: The king owns 10 private farms. If this is successful, the king will try to replicate this on the other farms.

AVAILABLE DOCUMENTATION

Photo Documentation:

Project Reports:

Electronic Archives:

Published Articles:

Video Tapes/Films:

TECHNICAL CHARACTERISTICS

Generator Type	Generator Size/Brand	Number of Generators
Diesel generators	50kW, 50Hz	2
15/50 wind turbine	AOC	1

Generator Description: The new power system consists of • two 50kW, 50Hz diesel generators with electronic governors and auto synchronizers
• one AOC 15/50 wind turbine
• 1.5 mile power distribution line of 5500 volts
• 12 ton per day ice maker
• three 1500 watt electric water heaters
• resistive dump load
• supervisory controller

Battery Brand:

AHR Capacity:

Number of Batteries/System:

DC Bus Voltage:

Inverter Brand:

Power Rating:

Balance of Systems Description:

Major Loads	Number	Demand

Demand Profile: Peak load is 32kW. Load is highly variable.

Demand Profile Graph:

Optional Deferrable Loads:

Technical Performance:

Provisions for monitoring and evaluation: NREL is considering monitoring the system.

[Battery Charging Station Information](#) (if applicable and available)

Resource Profile

Solar Radiation:

Hydro Head:

Wind Speed (Average, Seasonal): Wind is 9 m/sec.

Electrification Alternative:

Grid Extension Cost:

Diesel Cost:

Other Cost:

ECONOMIC AND FINANCIAL PROFILE

Economics

EPC Capital Costs (engineering, procurement, construction):
\$220,000 US\$

Non-Fuel O&M Costs (fixed and variable): US\$12,000

Fuel Costs:

Cost per kWh of production and distribution:

Cost recovery mechanisms and rates:

Power Purchase Agreement with local utility or cooperative:

Contract with end users:

Financing

Financier	Type	Amount

Financial Description:

Extent and role of subsidies, tariffs, and duties:

Economic rate of return:

Project financial rate of return:

Environmental and other credits (monetized):

HOST COUNTRY INFORMATION

Demonstrated ability to pay for electric service:

Estimated willingness to pay for electric service:

Community Organization:

Social Economic/Cultural characteristics of end user groups: The energy is to be used in productive uses for the farm, productive uses for local fishermen, and consumption (hot showers, lighting) uses for farm workers.

Participation of women in renewable energy project: All of the farm workers are male, for religious and social reasons.

Country Overview:

LESSONS LEARNED

Technical: It is a long way to Morocco and there is no local technical support. There aren't any cranes in the area so they "rented" a helicopter from the Moroccan Army to erect the turbine.

Political:

Institutional:

Socio-Cultural: When you go to another country you abide by their rules and customs. Learned how to slaughter a sheep to celebrate the introduction of electricity.

Economic/Financial:

What would you do differently the next time: The project would have gone more smoothly if they could have cut the time in half.

What would you do the same:

CONTACT

Contact: Jigar *
Organization/Company: Atlantic Orient Corporation
Address:
City: State: Postal Code:
Country:
Phone Number 1:
Phone Number 2:
Fax Number 1:
Fax Number 2:
Email Address: atlanticorient@juno.com

PHOTOS/GRAPHICS

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Appendix L: Case Study Example

Questionnaire



DATE: 3 July, 2006

NAME: John Osuwu

Personal Background

1. What is your objective for your time in London?
Working and sending home money to support my father's tailor shop in Kumasi
 - a. Did you bring family with you? YES NO
 - b. What factors caused you to decide to leave Ghana?
Economics. Family has not been able to support business because energy bills are too high.

2. Do you intend to return there to live in the future? YES NO
 - a. If so, when and under what circumstances?
If my father no longer needs my help, I will return home

 - b. Would you be more likely to return if given job training? YES NO
 - c. If yes, how can we contact you?
I live at 36 Surrey Road, Flat C, Pollards Hill, Merton, S4

3. What do you do for work?
I work in a café in Pollards Hill
 - a. Do you have experience in metal or woodwork, or similar trade?
No

Home Background

4. Could you describe the region where you live in Ghana?
It is hot, sunny, and breezy. The land is very flat grassland
 - a. Is there a large amount of local agriculture? **No. We live in the city of Kumasi**
 - b. What is the local topography like (hills, plains, etc)? **Plains**

5. What is the land ownership situation in your home area? (i.e. Do people own land or rent, is land community-owned, etc)
The chief owns most of the land and rents it to tenants
 - a. Specifically, do you own your land?
We rent from the chief

6. What sorts of terrain and natural resources do you have available? (Rivers, grassland, etc)

There is a river on our land

- a. Is there a lot of available biomass (vegetation)?

No, we are in the city.

7. What is the climate like year round?

Hot, rainy around March and late August

- a. Is there a long rainy season?

YES [**X**] NO[]

- i. Can you give approximate dates?

Early March through April, and Mid-August through September

- b. Is there consistent wind?

YES [] NO[**X**]

- ii. If so, how strong?

About 15 knots

- c. Are strong storms (with extremely strong wind) common?

YES [**X**] NO[]

Storms coinciding with rainy season winds reach 30 knots (I worked for the meteorological society)

Energy Related

8. Are you connected to grid power?

YES [**X**] NO[]

- a. If so, does the grid provide consistent power?

No, we have power about ½ of the time

- b. If not, is the grid near you at all?

N/A

9. Do you know of any (and if yes, what) energy implementation attempts that have been made in your area? **N/A**

10. What sort of electric power generation (if any) do you have?

We are considering solar panels, but have nothing yet

- a. If running on petroleum generation, how much do you use?

N/A

11. What sorts of appliances or electrical uses do you have in your home?

My father has a tailor's shop, and runs sewing machines and lights

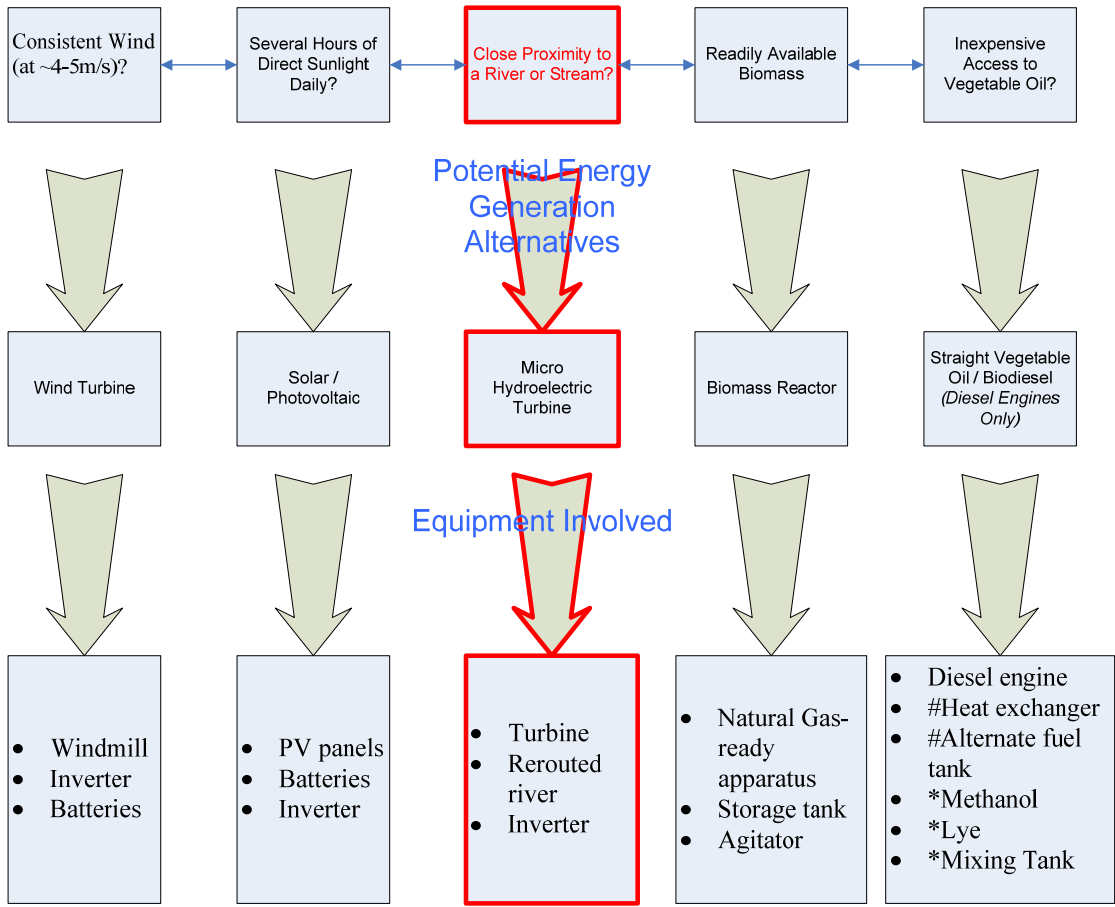
- a. Can you tell us about how much electricity you use?

We use 120V, 20amps for the shop (up to 2.4KW)

Flow Chart for Power Solutions



Assessing Energy Alternatives



Micro Lending

NGO Name	Country of Origin	Street Address	Additional	City	State	Post Code	Phone Number	Email	Website
Africa Alive Microcredit Association	USA	Africa Alive Microcredit Association	3428 Long Beach Blvd., #197	Long Beach	California	90807	1-562-234-0077	janetravel0304@yahoo.com	http://www.aama-ghana.org
Atidekate	United States	171 Pier Avenue, #370		Santa Monica	CA USA	90405	213-382-6078	contact from web page	www.atidekate.com
CanAfrica Foundation	Canada	2866 Crosscurrent Dr.		Mississauga	Ontario	L5N 6L1	1-866-222-0934	info@canafrika.org	http://www.canafrika.org/

Appendix M: Use of the NGO Database

The database was created with Microsoft Access 2003. All the data that was put into the database was stored in a table entitled “NGO Full Information.” To input information use of the form “NGO Full” is required. This form can be found on the main menu for the database under the heading entitled “Objects” under the field “Forms” and can be used to add more data to the database.

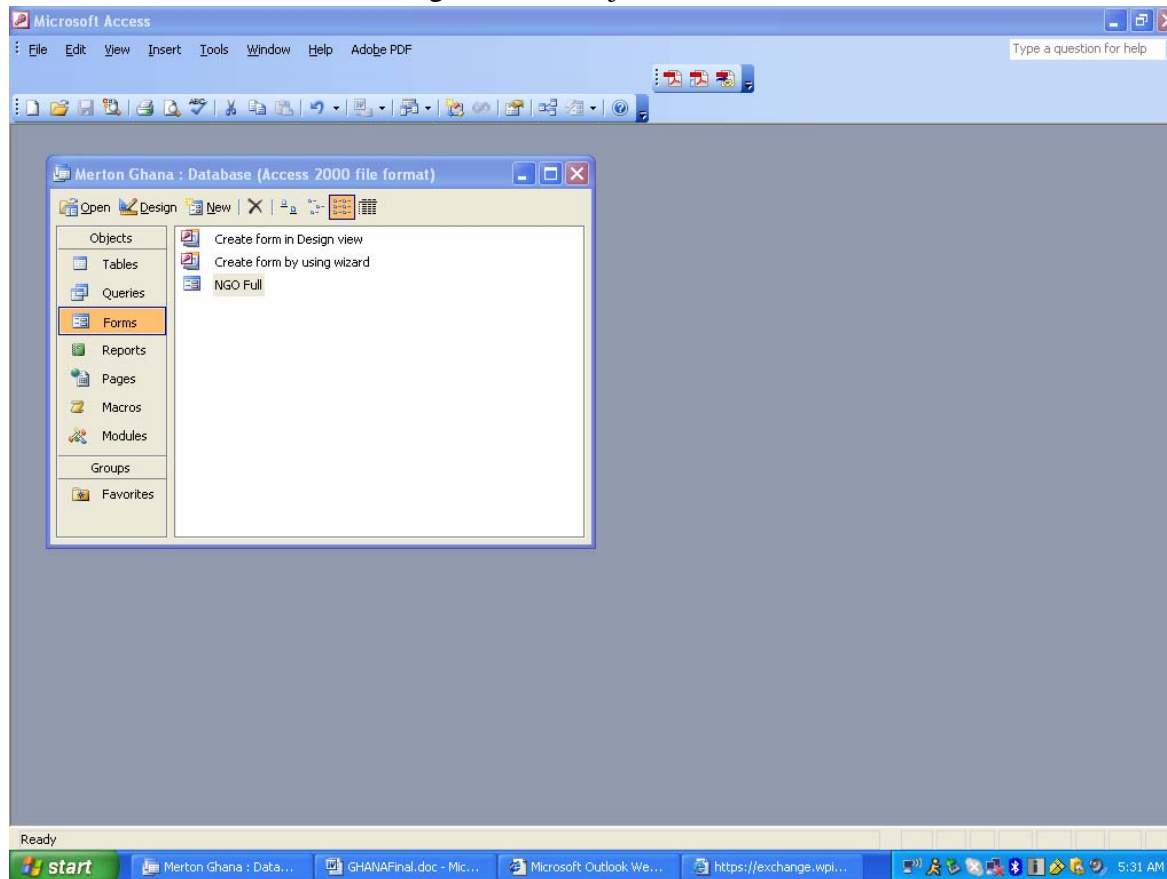


Figure 15 Database Main Menu

The database is also equipped with Queries to allow easy retrieval of database information. There are 5 pre made queries corresponding to the 5 categories NGOs were grouped into. To access these from the main menu you must select the category “Queries” under the menu heading “Objects.” Once in the queries menu, simply click on the title of the category you are looking to use and a table will appear with only the NGO type you are looking for.

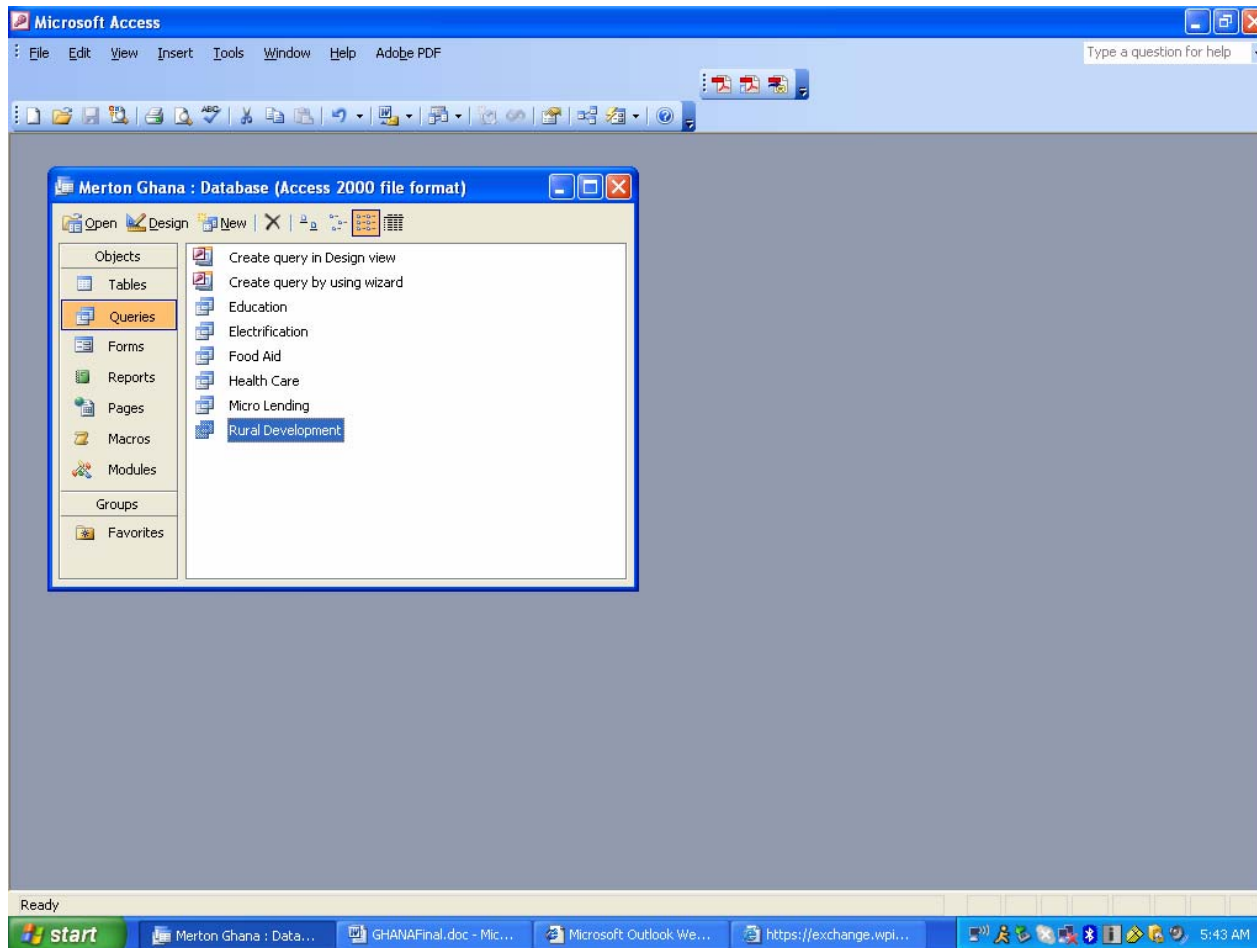


Figure 16 Queries Menu