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*Title:*

## **Technical & Economic Viability Analysis of Renewable Energy Technologies in Ghana.**

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## DECLARATION

I hereby declare that this dissertation is solely the result of my effort. This research was an independent study under the supervision of Prof. Dr. rer. nat. Jürgen Ertel and Prof. Dr. iur. Eike Albrecht. All other source/work used has been adequately referenced.

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## DEDICATION

I dedicate this work to my wife and my unborn children.

This is how far you've brought me Oh, God! All the glory is thine.

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## **ABSTRACT (ENGLISH)**

Ghana is far from becoming an energy independent state. The current energy mix in Ghana is: traditional biomass (66.7%); crude oil/petroleum products (26.2%); and electricity (7.1%) mainly from large hydro plants. The existing energy insecurity dilemma, where demand for energy is desperately needed for sustainable development leaves Ghana with no other option than to exploit its renewable energy resources. The study seeks to address three main research questions: (a) Are Renewable Energy Technologies (RETs) technically and economically viable in Ghana? ; (b) Can RE projects be self sustained in Ghana without continual external support? ; (c) Can RETs be used as an engine for local development? Both qualitative and quantitative methods were employed in addressing the research questions. The four main RE resources identified in Ghana are biomass, solar, small hydro and wind energy. Detailed case study analysis for each resource was done for identification of technically and economically viable options. The study concludes with a strategy on the where, what, why and how to implement viable RE projects in Ghana and a 'best policy' recommendation for successful market diffusion of RETs. The study proposes that RETs must be delivered in forms that match basic and economic self-reliance needs of the local people and the generated electricity should be tied directly to viable end-use activities.

## **ABSTRACT (GERMAN)**

In Ghana ist die Energieversorgung nicht gesichert. Der Energie-Mix in Ghana besteht aus traditioneller Biomasse (66,7%), Erdöl/-produkten (26,2%) und Elektrizität (7,1%) – groß Wasserkraftanlagen. Die unsichere Energiesituation in Ghana, die die nachhaltige Entwicklung negativ beeinflusst, lässt dem Land nur die Erforschung Erneuerbarer Energien (EE). Diese Studie beschäftigt sich mit drei Hauptfragen: (a) Sind die Technologien für EE in Ghana technisch und ökonomisch realisierbar?; (b) Können EE-Projekte in Ghana ohne kontinuierliche Unterstützung von außerhalb durchgeführt werden?; (c) Können Anlagen für EE als Antrieb für die lokale Entwicklung genutzt werden? Diese Fragestellungen wurden quantitativ und qualitativ analysiert. Als Ergebnis wurden vier EE identifiziert, die für Ghana geeignet sind: Biomasse, kleine Wasserkraftanlagen, Solar- und Windenergie. Mit detaillierten Fallstudien wurden für diese Ressourcen die technische und ökonomische Machbarkeit überprüft. Am Ende steht eine Strategie, in der das Wo, Wie und Warum für realisierbare EE-Projekte in Ghana geklärt wird. Außerdem wurde ein Vorschlag für eine optimale Strategie der erfolgreichen Marktdurchdringung der EE-Technologien erarbeitet. Diese Studie schlägt vor, dass die erzeugte Elektrizität vom EE an ökonomischen Endverbraucher-Aktivitäten gebunden ist.

## **ACRONYMS/ABBREVIATIONS**

<b>AESC</b>	<b>Architectural Engineering Services Corporation</b>
<b>AESL</b>	<b>Architectural Engineering Services limited</b>
<b>AREED</b>	<b>African Rural Energy Enterprise Development</b>
<b>AWEA</b>	<b>American Wind Energy Association</b>
<b>BAU</b>	<b>Business-as-Usual</b>
<b>BOHS</b>	<b>Battery Operated Home System</b>
<b>BRRI</b>	<b>Building and Road Research Institute</b>
<b>BWEA</b>	<b>British Wind Energy Association</b>
<b>CANMET</b>	<b>Canada Centre for Mineral &amp; Energy Technology</b>
<b>CBA</b>	<b>Cost Benefit Analysis</b>
<b>CDM</b>	<b>Clean Development Mechanism</b>
<b>CEPS</b>	<b>Customs, Excise and Preventive Services</b>
<b>CHP</b>	<b>Combined Heat &amp; Power</b>
<b>CIDA</b>	<b>Canadian International Development Agency</b>
<b>DBEDT</b>	<b>Department of Business, Economic Development and Tourism</b>
<b>DCEP</b>	<b>District Capital Electrification Programme</b>
<b>DENG</b>	<b>Danafco Engineering</b>
<b>DNC</b>	<b>Declared Net Capacity</b>
<b>EC</b>	<b>Energy Commission</b>
<b>EC*</b>	<b>European Commission</b>
<b>ECG</b>	<b>Electricity Corporation of Ghana</b>
<b>ECOWAS</b>	<b>Economic Community of West African States</b>
<b>EFL</b>	<b>Electricity Feed Law</b>
<b>EPA</b>	<b>Environmental Protection Agency</b>
<b>ERG</b>	<b>Energy Research Group</b>
<b>ERP</b>	<b>Economic Recovery Programme</b>
<b>ESDP</b>	<b>Energy Sector Development Programme</b>
<b>ESMAP</b>	<b>Energy Sector Management Assistance Programme</b>
<b>FFL</b>	<b>Fossil Fuel Levy</b>

<b>FPIB</b>	<b>Forest Product Inspection Bureau</b>
<b>GEF</b>	<b>Global Environment Facility</b>
<b>GHADES</b>	<b>Ghana Solar Energy Association</b>
<b>GHG</b>	<b>Green House Gas</b>
<b>GIS</b>	<b>Ghana Institution of Surveyors</b>
<b>GoG</b>	<b>Government of Ghana</b>
<b>GSB</b>	<b>Ghana Standard Board</b>
<b>GTZ</b>	<b>Gesellschaft für Technische Zusammenarbeit</b>
<b>GWC</b>	<b>Ghana Water Company</b>
<b>GWSC</b>	<b>Ghana Water and Sewerage Corporation</b>
<b>IIR</b>	<b>Institute of Industrial Research</b>
<b>IPP</b>	<b>Independent Power Producer</b>
<b>KITE</b>	<b>Kumasi Institute of Technology &amp; Energy</b>
<b>KNUST</b>	<b>Kwame Nkrumah University of Science and Technology</b>
<b>LPG</b>	<b>Liquefied Petroleum Gas</b>
<b>LRMC</b>	<b>Long-Run Marginal Cost</b>
<b>MEST</b>	<b>Ministry of Environment, Science and Technology</b>
<b>MFP</b>	<b>Ministry of Fuel and Power</b>
<b>Mmcf/d</b>	<b>Million cubic feet per day</b>
<b>MME</b>	<b>Ministry of Mines and Energy</b>
<b>MOE</b>	<b>Ministry of Energy</b>
<b>MOFA</b>	<b>Ministry of Food and Agriculture</b>
<b>MOH</b>	<b>Ministry of Health</b>
<b>MORE</b>	<b>Modern Renewable Energy</b>
<b>MSHG</b>	<b>Multi-Stakeholder Small Hydro Group</b>
<b>NASA</b>	<b>National Aeronautics and Space Administration</b>
<b>NASEP</b>	<b>National Solar Energy Programme</b>
<b>NEB</b>	<b>National Energy Board</b>
<b>NEF</b>	<b>National Electrification Fund</b>
<b>NEFB</b>	<b>National Electrification Fund Board</b>
<b>NEP</b>	<b>National Electrification Project</b>
<b>NEPS</b>	<b>National Electrification Planning Study</b>



<b>NES</b>	<b>National Electrification Scheme</b>
<b>NFFO</b>	<b>Non-Fossil Fuel Obligation</b>
<b>NFPA</b>	<b>Non-Fossil Purchasing Agency</b>
<b>NGO</b>	<b>Non-Governmental Organisation</b>
<b>NRES</b>	<b>National Renewable Energy Strategy</b>
<b>O &amp; M</b>	<b>Operation and Maintenance</b>
<b>PNDC</b>	<b>Provisional National Defence Council</b>
<b>PPA</b>	<b>Power Purchase Agreement</b>
<b>PSDP</b>	<b>Power Sector Development Programme</b>
<b>PURC</b>	<b>Public Utilities Regulatory Commission</b>
<b>PV</b>	<b>Photovoltaic</b>
<b>R&amp;D</b>	<b>Research &amp; Development</b>
<b>RECs</b>	<b>Regional Electricity Companies</b>
<b>REDP</b>	<b>Renewable Energy Development Programme</b>
<b>RESA</b>	<b>Renewable Energy Sources Act</b>
<b>RETs</b>	<b>Renewable Energy Technologies</b>
<b>RPS</b>	<b>Renewable Portfolio Standard</b>
<b>SCD</b>	<b>Solar Crop Dryer</b>
<b>SHEP</b>	<b>Self-Help Electrification Programme</b>
<b>SHP</b>	<b>Small Hydro Power</b>
<b>SOHLS</b>	<b>Solar Home Lightening System</b>
<b>SRMC</b>	<b>Short-Run Marginal Cost</b>
<b>SSC</b>	<b>Solar Service Centres</b>
<b>SWH</b>	<b>Solar Water Heater</b>
<b>SWP</b>	<b>Solar Water Pump</b>
<b>TSWH</b>	<b>Thermiosiphon Solar Water Heater</b>
<b>UNDP</b>	<b>United Nations Children Fund</b>
<b>UNEP</b>	<b>United Nations Environment Programme</b>
<b>UNICEF</b>	<b>United Nations Children’s Fund</b>
<b>US</b>	<b>United States</b>
<b>USAID</b>	<b>United States Agency for International Development</b>
<b>VRA</b>	<b>Volta River Authority</b>

<b>WHO</b>	<b>World Health Organisation</b>
<b>WSSD</b>	<b>World Summit for Sustainable Development</b>
<b>¢</b>	<b>Ghanaian Cedi</b>
<b>\$</b>	<b>American Dollar</b>

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## **PART 1: INTRODUCTION, METHODOLOGICAL APPROACH & RENEWABLE ENERGY POLICY ANALYSIS**

### **CHAPTER 1 Introduction**

*"It seems to me that even the wisest philosophers of the Renaissance or the most daring minds from the past could not estimate the real size of our planet. Earlier, it seemed immeasurably great, almost infinite. Only after the middle of this century did man, having gone up above the Earth into space, see with surprise and disbelief just how small the Earth really is. Some saw it as an island in the limitless ocean of creation. Some compared it with a spaceship with a crew numbering more than six billion".*

-Pavel Popovich, Cosmonaut, USSR, Vostok 4, Aug 1962 and Soyuz 14, July 1974.

*"... issues of environmental degradation, are just as significant and immediate threat as unstable states and weapons of mass destruction".*

-Rt. Hon. Tony Blair, Prime Minister of Great Britain, 25th February 2003.

#### **Recap to the study**

Predominant environmental issues linked to the use of energy resources in Ghana are; deforestation which is occurring at the rate of 22,000 hectares or 2.1% per annum (Hagan, 1994); desertification and land degradation (soil erosion). This coupled with existing energy insecurity dilemma, where demand for energy services are desperately needed for survival and sustainable development, leaves Ghana with no other option than to exploit utilization of its renewable energy resources. However, most of the modern renewable energy (RE) projects established over the years in Ghana are not viable and many have already collapsed. Certain RE projects are in existence only because of continual donor and external support, which in itself is not sustainable and these projects will collapse as soon as external funding ceases. This research seeks to find answers to the following questions: why earlier RE projects failed; whether applications of RE technologies are technically and economically viable in Ghana and which types; also on the where, why, what and how to implement RE technologies/projects in Ghana. The study is to bridge up the knowledge gap and to develop scenarios for potential renewable energy projects, that may be viable, when all the options are considered and to directly link RE projects to existing economic activities in selected localities in Ghana.

This chapter first takes a brief look at Ghana's location, economy, energy insecurity issues and available RE resources as well as the status quo with RE financing. This will eventually

lead to objectives and analytical approach that is employed in the study in order to find answers to the questions raised earlier on. Finally in this chapter is contribution of the research to existing knowledge.

### 1.1 A brief overview of Ghana

Ghana is a tropical country lying between latitude 4° and 12°N and longitude 30°W and 1°E in Western Africa (Figure 1.1). It borders the Atlantic Ocean to the south, between Cote d'Ivoire (west), Togo (east) and Burkina Faso to the north (Figure 1.2). Formed from the merger of the British colony of the Gold Coast and the Togoland trust territory, Ghana in 1957 became the first sub-Saharan country in colonial Africa to gain independence. It is presently a democratic nation and often referred to by international community as a model for African democracy. It occupies a total area of 239,460 km<sup>2</sup> (comprised mainly of 230,940 km<sup>2</sup> land mass and 8,520 km<sup>2</sup> water bodies). A summary of the status quo with regards to the economy, demography and environmental issues in Ghana is presented in Table 1.1.

Figure 1.1 Geographic Map of Ghana.



Figure 1.2 Map of Africa showing the location of Ghana.



Table 1.1 Summary of important economic, demographic and environmental issues in Ghana.

<b>Capital</b>	<b>Accra</b>
<b>Economy-Overview</b>	Well endowed with natural resources, Ghana has roughly twice the per capita output of the poorer countries in West Africa. Even so, Ghana remains heavily dependent on international financial and technical assistance. Gold, timber, and cocoa production are major sources of foreign exchange. The domestic economy continues to revolve around subsistence agriculture, which accounts for 35% of GDP and employs 60% of the work force, mainly small landholders. Policy priorities include tighter monetary and fiscal policies, accelerated privatization, and improvement of social services. Receipts from the gold sector should help sustain GDP growth in 2004. Inflation should ease, but remain a major internal problem.
<b>GDP-real growth rate</b>	4.7% (2004 est.)
<b>GDP-per capita</b>	purchasing power parity-\$ US 2,200 (2004 est.)
<b>GDP-composition by sector</b>	<i>agriculture: 35.4%</i> <i>industry: 25.4%</i> <i>services: 39.2% (2004 est.)</i>
<b>Population Below Poverty Line</b>	31.4% (1992 est.)
<b>Environment-current issues</b>	recurrent drought in north severely affects agricultural activities; deforestation; overgrazing; soil erosion; poaching and habitat destruction threatens wildlife populations; water pollution; inadequate supplies of potable water
<b>Environment-international agreements</b>	<i>party to:</i> Biodiversity, Climate Change, Climate Change-Kyoto Protocol, Desertification, Endangered Species, Environmental Modification, Hazardous Wastes, Law of the Sea, Ozone Layer Protection, Ship Pollution, Tropical Timber 83, Tropical Timber 94, Wetlands <i>signed, but not ratified:</i> Marine Life Conservation
<b>Population</b>	20,757,032 (2004 est.)
<b>Natural resource</b>	gold, timber, industrial diamonds, bauxite, manganese, fish, rubber, hydropower (the Lake Volta is the world's largest artificial lake)
<b>Exchange Rate</b>	cedis (¢) per US dollar 9,130.00 (2005) 8,800.40 (2004), 8,458.50 (2003), 7,932.70 (2002), 7,170.76 (2001), 5,455.06 (2000), 2,669.3 (1999)

(Source: CIA, 2004).

## 1.2 Energy Insecurity and Consumption Patterns in Ghana

A country is said to have achieved an energy security status when all of its internal energy demands are met through generated capacity and/or exploitation of natural resources locally without having to rely on the external energy supplies which are highly volatile.

Ghana's annual energy consumption is estimated at 6.6 million tonnes of oil equivalents (*TOE*) and per capita energy consumption is estimated at 360 kilograms of oil equivalent (*KOE*) [Amissah-Arthur & Amonoo, 2004]. Typical of a developing country, Ghana's domestic energy consumption is much higher than commercial consumption. It is thus far from attaining a state of energy security. The energy balance picture in Ghana is described as follows (Brew-Hammond & Crole-Rees, 2002);

- Traditional biomass (woodfuels-firewood and charcoal) accounts for 66.7% of total energy consumed.
- This is followed by crude oil and petroleum products (26.2%)-this is import from the volatile oil market
- Electricity (7.1%) Local generated capacity is mainly from two main large hydro plants, the Akosombo and Kpong with total installed capacity of 1,122 MW and a 550 MW thermal plant. Additionally, 220 MW electricity is imported from neighbouring Cote d'Ivoire.

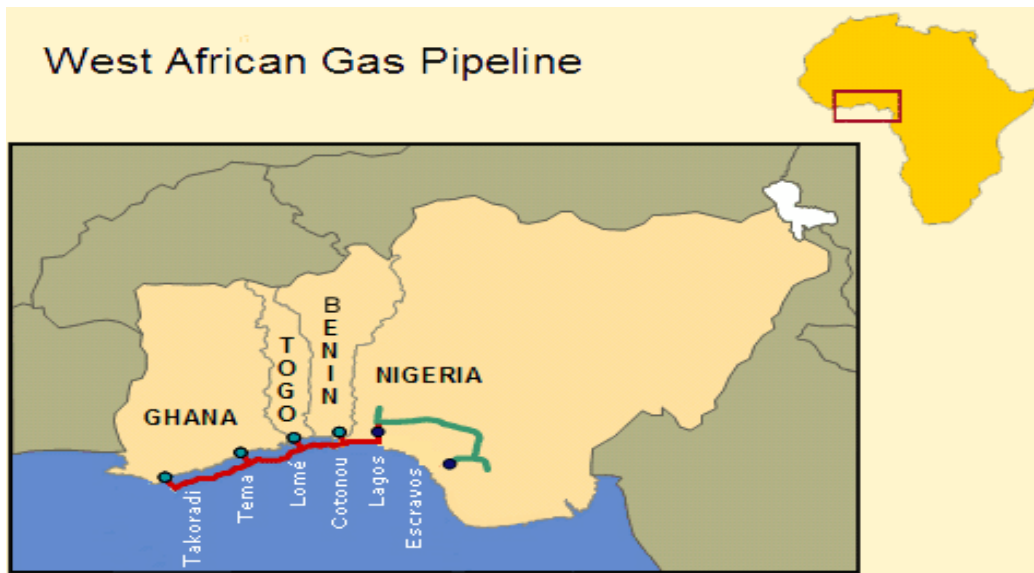
In total about 40% of the entire Ghanaian population have access to electricity (Turkson & Amadu, 1999). Seventy-seven percent (77%) of the urban population and only 17% of rural dwellers have access to electricity (GLSS, 2002). The energy consumption patterns in both rural and urban dwellers will be discussed in details later in this chapter.

Electricity consumption in Ghana has been growing at the rate of 13% per annum since 1991 (Turkson & Amadu, 2002). The inability of the country to meet the growing demand for electricity coupled with low water levels in the two hydro electric dams led to the rationing of power in major Ghanaian cities in 1998, where sections of the city receives power for just 6 hours in a day followed by period of blackout. The continual shortage of power (electricity) in Ghana led to the embarkment of the West African Gas Pipeline Project (WAGP). The WAGP will traverse 620 miles (1,033 kilometers) both on and offshore from Nigeria's Niger Delta region to its final planned terminus in Ghana. The \$ US 500-million project will initially transport 120 million cubic feet per day (Mmcf/d) of gas to three destinations in

Ghana (Tema, Takoradi and Effasu), Benin and Togo beginning in June 2005 (Figure 1.3) [(US EIA, 2003)]. Gas deliveries are expected to increase to 150 Mmcf/d in 2007, to 210 Mmcf/d in 7 years and be at 400 Mmcf/d when the pipeline is functioning at its capacity that will be approximately 15 years after construction (US EIA, 2003).

Thus cleaner-burning gas supplied by the WAGP will replace petroleum products used in the generation of electricity. An estimated 15,000-20,000 barrels per day of crude oil will be saved by the Government of Ghana by running its thermal power plants on gas from WAGP.

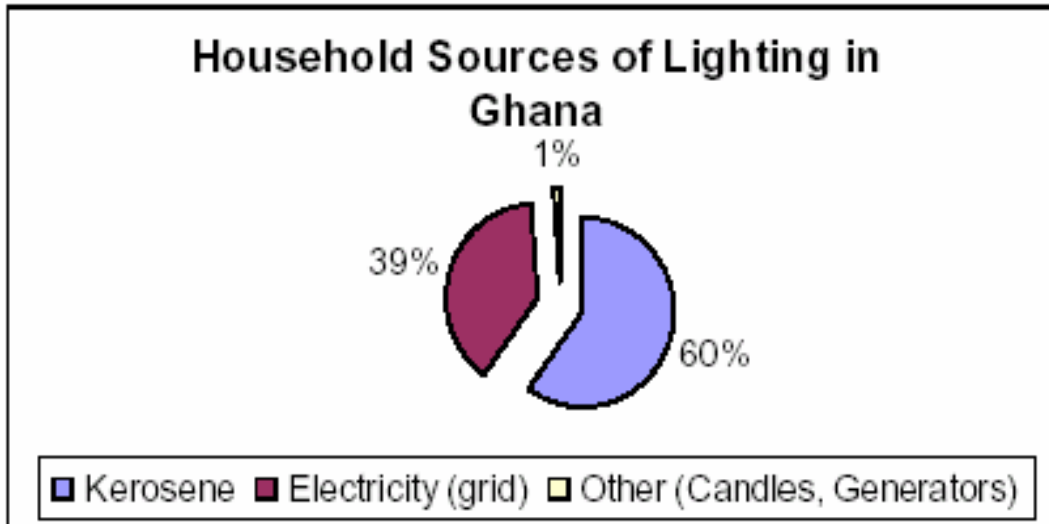
Figure 1.3 The West African Gas Pipeline transporting gas from source in Nigeria to Ghanaian destinations.



(USEIA, 2003)

As mentioned earlier on in this chapter, Ghana being a tropical country does not require any energy for home heating therefore domestic energy utilization (which forms the bulk of energy consumption in Ghana) is primarily for cooking and lighting. According to the Ghana Living Standards Survey (2002), electricity and kerosene are the main sources of energy for lighting in Ghana (Figure 1.4). About 60% of all households in the country (both urban and rural) still use kerosene for lighting, while 39% of household use grid-connected electricity for lighting (Tse, 1999). Only 1% of households use candles, generators and/or other sources [(MME, 2000), (Tse, 1999)].

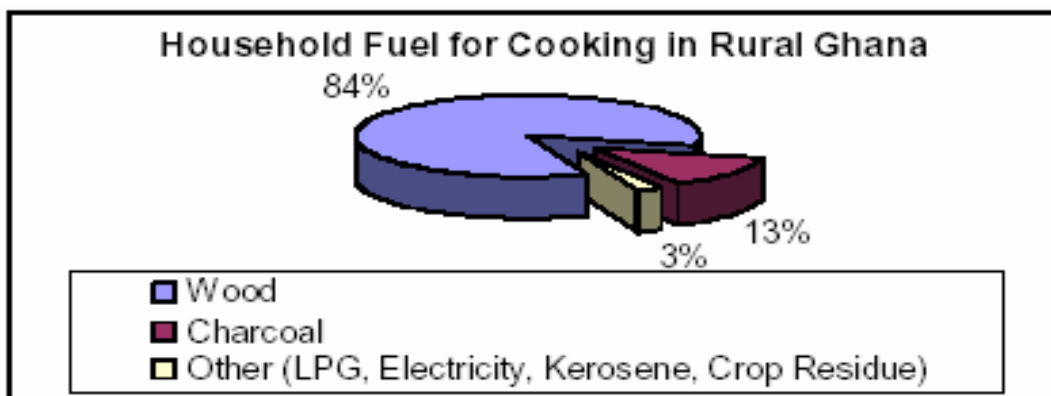
Figure 1.4 Domestic Source of Lighting in Ghana.



### 1.2.1 Energy Consumption-Rural Ghana

It is estimated by GLSS (2002) that 84% of households in rural Ghana use fuel-wood in its untransformed state as their source of fuel (Figure 1.5). A further 13% depend on charcoal as their fuel of choice for cooking (MME, 2000). All other sources, for example electricity, kerosene and Liquidified Petroleum Gas (LPG), together account for less than 3% of consumption and are therefore relatively insignificant (KITE, 2002).

Figure 1.5 Domestic Fuel Consumption (for cooking) in Rural Ghana.



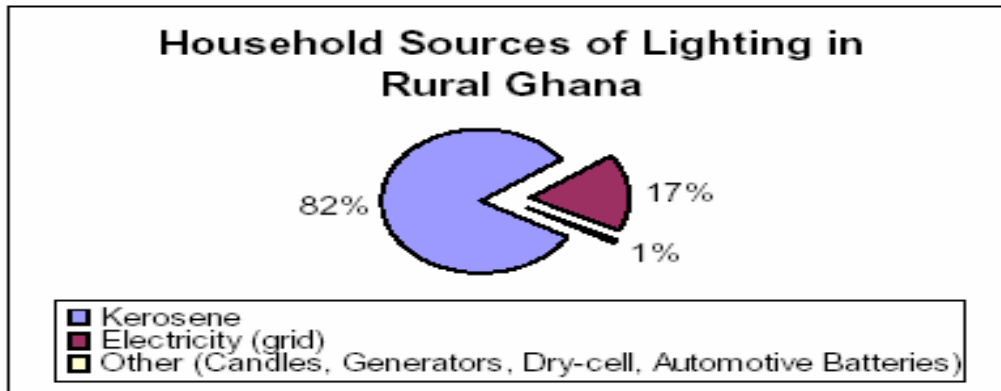
Majority of the poor depend on wood fuel for cooking and they make use of a three-stone stove which is very inefficient and negatively affect the health of users via indoor air pollution resulting from the large amount of smoke generated from inefficient combustion

process. The inefficiencies involved in such cooking practices often results in high fuel wood consumption which then place a heavy burden on the wood resource and the environment, resulting in overexploitation and consequently deforestation.

Women and children in rural communities invariably gather fuel wood for household use at no monetary cost from their natural environment but they however spend considerably amount of time and effort, walking several kilometers on foot only to collect wood fuel. The time spent however in collecting wood fuel is quite significant as large distances are covered by foot in order to obtain wood fuel. Thus provision modern energy services linked together with productive economic use provides an opportunity to break the vicious cycle of poverty and this is an area this study seeks to emphasize.

In satisfying lighting needs in rural areas, as much as 82% of households still use kerosene, candles and other traditional fuels as sources of light (Figure 1.6)[(GLSS, 2002)]. Only 17.1% of rural households obtain their lighting from grid-connected electricity (Atakora & Brew-Hammond, 1999). Diesel-generators, dry-cell and automotive batteries together make up the remaining 0.9% (GLSS, 2002).

Figure 1.6 Fuel for Lighting in Rural Ghana.



### 1.2.1.1 Economic Activity & Poverty in Rural Ghana –The Energy Remediation

There are three main ecological zones in Ghana, namely the coastal, forest and savannah zones. For all three zones, rural dwellers are predominantly involved in agriculture as their main economic activity (GLSS, 2002). The specific activities include fishing, farming and

animal rearing, but the level of participation in these activities varies by region. The predominant activity in each zone provides a good indicator for initiatives that are intended to target poverty reduction in the zone (Brew-Hammond & Crole-Rees, 2002).

Those with the highest incidence of poverty are food crop farmers constituting about 59% of the poor in Ghana (GLSS, 2002). It is the intention of this study to disseminate findings from this research to grass root agencies and non-governmental agencies (NGOs) that are into developmental activities such as the installations of renewable energy systems. The main concept to be carried across is to directly tie RE applications to existing economic activity in benefiting communities, which in the above case will be agriculture. In this concept for an example the generated electricity end use will be linked to existing economic activities in rural communities such as in water pumping for irrigating farm crops. The irrigation will serve to substitute the otherwise dependence on rainfall which is unreliable, leading to continual bumper harvest, resulting in improvement in economic status of farmers and subsequently the ability to pay back the investment cost. Another techno-economically viable option is in solar crop drying applications in farming communities where solar crop dryers will be used to dry harvested produce which will result in reduced post harvest losses and the improvement of quality of cash crops both for internal consumption and export.

#### **1.2.1.2 The Link between Energy & Sustainable Development**

In the United Nations Conference on Environment and Development (UNCED) which took place from 3-14 June 1992 in Rio de Janeiro, Brazil, the following five major agreements were made (SD, 2004):

- **Agenda 21**-a broad, 40 chapter statement of goals and potential programs related to sustainable development;
- **The Rio Declaration**-a brief statement of principles on sustainable development;
- **The Biodiversity Treaty**-a binding international agreement aimed at strengthening national control and preservation of biological resources;
- **The Statement of Forest Principles**-a non-binding agreement on development, preservation, and management of the Earth's remaining forests;
- **The Framework Convention on Climate Change**-a binding international agreement that seeks to limit or reduce emissions of gases, mainly carbon dioxide and methane, associated with the potential for global warming.

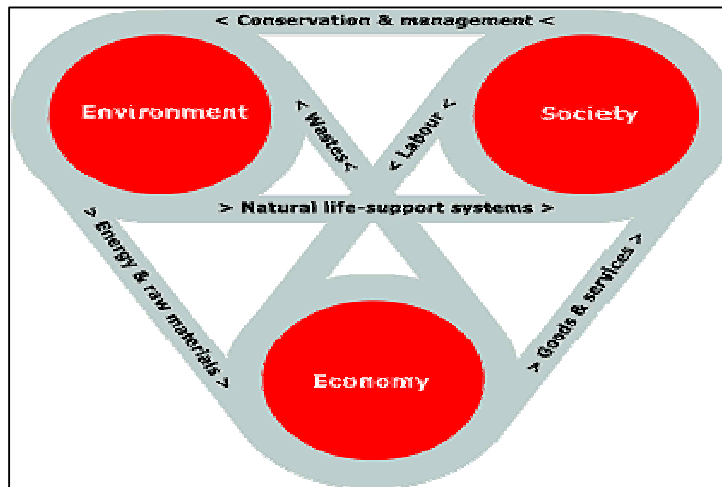


In Rio (1992), Ghana was among 178 countries that committed themselves to the guiding vision of sustainable development. Sustainable development can be defined as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Brundtland Report, 1987). Sustainable development is often seen as encompassing three dimensions of equally important factors: economic development, social development, and protection of the environment-also referred to as the ‘triple bottom line’ in industry.

Energy was not dealt with specifically at the United Nations Conference on Environment and Development (UNCED) in 1992 and did not receive a chapter of its own in Agenda 21 (KITE, 2002). However, energy considerations were included in several Agenda 21 chapters, most notably in the chapter on atmosphere. As Agenda 21 and the Rio Conventions were being implemented in the 1990s, energy emerged as a significant consideration [(Costanza & Patten, 1995), (Cappra, 2002)]. This was recognized at the five-year follow-up meeting to UNCED in 1997, which decided that the ninth session of the Commission on Sustainable Development (CSD-9) would address energy, transport and atmosphere (Costanza & Patten, 1995). CSD-9 was preceded by comprehensive preparations on energy issues, including in meetings of the *Ad Hoc* Open-Ended Intergovernmental Group of Experts on Energy and Sustainable Development as well as regional intersessional meetings. Key CSD-9 outcomes on energy included: acknowledgement of the unsustainable nature of the current energy situation; recognition that the Millennium Development Goals (which were set out in the UN Millennium Declaration in September 2000 and include the target of halving the proportion of people subsisting on one dollar a day or less by the year 2015) cannot be met without increased access to modern energy services; agreement that all countries need to improve energy efficiency, rely more on renewable energy and invest in advanced energy technologies; and a decision that the international dialogue on these issues should be continued in preparation for the World Summit for Sustainable Development (WSSD) [Clayton & Radcliffe, 1996].

The objective of sustainable development is therefore not only economic growth: it is also social development, the eradication of poverty, improvement of health, conservation of natural resources e.g. raw materials and energy etc, environmental protection, and a better quality of life (Bossel, 2001) as shown in Figure1.1.

Figure 1.7 The Complex Interplay between Energy and Several Factors in Sustainable Development.



(Source: UNDP, 1999).

An adequate supply of energy is an important key to sustainable economic and social development for many countries (Bossel, 1996 & 1999). Essential prerequisite for poverty reduction is access to such modern energy services as mechanical power to drive irrigation pumps, light to facilitate studying, heat for cooking or refrigeration for the storage of medicines. Besides these poverty reduction aspects-energy use for income generating purposes, in social infrastructure institutions and in the domestic sphere-climate protection and preservation of natural resources also play an important role (Bell, 1991).

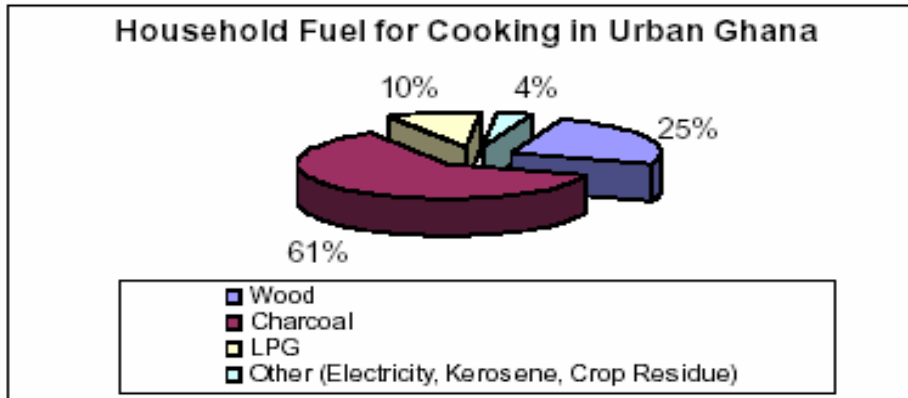
#### 1.2.1.2.1 Integrated Renewable Energy Systems and Sustainable Development

The topic of energy for sustainable development in the least developed countries (LDCs) was considered by the Third UN Conference on LDCs (LDC-III) held in Brussels in May 2001 (Dresner, 2002). The need for energy for sustainable development and poverty alleviation was recognized at this meeting - a Round Table on Energy, organized by UNIDO, produced a list of proposed deliverables, which included: increased use, through regional initiatives, of the multifunctional platform, a simple diesel engine that can perform a wide variety of tasks in rural communities; local assembly and manufacture of renewable energy equipment; creation of energy efficiency centers and energy service companies; and development of feasibility studies and investment strategies for renewable energy projects (Elliot, 2000).

### 1.2.2 Energy Consumption – Urban Ghana

In urban Ghana (Figure 1.7) the proportion of energy consumption for cooking is as follows; charcoal use accounts for 61%, fuel-wood 25%, LPG 10% and 4 % from other sources like electricity (RDREG, 2002).

Figure 1.8 Domestic Cooking Fuel in Urban Ghana.



Liquidified Petroleum Gas (LPG) is now becoming an important forming 4% of urban fuel for cooking energy mix. However, LPG Distribution in rural areas is rare and the Ghanaian government is currently putting enough effort to develop low-cost gas appliances for dissemination in rural areas with the goal to reduce their over dependence on wood fuel for their energy needs.

### 1.3 Renewable Energies

#### Definition of Renewable Energies (REs)

Renewable energies are defined according to USEIA (2004), as:

- “Naturally, but flow-limited resources that can be replenished. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Some (such as geothermal and biomass) may be stock-limited in that stocks are depleted by use, but on a time scale of decades, or perhaps centuries, they can probably be replenished;”
- ‘They include: biomass, hydro, geothermal, solar and wind. In the future, they could also include the use of ocean thermal, wave, and tidal action technologies. Utility

renewable resource applications include bulk electricity generation, on-site electricity generation, distributed electricity generation, non-grid-connected generation, and demand-reduction (energy efficiency) technologies”.

Renewables do not however, include energy resources derived from fossil fuels, waste products from fossil sources, or waste products from inorganic sources.

#### **Advantages and Benefits of Renewable Energies (ICRE, 2004)**

- They reduce the reliance on energy imports and diversify energy supply mixes by making use of locally available resources, thus contributing to energy security.
- As REs have low to zero greenhouse gas emissions, they reduce human-induced climate impacts.
- REs help to reduce negative health impacts from airborne emissions.
- In industrialized countries, renewables have already spurred the development of new industries and services for planning, manufacturing, operating and maintenance and demonstrated their potential to create highly qualified employment in new small and medium-sized enterprises. They can create decentralized markets and contribute to local economic development by introducing new capital and innovation and by developing new sources of revenue for local communities in the developing world too.
- Being modular, diverse and distributed, REs offer potential for decentralized technological innovation and allow for wider participation in decision-making about energy options. Especially in the use of traditional biomass, improve technologies can help combat the depletion of this resource.

For many remote areas, renewable energy technologies are cost effective and competitive supply options and contribute to offering access to modern energy services for large parts of the rural population in the developing world (IEA, 1998). Renewables may not be able to completely replace existing conventional energy systems, as the use of fossil fuel will continue to supply energy in the near to medium term future globally [(Georgescu-Roegen 1986), (Grübler *et. al.*, 1999)]. In spite of all these societal benefits, renewables are usually found to be more expensive than conventional electricity sources when compared on a

financial cost basis. Because of this, both monopoly and competitive electricity producers have concentrated their investment on conventional electricity technologies, with renewables usually accounting for only a small percentage of the generating stock (Berry & Jaccard, 2001).

There are three main reasons for the discrepancy between the social and economic benefits of renewables and their high financial cost relative to conventional, polluting generation sources (Berry & Jaccard, 2001) and these are:

- Some jurisdictions provide subsidies to conventional generation sources.
- The full costs of pollution (externalities) are not included in the financial cost of conventional electricity sources.
- Renewables are often associated with newer, higher cost technologies, whose relative costs will fall in time with widespread commercialization because of economies of learning and economies of scale in equipment manufacture.

#### **1.4 Renewable Energy Resource Assessment in Ghana**

Renewable energy resources are diverse and vary from country to country. Ghana's known renewable energy resources are biomass, solar, small hydro and wind (RDREG, 2002).

##### **1.4.1 Biomass**

Biomass forms the dominant source of energy accounting for 66.7% of the total national energy consumption with wood fuel being the dominant biomass form used in Ghana [(National Energy Statistics, 1998), (Brew-Hammond & Crole-Rees, 2002)]. Biomass is used in both domestic and commercial sectors for cooking and many other heat applications. Assessment of biomass energy resource potential in Ghana (will be discussed in details later in Chapter 4), resulted in four main resources namely, forest resources; logging residues, wood processing residue and crop residue/animal waste.

##### **1.4.2 Solar**

Ghana being a tropical country, lying beneath the equator, is well endowed with solar energy resources, receiving daily solar irradiation of between 4 and 6kW/m<sup>2</sup> and a corresponding annual sunshine duration of 1800-3000 hours. Conditions are therefore ideal throughout the country for the exploitation of Ghana's solar energy sources through various conversion technologies. Solar energy already makes substantial (although unquantified) contribution to the nation's energy supply (Akuffo, 1998). Traditional applications of solar energy in Ghana

include sun drying of agricultural produce, fish, fuel wood and clothes. Many wood processing and brick and tile industries also rely heavily on direct sun drying. However, modern applications of solar technologies in Ghana are rather few, mostly confined to the areas of telecommunications, rural health installations, lighting and water supplies (MME, 1998). A detailed analysis of the application of solar technologies in Ghana is given in Chapter 5.

### **1.4.3 Small Hydro Power**

Until late 1997 and early 1998, virtually all of Ghana's electricity was produced from two hydro dams at Akosombo and Kpong, which have a combined installed capacity of 1,122 MW (Energy Foundation, 2002). It is estimated that Ghana may have the potential for additional 2,000MW of hydropower of which 1,205MW will be from large hydro sources and the rest from medium to small hydro plants (Odai, 1999). Detailed resource assessment and analysis undertaken in Chapter 6 provides empirical information with regards to the viability of small hydro power schemes in Ghana. Throughout this chapter and the rest of the report, we will use the term 'small hydro' to refer to all hydro systems less than 10MW.

### **1.4.5 Wind**

Results obtained from previous main land wind resource feasibility studies undertaken by the National Renewable Energy Laboratory (NREL) of the Department of Energy, United States concluded that prevailing wind speed in the country is too low to encourage wind technologies (KITE, 2002). However a recent wind resource feasibility study along the coast of Ghana shows viable potentials for setting up the first wind farm in West Africa (RDREG, 2002). A more detailed analysis of the resource assessment in Ghana is given in Chapter 7 of this dissertation.

## **1.5 Techno-economic Viability Aspects of RETs in Ghana**

Depending on a country's geographical location, appropriate renewable energy 'technolog(y)ies' could be selected in stand alone or hybrid systems, off-grid, isolated grid or central grid applications, all aimed at meeting required energy demand. Furthermore any country and locality has its own peculiar circumstances in terms of capacity, financial, socio-cultural attributes, etc which suggests to a large extent the most appropriate technology application, economic viability and sustainability of development projects.

Technical viability used in the study mainly refers to technological capacity in terms of availability of spare parts, the existence of local artisans trained to master all aspects of the technology, and the ability of local people to operate, maintain and fix the technology in case of breakdowns. With regards to economic viability, the most basic condition for success is the financial profitability of projects, represented by the Net Present Values (NPV), Profitability Index (PI), Benefit Cost (B-C) Ratio, Internal Rate of Return (IRR), etc. The NPV, PI, B-C ration and IRR are explained below using RETScreen definitions (RETScreen, 2005):

#### *Net Present Value*

This is the value of all future cash flows, discounted at the discount rate, in today's currency. NPV is thus calculated at a time 0 corresponding to the junction of the end of year 0 and the beginning of year 1. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present value of these cash flows, called the NPV, determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project.

#### *Profitability Index*

This is an expression of the relative profitability of the project. It is calculated as the ratio of the net present value (NPV) over the project equity. Positive ratios are indicative of profitable projects. The profitability index, similar to the benefit-cost ratio, leads to the same conclusions as the net present value indicator

#### *Benefit Cost Ratio*

This is the ratio of the net benefits to costs of the project. Net benefits represent the present value of annual revenues (or savings) less annual costs, while the cost is defined as the project equity. Ratios greater than 1 are indicative of profitable projects. The net benefit-cost (B-C) ratio, similar to the profitability index, leads to the same conclusion as the net present value indicator.

### *Rate of Return*

Represents the true interest yield provided by the project equity over its life before income tax. It is also referred to as the return on investment (equity) (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the net present value of the project to be equal to zero. If the internal rate of return of the project is equal to or greater than the required rate of return of the organisation, then the project will likely be considered financially acceptable (assuming equal risk). If it is less than the required rate of return, the project is typically rejected.

Economic analysis produces an estimate of the project's financial profit, i.e. the Net Present Value of the profits when all inputs and outputs are measured at market prices (UNIDO, 1988).

This research will seek to undertake a very detailed case study analysis of all RETs in Ghana so as to identify whether there were technological problems leading to collapse of projects, which kind of technological incapacity and how to remediate such problems. Most RETs projects in Ghana rely heavily on external funding (from donor or government sources) and collapse the moment external inflow of cash ceases. It can not be overemphasized that such projects are unviable financially. Extensive financial analysis will be undertaken for each RET in Ghana in order to assess their economic viability. With the aid of the RETScreen software (chapter 2), cost benefit analysis for proposed RETs and projects will be undertaken in order to identify which RE project types are viable under Business-as-Usual (BAU) situations as well as with changes in key financial parameters with time.

### **1.6 Motivation to Research into this Topic**

Due to an existing knowledge gap, it has been suggested by RDREG (2002) that a very careful and thorough study on the technical and socio-economic viability of exploiting renewable energy resources in Ghana should be conducted. Recall that most modern renewable energy (RE) projects established over the years in Ghana have already collapsed and some projects exist only because of continual donor external support. The quest to bridge the techno-economic RE viability knowledge gap and to find answers to the collapse of projects, all served as the motivation to undertake this research.



### **1.6.1 The Research Question**

It can be recalled that the following research questions which serve to shape the direction of the study were asked from the very beginning of this chapter. They are:

- Are Renewable Energy Technologies (RETs) technically and economically viable in Ghana?
- Can RE projects be self sustained in Ghana without continual external support?
- Can RETs be used as an engine for local development?

An attempt to scope the research and to find answers to the above research questions led to the formulation of the objectives below.

### **1.6.2 Main Objectives**

- (a) Assessment of renewable energy policies in Ghana for identification of gaps.
- (b) Identification and analysis of factors that has led to the un/successful diffusion of RETs in Ghana.
- (c) Application of results from objective (b) to selected RETs with the aim of ensuing viability and promoting successful market diffusion.
- (d) Techno-economic viability analysis for future renewable energy projects using the RETscreen tool.

#### **1.6.2.1 Sub-objectives**

In order to achieve the very broad main objectives formulated above, they are further broken down into sub-objectives which are;

- (i) In depth analysis of administrative energy structures and policies in Ghana in order to examine how they influence the promotion of renewable energy RETs in Ghana. Extensive review of renewable energy policies, instruments and measures employed in other parts of the world so as to identify and import suitable policies to the Ghanaian situation.
- (ii) Comprehensive assessment of RE resources and techno-economic evaluation of existing projects for success/failure cases as an information enriching activity in order to render appropriate recommendations for future projects and policies.

- (iv) Development of scenarios and models using the UNEP recommended RETScreen software to propose technically and economically viable, sustainable RE projects.
- (v) Cost benefit analysis for future RE projects in Ghana.
- (vi) Formulation of best practice policies for RETs dissemination in Ghana.
- (vii) Renewable energy strategy on the where, what, why and how to implement viable projects in Ghana.

### **1.7 Expected Audience for this Research and Potential Impacts**

This research project is intended to assist stakeholders. Identified stakeholders include: Rural Communities, International Donor Agencies, Local RET vendors, Local R & D institutions Technology, Training Institutions, NGOs, Investors, Government, Local and Multilateral Development Banks.

This thesis will assist stakeholders by:

- Improving knowledge base in RETs in Ghana.
- boosting investment confidence in RETs

To these stakeholders, the research will give them something that does not currently exist-structured and well confounded practical guidance on the where, why, what and how to implement viable RE projects in Ghana.

It is expected that other groups not mentioned above may be interested in this work, even though the research does not directly target them.

If the research should find that RETs are technically and economically viable, it is hoped that it will stimulate further interest and research in what is still a very new field. In addition, by providing a clear and well-founded structured approach for stakeholders, it is hoped that the research will increase the number of viable RETs in the marketplace. If the research should find that RETs are not viable, the impact is likely to be a decrease in stakeholder's interest in RETs. This result will still be useful, as valuable resources may then be targeted elsewhere by research funding bodies.

## **1.8 Contributions to Knowledge**

The contribution of this work to knowledge includes:

1. Development of an energy policy that directly links decentralized RE projects to already existing economic activity at the grassroots' level. In the short term, this helps in improving economic status of the community, which subsequently results in ability to pay back for the renewable energy project investment and running cost in the longer term.
2. New knowledge on the technical and economic viability of employing RETs in Ghana and the West African sub region using the very modern RETScreen software. Possibly this document could be one of the very first research publications that make use of the application of these software to the African energy situation.
3. Development of knowledge on RETs research and development in Ghana.

## **1.9 Analytical Approach and Organization of the study**

In pursuing these objectives, the study adopts both qualitative and quantitative approaches to studying the issues raised. The qualitative approach is used to describe the background to the study. An assessment of RE policies and resources, evaluation of projects and stakeholders analysis is made.

The performance of potential (future) RE projects without appropriate pre-feasibility and feasibility analysis is uncertain. Accordingly, a quantitative approach based on different scenarios has been developed. In this approach, alternative scenarios for future projects are postulated and analyzed using the RETScreen tool.

The study is organized in three parts. Part 1 deals with background to the study, methodological approach and RE policy analysis. Part 2 first provide a technical overview of the operating mechanisms of the various technologies, then follows detailed analysis and project performance evaluation and finally development of models for future viable projects. Part 3 draws up conclusions from the first two parts to formulate best policies and effective market diffusion options for RETs in Ghana.

As can be seen the present chapter, (chapter 1), lays out the background to the study with its objectives. Chapter 2 provides an overview of the research methodological approaches

utilized in the study. Chapter 3 examines available well known renewable energy policies and instruments utilized in other parts of the world. It also analyses RE measures employed in Ghana for identification of gaps. These three chapters make up Part 1.

Chapters 4,5,6 &7 which together makes up Part 2, is a detailed technical & financial assessment of biomass, solar, small hydro and wind energy technologies respectively in Ghana.

Chapter 8 draws up conclusions from the entire study to formulate ‘best policy recommendations’ from previous chapters. Chapter 9 is a summary of all results accrued from the study, it provides a matrix for the relative ranking of RETs in Ghana and maps up a strategy on the why, how, what and where to implement viable RE projects in Ghana. These two chapters make the Part 3, the conclusion of this study.

## **CHAPTER 2 METHODOLOGICAL APPROACH**

### **2.1 Qualitative Assessment**

The qualitative approach is used to describe the background to the study and it involves the assessment of existing RE policies and resources, evaluation of projects and barrier analysis on each of the identified RET.

The study started with significant amounts of desk study to compile a full inventory of all types of renewable energy interventions in Ghana. Those interventions that target the poor or rural dwellers were particularly of interest. Field surveys and site visits were undertaken for data collection on the projects, to interview beneficiaries and more importantly, to verify at first hand, the authenticity in the reports that were utilized.

### **2.2 Quantitative Analysis**

Quantitative analysis of the research was undertaken using the RETScreen® International Renewable Energy Project Analysis Software. Prior to settling on RETScreen, an extensive and exhaustive search was undertaken to first of all identify a standardize tool that can be used to promote the implementation of renewable energy projects. The appropriate tool was to have access to a very rich database i.e. besides provision of empirical engineering and financial calculations on RETs, the preferred tool must provide detail information on equipment suppliers and service providers on all five continents. Finally, the software must be user friendly and flexible without compromising on the technical details-the goal of the latter is to be able to run models developed in this dissertation to the appreciation and understanding of the not-so-technical mind (specifically people without engineering and financial background). There is the need for government, politicians, policy makers and all stakeholders with the power of making things happen in this field to understand clearly how the tool works.

Several RETs and related softwares were identified and reviewed. The criteria described above were employed to narrow down on the number of softwares. Eventually two very good softwares remained; the first, HOMER Software developed by NREL, Department of Energy (USA) was much more technical and less user friendly for required purpose. The second was the RETScreen software. This software is an innovative and unique energy awareness, decision support and capacity building tool.

The added advantage to the selection RETScreen was that, it has the United Nations Environment Programme's (UNEP) recommendation and the software is available for free, in both English and French. Validation studies between the two softwares showed very comparable results from their calculation processes which can be found later in this chapter.

### **2.2.1 RETScreen**

The RETScreen software is developed by CANMET, Natural Resources Canada in collaboration with NASA (provision satellite-derived surface meteorology and Solar Energy Data Set), the World Bank (provision of data on World Bank Prototype Carbon Fund) and UNEP.

RETScreen is used for analyzing the technical and financial viability of potential renewable energy projects. The core of the tool consists of standardized and integrated project analysis software that evaluates the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy efficient and renewable energy technologies compared to conventional energy projects. In addition to the software, the tool includes product cost and international weather databases (from NASA, USA); an online manual; electronic textbook; and an internet-based marketplace and forum for one to get quick solutions with regards to any difficulty encountered with the use of the tool. The software is available for free download at [www.etscreen.net](http://www.etscreen.net).

#### **RETScreen Objectives**

Numerous opportunities for implementing commercially viable clean energy projects around the world are currently being missed because various decision-makers still do not routinely consider them (CANMET, 1991). National and regional planners, industrial engineers, commercial and institutional building architects, and utility and community energy planners, for example, too often fail to appreciate the benefits of energy efficient and renewable energy technologies (RETs) at the critically important initial planning stage, even when these technologies have proven to be cost-effective and reliable in similar situations elsewhere (CANMET, 1991). If clean energy technologies are not considered and put on the table upfront in the decision-making process, it is usually next to impossible for them to be considered in the program development or project implementation stages (CANMET, 1991). The result then is missed project opportunities that could otherwise help countries meet energy needs locally, and in a sustainable way, while reducing greenhouse gas emissions, saving money and increasing energy security and self reliance.

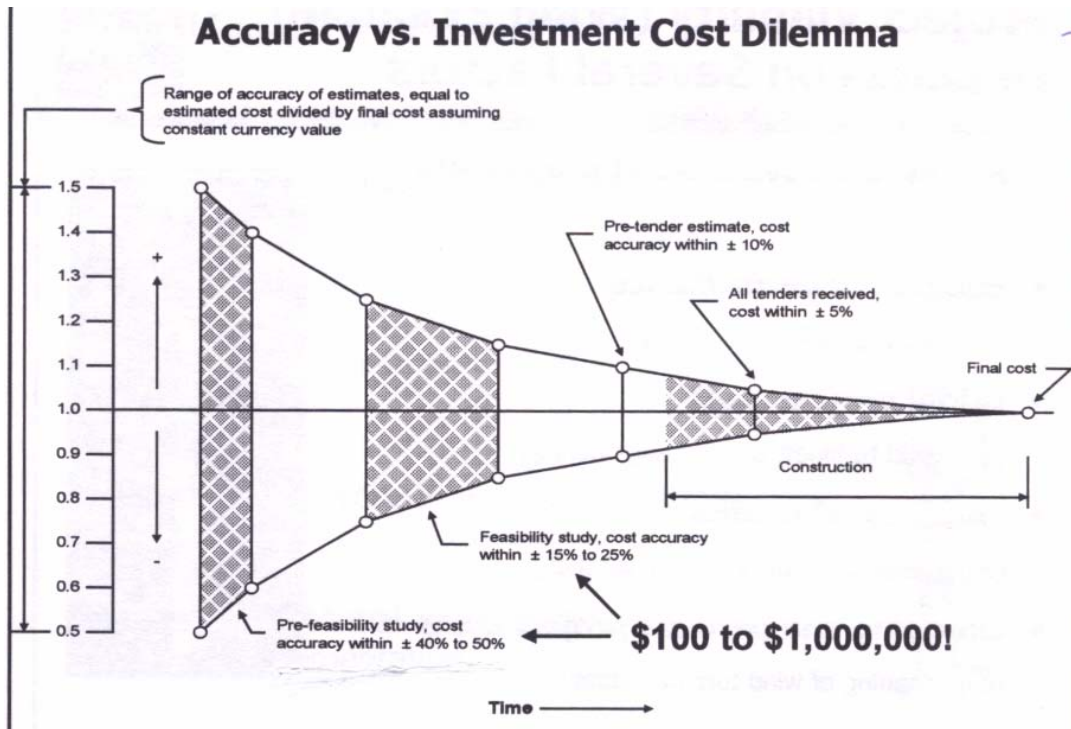
This is one of main driving factors that led to the development of the RETScreen. The software can be employed effectively in promoting the deployment of renewable energy systems by helping to build the capacity of planners, decision-makers and industry to implement more projects successfully (RETScreen, 2005). Thus fostering increased market uptake of renewable energy technologies (RETs) that reduce the reliance on conventional energy sources.

The RETScreen software is specifically targeted at the pre-feasibility and feasibility levels of project analysis. It is intended to simplify the evaluation of renewable energy projects at the critically important initial planning stage. Most engineering and architectural projects follow a similar procession of steps: inception, feasibility, design, engineering and finally construction. It is usually at the initial stages that the project proponents decide on which technologies will be used. Resources are typically not available to analyze technology options that may be unfamiliar to the proponents and Renewable Energy Technologies (RETs) are thus often overlooked. RETScreen is designed to address this problem by making available a tool that can quickly and cheaply evaluate the viability of one or more RET options early on in the project.

RETScreen is not intended to be a detailed engineering design tool as detailed engineering design is generally not appropriate at the early feasibility stage of a project. Rather, it is often in the interest of the project to evaluate multiple technology options at a preliminary level of analysis. Once the most promising technology is identified, more effort and resources may be justified to improve the accuracy of the analysis.

Figure 2.1 graphically demonstrates the typical progression of increasing project definition accuracy as the project moves from inception to completion. Progress along the horizontal axis is generally also indicative of the increasing financial investment in the project. The graph reflects that it is often not practical or necessary to define a project with great accuracy at the early stages of its development cycle. Figure 2.1 is based on an actual survey of project costs for small hydroelectric projects conducted by the World Bank (RETScreen, 2005).

Figure 2.1 Accuracy of Project Cost Estimates.



(Source: RETScreen, 2005)

## 2.3 RETScreen Features

### 2.3.1 Software and Data Tools

The software and data tools are implemented in the form of Microsoft® Excel Workbooks (spreadsheets). The RETScreen® software is comprised of 8 stand-alone technology models (each a separate Workbook):

- Small Hydro
- Photovoltaics
- Solar Air Heating
- Wind Energy
- Biomass Heating
- Solar Water Heating
- Passive Solar Heating
- Ground-Source Heat Pumps
- A model, for Combined Heat and Power (CHP) systems, is currently under development.



Integrated into each model are technology-specific databases. The intent of these data sources is to put as much relevant information as possible at the disposition of the user in order to expedite and simplify the analysis process.

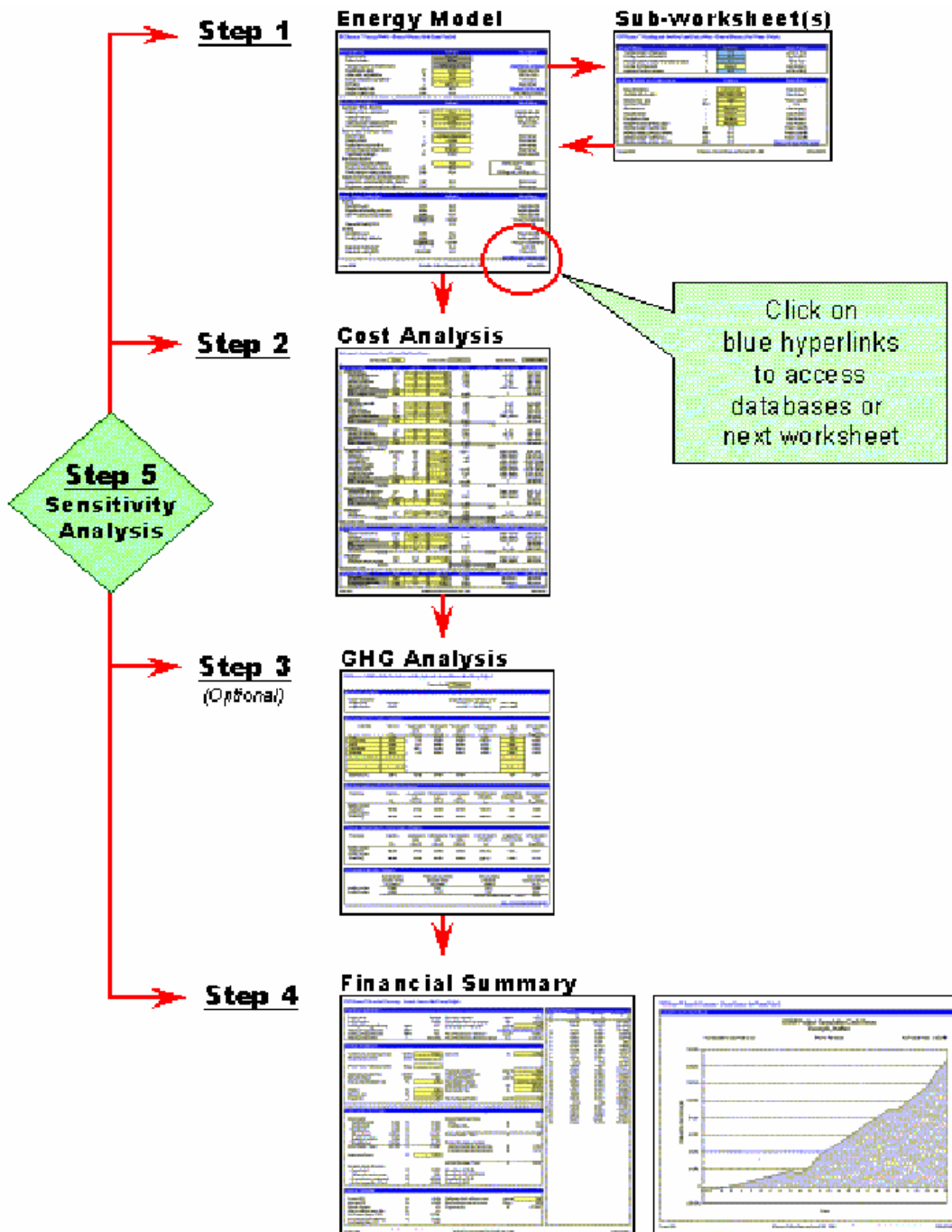
The RETScreen® data sources consist of the following:

- **International Product Data:** technical specifications from over 1,000 suppliers that serve as inputs to the technical portion of the analysis.
- **International Weather Data:** two separate, complementary databases are available:
  - Weather data from 1,000 ground monitoring stations
  - Satellite-derived NASA Surface Meteorology and Solar Energy Data Set
- **Cost Data:** generic and typical cost information (for the Canadian context) to help users with the financial portion of the analysis.
- **Online User Manual:** a comprehensive help system that guides users in using the software and provides valuable background and reference information.

The main principles and standard features of the RETScreen® models can be summarized as follows:

- Technical, financial and greenhouse gas (GHG) analyses are integrated into one tool;
- Input requirements are simplified as much as possible while still allowing for sufficient detail and accuracy, as appropriate for pre-feasibility and feasibility studies;
- Most models consider an incremental analysis: a ‘proposed’ scenario that includes RETs is compared against a ‘base case’ scenario without RETs;
- Financial analysis is based on the life cycle of the RE equipment;
- The analysis approach for all technology models is standardized, to provide a consistent “look and feel”, improve ease of use and allow for objective comparisons of different RETs (Figure 2.2 shows the standard analysis flow);

Figure 2.2 RETScreen flow chart showing the 5 main steps in the tool.



(Source: RETScreen, 2005)

### 2.5 Calculation Algorithms and Validation

As seen in Figure 2.2, for particular renewable energy technology say wind, the user first starts with the Energy Model of the software by providing information such as:

the annual average wind speed, height of wind measurement, grid type, number of turbines, array losses etc. Then the user continues with provision of data for the *cost analysis* sheet where cost information estimates on feasibility study, development, engineering, energy equipment, balance of equipment and miscellaneous cost must be provided. Thirdly is the *Green House Gas (GHG)* analysis window where the user has the option to decide either to run a GHG analysis or not. Finally is the *financial summary* sheet where the user provides information on the avoided cost of energy (which is otherwise the cost of energy for which your technology/project will be replacing), discount rate, inflation, the project life span etc. The user can decide to run a *sensitivity analysis* for his/her project. The software then calculates for the user the total project cost, the annual renewable energy delivered, the annual net GHG emissions reduction, the annual life cycle savings, simple payback period, the net present value (which is the value of all future cash flows, discounted at the discount rate, in today's currency) and the benefit-cost (B-C) ratio. The B-C ratio is the ratio of the net benefits to costs of the project. It can be recalled from chapter 1 that net benefits represent the present value of annual revenues (or savings) less annual costs, while the cost is defined as the project equity. Ratios greater than 1 are indicative of profitable projects.

The calculation approach for each renewable energy technology model is unique, but in all cases the algorithms are simplified to minimize calculation times and input requirements. The individual technology models are based on simplified monthly analyses of energy flows (as opposed to hourly or bin methods) or on annual calculations. Nevertheless, the calculation algorithms are generally powerful enough to account for numerous design variations and yield analysis results that correlate well with measured data and / or more powerful hourly simulation tools such as HOMER (HOMER, a detailed hourly model developed by the US National Renewable Energy Laboratories, NREL).

All technology models have been validated against available references, usually hourly simulation tools that are accepted as industry benchmarks. For each technology model, detailed calculations algorithms as well as validation results are presented in the RETScreen e-Textbook(RETScreen, 2005).

Example of validation results from the e-Textbook are presented in Figures 2.3 and 2.4. These results are for the RETScreen photovoltaic (PV) model: RETScreen is used to analyze the performance of an off-grid PV-diesel hybrid system and the results are compared against those from HOMER, which is an optimisation model for designing stand-alone electric

power systems and is the reference standard for such models in North America. The results illustrate the adequacy of the RETScreen PV model for pre-feasibility studies.

Figure 2.3 Comparison of PV energy production calculated by RETScreen and HOMER (validation example).

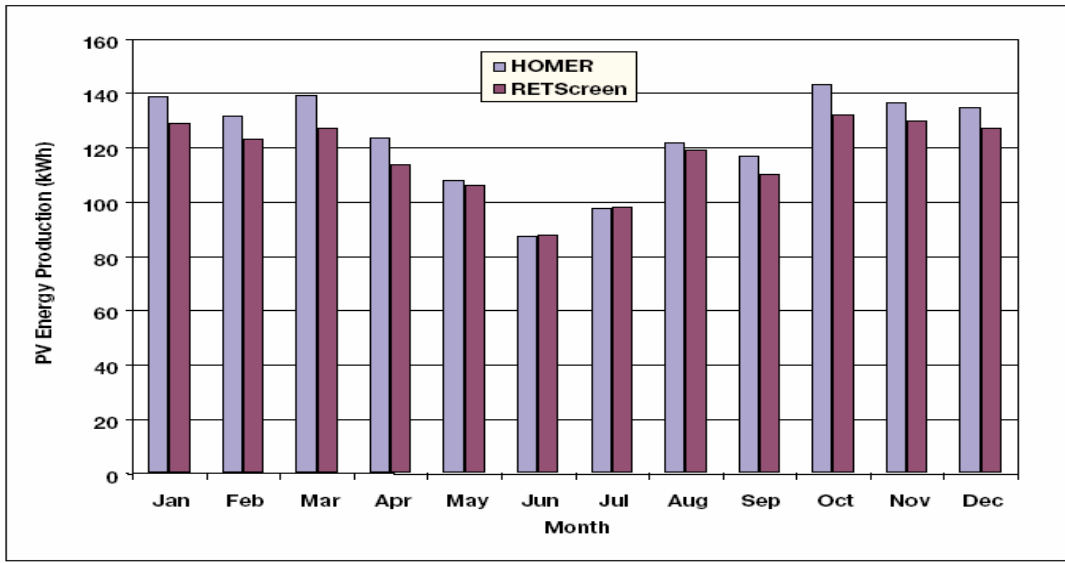
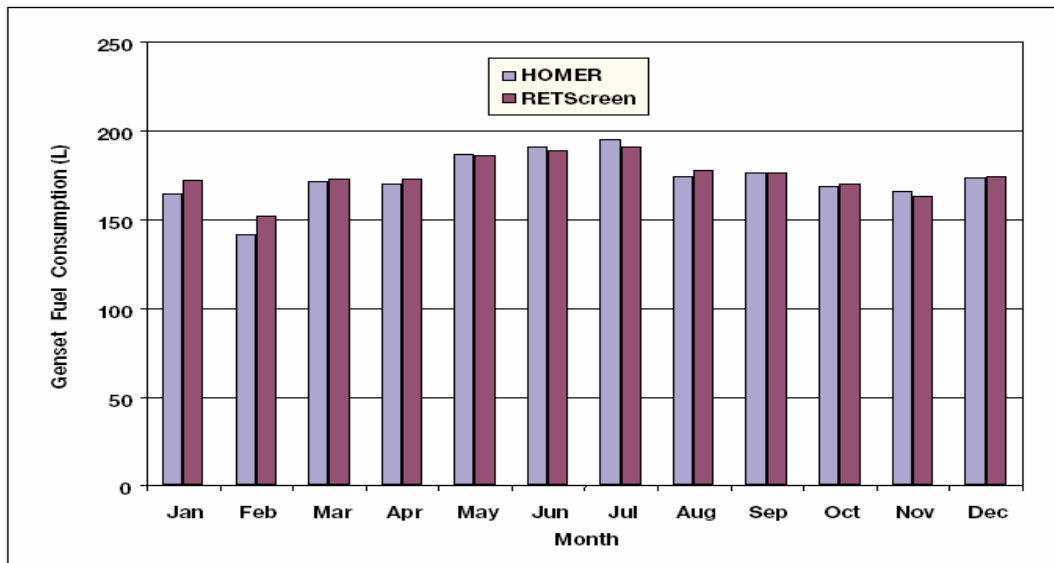


Figure 2.4 Comparison of Genset fuel consumption calculated by RETScreen and HOMER (validation example).



As shown in Figure 2.3 on a yearly basis RETScreen predicts slightly less PV energy production than HOMER does (1,404 vs. 1,480 kWh, or a difference of 5%). Part of this difference (around 2%) is attributable to differences in the calculations of incident solar radiation (RETScreen, 2005). Contributions from the genset, reported in Figure 2.4 as fuel consumption, are virtually identical (2,096 vs. 2,079 L). Overall, these differences are insignificant and illustrate the adequacy of the RETScreen PV model for pre-feasibility studies.

## **2.6 Limitations of the Model**

- The model is static, rather than dynamic in that the user evaluates each of the technologies independent of one another, rather than in an integrated fashion
- Only annual energy production is considered, rather than a more detailed time series analysis which would consider energy production and load variations on a much shorter time scale (e.g. 1 hour) similar to HOMER. This minimized data requirement approach will make it easier for the user to prepare an analysis, but modelling accuracy may be partially reduced as a result.
- Generic load duration curves are used for isolated diesel-grid electrical generation applications.
- The tool cannot evaluate smaller scale projects where energy storage is required (e.g. stand alone photovoltaic systems).
- The user will have to obtain additional data for regions not provided in the current database
- The range of cost data provided is primarily based upon Canadian and US projects. Costs will likely vary in other regions.
- Only pre-tax calculations are performed as part of the RETScreen pre-feasibility analysis model. The tax status of the project proponent could impact the financial outlook of the project and, therefore, should be evaluated during a more detailed feasibility analysis study.
- It is assumed that the user will have access to information regarding the avoided costs of energy, and /or capacity, for the conventional energy systems that the potential RETs projects are being compared with. Information in the manual only helps provide a 'ball-park' estimate of these avoided costs.
- Projects cost information is provided in Canadian dollars with a base year of 1997. The user will have to apply a currency exchange rate when evaluating projects outside

of Canada. Also, some of the data may be time sensitive so the user should verify current values where appropriate.

- Much of the data in the Canadian Remote Communities Database consists of 'rough' approximations and should be verified with local data, if available. In either case the database provides a starting point for preparing a sensitivity analysis.

## **CHAPTER 3 RENEWABLE ENERGY POLICY CONCEPT AND MEASURES IN GHANA**

*“Energy policies are an instrument which can be used both to promote sustainable development and to achieve integrated development goals.”  
(UNDP, 1999), (EC\*, 1999)*

### **Introduction**

The first part of this chapter provides an overview of policy instruments and measures available to policy makers in the renewable energy sector. The second half is an analysis of current renewable energy policies in Ghana for identification of gaps. The chapter provides an in-depth study of all relevant energy policies/measures in Ghana for the purposes of analyzing how such measures/policies influence the market diffusion of renewable energy technologies.

Suggestions on ‘best policy recommendations’ which is a synthesis of all essential options-technical, economic, social, environmental, stakeholder etc will however be made at the concluding section of this dissertation.

### **3.1 Policy Instruments and Measures for Renewable Energy Technologies**

A policy may generally be defined as a ‘set of ideas or a plan of what to do in particular situations that has been agreed officially by a group of people, a business organisation, a government or a political party’ (Cambridge international dictionary of English, 2000). Simply put, a policy is a statement of intent, which can be expressed in various ways. Policies are sometimes expressed as visions, as goals and objectives; as organisational strategies; as programme strategies; as targets; as implementation plan; as a guideline or as a directive (Asamoah-Baah and Smithson. 1999). A policy should specify relevant policy instruments or measures, which will be used for implementation and should also specify the appropriate time frame within which the policy objectives must be achieved, and for which instruments are relevant. A policy can be formal or informal.

A common policy objective in many countries with regards to renewable energy technologies is to develop and disseminate the technologies in order to diversify the energy mix and ultimately reduce the global dependence on non-renewable (Kleinpeter, 1995). Interest in RETs also provides decentralised options for supplying energy to remote rural communities.

As mentioned earlier however, most RETs have large up-front costs, which few operators, dealers or purchasers can afford outright. There is therefore the need to devise appropriate policy instruments and measures, which will facilitate easy adoption of RETs. According to Goldemberg (1998), whatever instrument or measure is adopted should be;

- Effective in quickly establishing reasonably large production and market demand levels, allowing companies to scale up production with the confidence that there will be market for them;
- Efficient in driving down cost as a cumulative production increases;
- Minimally disruptive of existing energy-financial systems during the transition period;
- Able-within the available financial resources-to support a diversified portfolio of options;
- Easily and transparently administered and require minimal administrative overheads; and
- Temporary, with sunset provision built into the commercialisation incentive scheme *ab initio*, but long enough to catalyse the desired activity.

In several instances, measures and instruments have been used simultaneously to achieve specific policy objectives (Teplitz-Sembitzky, 1990). These are cases where taxes have been imposed on one energy source (fossil) and the money raised used to support R&D as well as demonstration projects/programmes in renewables.

One instrument that has featured quite prominently in the ongoing reforms in the energy sector is pricing. Pricing has become an important tool following the observation that throughout much of Africa and a greater part of the developing world, energy-pricing policies have tilted the playing field against sustainable and equitable energy development (Palmedo, 1978). This is due to the fact that conventional electricity and fuels are almost universally priced below their marginal cost (EC/UNDP, 1999). From an economic point of view appropriate pricing can encourage more rational decisions, and better resource use. Some specific examples of policy instruments and measures that have been used to promote RETs include the following:

### **3.1.1 Non-Fossil Fuel Obligation (NFFO)**

The NFFO is a scheme by which electricity companies are obliged to buy a fixed amount of power from non-fossil power producers. The renewable NFFO requires the Regional



Electricity Companies (RECs) to buy a fixed amount of nuclear and renewable electricity from non-fossil fuel power producers. The RECs pay the generators a premium price for the renewable electricity and the difference between the premium price and the average monthly pool purchasing price is reimbursed to the RECs by the Non-Fossil Purchasing Agency (NFPA) from the Fossil Fuel Levy (FFL) on electricity, paid via customer electricity bills.

In the United Kingdom (UK), the government provides support for electricity generated from renewable sources principally through the NFFO in England and Wales, the Scottish Renewable Obligation (SRO) in Scotland and the Northern Ireland (NI-NFFO). The NFFO was adopted as part of the Electricity Act of 1989, which privatized the electric power sector. The NFFO evolved from the need to find a means of supporting nuclear power, after it was realized that nuclear power could not survive privatisation without subsidy (UNDP, 1997). Later on the NFFO came to be understood to include both renewable and nuclear energy (Mitchell 1995). Despite its origin, the renewable NFFO has turned out to be a major boost for renewable. The NFFO has been used mainly as a mechanism for moving market-ready RETs into the marketplace, and for increasing the number of independent power producers (IPPs). The aim of NFFO was to bring into operation by the year 2000, a base load of 1500 MW of renewable electric supplies (Goldemberg, 1998).

Several orders of projects have been developed under the renewable NFFO. To date five NFFO orders have been made in England and Wales, two equivalent orders in Northern Ireland and three in Scotland. The first order (NFFO-1) was made in 1990 for 75 projects and 150MW Declared Net Capacity (DNC), NFFO-2 was made in 1991 for 122 contracts and 472 MW DNC, NFFO-3 was made in 1994 for 141 contracts and 627 MW DNC and NFFO-4 made in 1997 for 195 contracts and 843 MW capacity (Mitchell 1995). The fifth and largest order, NFFO-5, was laid in September 1998 for 1,177MW (Mitchell 1995). The first two SRO orders led to 56 projects and with a combined capacity of 189 MW (UNDP, 1997). SRO-3 was laid in February 1999 for 150MW. Contracts for the first 3 NFFO orders expired in 1998 and out of the estimated DNC of 1250MW, 650 MW of electricity plants were commissioned. The NFFO has been abolished since 1999 but existing NFFO contracts will run till March 2014 (UNDP, 1997). With the abolition of the NFFO, the UK government intends to provide future support for renewables by imposing an obligation on electricity suppliers to contract (or buy out their obligation to contract) an increasing percentage of electricity from renewable sources (Mitchell 1995).

It is clear that the NFFO utilises a range of economic instruments, supported by a normative measure of legislation to realise its goal of bringing on board 1500MW of renewable energy. The NFFO has also made cost convergence between renewable and the conventional energy an explicit goal over the last several years. Resulting from the implementation of NFFO is the substantial cost reductions in the electricity supplied mainly from wind-from an average price of 7.2 pence/kWh for NFFO-2 to 4.35 and 3.46 pence/kWh for NFFO-3 and NFFO-4, respectively[(UNDP, 1997),(Mitchell 1995)]. It is worth noting that prices for NFFO-5 averaged 2.71pence/kWh (Mitchell, 1995).

### **3.1.2 Renewable Portfolio Standard (RPS)**

The aim of the RPS policy is to guarantee a minimum market for the renewable industry, thus allowing them to make the investments needed to bring down costs and eventually attain full competitiveness (DBEDT, 2000). The RPS works by ensuring that a small but increasing minimum percentage of qualifying renewable energy is included in the portfolio of electricity resources serving a state or country. It has been described as ‘a flexible, market-driven policy that can ensure that the public benefits of renewable energies continue to be recognized as electricity markets become more competitive’ (AWEA, 1997). Because it is a market standard, the RPS relies almost entirely on the private market for implementation.

Central to RPSs is the system called renewable energy credits (RECs) or ‘credits’. A credit is a tradable certificate of proof that one kWh of electricity has been generated by a renewable-fuelled source. The RPS requires all electricity generators (or retailers, depending on policy design) to demonstrate, through ownership of credits, that they have supported an amount of renewable energy generation equivalent to some percentage of their total annual kWh sales. Investors and generators all make decisions about how to comply, including: the type of renewable energy to acquire, which technologies to use, what renewable developers to do business with, what price to pay, and which contract terms to agree to (AWEA, 1997). Generators decide for themselves whether to invest in renewable energy projects and generate their own credits, enter into long-term contracts to purchase credits or renewable power along with credits, or simply to purchase credits on the spot market. Only the bottom line is enforced: possession of sufficient number of credits at the end of each year. Through credit trading, the RPS relies on the initiative of businesses to ensure that the standard is met at the lowest possible option. Thus electricity providers have great flexibility in meeting their requirements.

The administrative requirements of government are less under a RPS than under NFFO, because the market, rather than an administrative process, is expected to choose the winning technologies and suppliers (DBEDT, 2000). The role of the government will then be limited to certifying credits, monitoring compliance, and imposing penalties if necessary. In spite of its flexibility and extensive reliance on the private market for implementation, there is little actual experience with the functioning of RPS. The RPS policy tool is being explored in many states and also at the federal level in the U.S. to encourage the used of renewable energy sources. The terms of RPSs vary among states to reflect on the states' specific energy situation and the types of renewable energy resources that are technically feasible.

The RPS is a policy tool whose rapid rise in popularity is explained by its continuous incentive for renewable producers to reduce costs, its direct link to the attainment of environmental targets, and its reduced requirements for government financial and management involvement. Additionally, it has been implemented recently by several European countries and Australia (KITE, 2002).

### **3.1.3 Electricity Feed-in Law (EFL)**

The German EFL (1991) obliges electricity utility companies to purchase, at a premium price, electricity generated from renewable energies in their supply area. For electricity from generation facilities not located in the area supplied by a system generator, the EFL imposed the obligation to buy on the utility closest to the site of the generation facility and has a system technically suitable to feed in the electricity. The price payable for renewables such as hydro power, landfill gas, sewage gas and biomass (with capacity not exceeding 5MW) was set at a minimum of 80% of the average revenue per kWh from the delivery of electricity by utilities to all final consumers (Goldemberg, 1998). The price for wind and solar energy was set at a minimum of 90% of average revenue per kWh (Goldemberg, 1998).

At the time of inception in 1991, the EFL did not place any limit on the amount of renewable energy, utilities were obliged to purchase. The EFL was consequently opposed by the utilities because they deemed its implementation burdensome. Efforts by the electric utilities to have the EFL declared unconstitutional failed, but it resulted in the amendment of the law in April 1998 by the German parliament (KITE, 2002). The amendment *inter alia* introduced a 5% cap on the amount of electric power the utilities were obliged to buy (Goldemberg, 1998). The 5% cap mean that the utilities are not obliged to buy more than 5% of the total

energy from renewable sources. The EFL has since February 2000 been replaced by the Renewable Energy Sources Act (RESA) which pays a guaranteed price for various forms of renewable energy.

The EFL provided impetus mainly for wind energy because of the compensation rates (higher price) paid for wind energy. Between 1991 and the end of 1999, approximately 4,400 MW of wind energy was installed under the EFL (Goldemberg, 1998). The story has however not been the same for the other renewables, especially solar and biomass. This is due partly to the fact that the compensation rates for PV and biomass have not been sufficient to stimulate large-scale market introduction of the technologies. Consequently, the compensation rates have been modified in the RESA 2000.

### **3.1.4 Examples of Financing Mechanisms**

Three main models: dealer, concession and retail are discussed in this section. The World Bank is employing these models (World Bank, 2000) as its new approach to rural renewable energy delivery. The objectives of these models are to: lower transaction costs, reduce barriers to market entry, spread and absorb risks, build service networks in rural areas, and develop specialised skills to manage local businesses and credit mechanisms (World Bank, 1998).

#### **3.1.4.1 The Dealer Model**

The dealer model is the most well known among the three and mostly used for the delivery of PV systems. Under this model, banks transfer the collateral problem from the end-user (who in most cases cannot provide collateral security to the banks) to the dealer, by lending to the dealers who in turn lend to purchasers using payment schemes compatible with their income. Thus, dealer model ensures that the high start-up costs, which characterise many RETs, are lowered and deferred through a credit mechanism arranged for customers by dealers through the banking system. The dealers bear the financial on top of technical risk. This model is best suited to large, relatively high income rural markets and depends on either cash or credit sales (Loiter & Norberg-Bohm, 1999). In Kenya, the market for PV developed when dealer began selling systems through existing small rural sales points such as general stores. Now more than 100,000 households in Kenya use PV systems; these are usually purchased piece by piece and in low watt increments e.g. 12 watts is almost standard (World Bank 1998).

The dealer model is also being pursued in the World Bank's Solar Home Systems Project in Indonesia; in contrast to Kenya however, sales are credit based.

#### **3.1.4.2 The Concession Model**

The concession model, also for PV system delivery, employs a very different set of incentives and is characterised by a risk profile, which is different from that of the dealer model (Wichert, 1997). The model depends more on regulation by contract than market forces, but helps ensure that large-scale economies are achieved. Here the government contracts and pays a local company to provide energy services to meet development objectives: e.g., PV lighting for schools. This provides entry capital for the company to offer credit and expand its business to other local markets such as PV for households, health clinics and community centres. In Argentina, for example, franchise rights for rural service territories have been granted to concessionaries that offer bids with the lowest subsidy to service rural households and community centres (Martinot *et. al.*, 2000a). Concessionaries can select from a range of off-grid technologies, although solar PV is anticipated to be the most cost-effective choice in the majority of cases (WEC, 1999). Users pay a connection fee and monthly service fee (set by government), and a declining subsidy is provided to the concessionaries based on the provisions of their contracts. Concessionaries are provided with partial financing of their start-up costs through the projects.

#### **3.1.4.3 The Retailer Model**

The small electricity retailer model is a community-based approach to renewable energy delivery that has been employed by the World Bank in projects for Sri-Lanka and Laos [(World Bank/IEA, 1999), (World Bank, 2000)]. Under this model, a community, organisation, or entrepreneur develops a business plan to serve local demand for electricity. The plan is submitted to the project's off-grid electrification committee and if approved, a loan is given. The retailer deploys the system and through fee-based service arrangement recovers cost, repays the loan, and earns profit.

### **3.2 Evolution of Renewable Energy Policy Instruments and Measures in Ghana**

The enactment of the PNDC Law 62 in 1983 was the starting point for the evolution of national policies having a bearing on renewable energy technologies. This law led to the establishment of the National Energy Board (NEB) [(Oteng-Adjei, 2000)]. The PNDC Law 62 remained in force as the guiding legislation for the implementation of projects in

renewable in Ghana until 1996, when the Energy Sector Development Programme (ESDP) was introduced (Akuffo, 1998).

Other relevant legislation for the energy sector includes the Energy Commission Act, 1997 (Act 541) and the Public Utilities Regulatory Commission Act, 1997 (Act 538). These Acts mainly introduced institutional and administrative reforms into the energy sector (KITE, 2002). The NEB was *inter alia* responsible for energy planning, energy efficiency and conservation, research and development of new and renewable energy technologies.

### **3.2.1 Measures employed by NEB to Implement Programmes and Projects**

In carrying out its function, the NEB created five key departments, one each for petroleum planning, electricity planning, renewable energy programmes, energy conservation programmes and energy information (RDREG, 2002). The NEB initiated a number of projects in the areas of renewables, electricity, petroleum, energy conservation and demand management, policy analysis, planning and institutional management. The NEB embarked on publicity to encourage people, in particular vehicle owners, to reduce their consumption of petroleum products. It also publicized RETs through its campaigns, although renewable energy was not targeted specifically as a substitute for petroleum products (Oteng- Adjei, 2000).

What NEB could not achieve however was the formulation of a comprehensive long-term plan for renewable and other sub sectors of the energy economy. This was seen as the weakest area of the NEB's activities (Akuffo, 1992). The development of a comprehensive and practicable framework for establishing a national energy strategy, which will provide a long-term perspective for the development of the energy sector in general, was recommended by Akuffo (1992). Perhaps the response of the MME to this recommendation was the institution of the Energy Sector Development Program (ESDP) in April 1996.

### **3.2.2 Accomplishments of the NEB**

The NEB initiated a total of 135 projects and programmes between 1989 and 1991 (Akuffo, 1992) of which 29 projects were on renewables (see Table 3.1). The renewable energy projects in Table 3.1 below mark the genesis of national effort to develop Ghana's renewable resources. The main measures used by NEB in carrying out its renewable projects were research and development, education & information as well as demonstration projects.

The NEB was abolished in March 1991 and all its assets and staff placed under the direct control of the Ministry of Energy. This ministry was created to replace the Ministry of Fuel and Power. It is however not clear as to how many of the 29 projects were completed or abandoned before the board was abolished (Akuffo, 1998)-since there are so many progress reports on these projects but just a few final reports (KITE, 2002).

Table 3.1 Summary of Projects under RETs established by NEB (1989 -1991)

<b>Year 1989</b>	<b>Year 1990</b>	<b>Year 1991</b>
1. Strategies for improving charcoal production in Ghana	10. Strategies for improving charcoal production in Ghana	22. Strategies for improving charcoal production in Ghana
2. Improved charcoal stove programme	11. Improved charcoal stove programme	23. Improved charcoal stove programme
3. Rural energy planning studies	12. Rural energy planning studies	24. Improved firewood stove project
4. Appolonia biogas project	13. Appolonia biogas project	25. Appolonia biogas village project
5. Public latrine biogas project	14. Integrated biogas project	26. Monitoring and evaluating the performance of solar PVs in Ghana
6. Monitoring and evaluation of the performance of solar PVs in Ghana	15. Biogas resource assessment	27. Solar and wind energy resource
7. Solar and wind energy resource assessment	16. Establishment of biogas laboratory and workshop	28. Prospects for solar water heating
8. Prospects for sawdust briquettes as renewable energy source in Ghana	17. Monitoring and evaluation of the performance of solar PVs in Ghana	29. Prospects for substituting solar energy for oil in large scale commercial crop drying
9. Demonstration of integrated solar power for villages	18. Demonstration of integrated solar power for villages	
	19. Promotion of sawdust briquettes as renewable energy source in Ghana	
	20. Solar and wind energy resource assessment in Ghana	
	21. Feasibility study of substituting solar energy for oil in large scale commercial crop drying	

(Source: Akuffo, 1992).



### **3.2.3 Overview of the Ghanaian RET Policy Situation**

Before discussing the status quo of Ghanaian RET policy, let's take an over summarized look at the overall goal of the Ghanaian government's energy policy.

The vision of the Government of Ghana for the energy sector is to develop "Energy Economy" that would ensure reliable supply of high quality energy services for all (both urban and rural) Ghanaian homes, businesses, industries and the transport sector while making significant contribution to the export earnings of the country (MME, 2001). The government is thus committed to electrifying all communities with a population size of over 5000 inhabitants by the year 2020 under the National Electrification Scheme (NES). Within the context of the stated vision and also to respond to the developmental priorities of government, the following seven (7) policy objectives and associated policy actions are intended to provide the framework for the development and implementation of energy sector programmes and projects in the country:

- Increase access to high quality energy services;
- Consolidate and improve existing energy supply system;
- Secure future energy supplies;
- Stimulate economic development;
- Minimize environmental impacts of energy supply and consumption;
- Strengthen institutional and human resource capacity and R&D in energy development; and,
- Special concerns – to accelerate the development and utilization of renewable energy sources.

At the core of the strategic drive to achieve these policy objectives, is the effort to attract private sector investment in all aspects of Ghana's energy development especially in the areas of electric power generation and distribution and petroleum products refining. In this regard, a number of reforms have been initiated in the energy sector particularly in the power and petroleum sectors with the primary aim of creating the necessary policy and regulatory environment for attracting private sector investments (MME, 2001).

In an effort to achieve the NES objective of electrifying communities with 5000 inhabitants by 2020, several mechanisms are being put in place to obtain the required energy from all feasible sources. Such effort includes building a 300MW thermal power plant by the Volta River Authority; a 150 MW installation capacity of natural gas power plant by the Ghana

National Petroleum Company and a RET Wish List (Table 3.2). Under the NES, Ghana's Government proposed expenditure of about \$ US 350,000 for renewable energy between 1996 and 2000, especially for the development of solar energy industries.

Table 3.2 A wish list for 2020 from Renewables.

<b>Duration</b>	<b>Solar(MW)</b>	<b>Modern Biomass (MW)</b>	<b>Wind (MW)</b>	<b>Small &amp; Medium Hydro(MW)</b>	<b>Total (MW)</b>
<b>Short Term (2000-2005)</b>	10	10	50	5	75
<b>Medium Term (2005-2010)</b>	50	100	200	200	550
<b>Long Term (2010 – 2020)</b>	200	500	500	300	1500
<b>Total</b>	260	750	750	505	2,125

RDREG, 2002

As seen from Table 3.2, Ghana has an ambitious policy target for utilizing RETs in its energy mix by the year 2020. The question is how feasible is this wish list – technically and economically? This study hopes to provide a crystal clear picture to the efficacy of the above wish list through; assessment of RE resources, analysis of current projects and modelling of future projects.

Ghana's renewable energy policies tend to favour the use of 'measures' more than 'economic instruments' in their implementation [(RDREG, 2002), (KITE 2002)]. A cursory glance at the functions and activities of the National Energy Board (NEB) reveals that research, development and demonstration as well as education and information were the main measures used (Akuffo, 1998). Again under the Energy Sector Development Programme (ESDP), these measures have tended to be favoured options as evident from both the short and medium term objectives of the Renewable Energy Development Programme (REDP) [(Oteng-Adjei, 2000)]. Subsidies are the only economic instrument explicitly mentioned under the REDP (KITE, 2002).

Some normative measures-mainly formulation and promulgation of legislations – have been used as well but no standards or targets have been employed. Reforming the energy sector,

especially the power sector, has also been embarked upon to revolutionize operations in the power sector. The main institutional reforms have been the setting up of the Energy Commission and the PURC, with the latter being mandated amongst other things to rationalize the tariff structure in Ghana (Akuffo, 1998).

According to KITE (2002), it needs to be acknowledged that although subsidy is the only economic instruments explicitly mentioned in ESDP, other economic instruments (although not mentioned in the ESDP) have been employed during implementation.

### **3.2.3.1 Economic Instruments**

#### **PV Import Duty Waiver and /or Reduction**

In May 1999, the then government decided to reduce the import duty on solar panels from 27% to 5% (RDREG, 2002). This was after two earlier publications stated that there would be a complete waiver of all duties on panels (Akuffo, 1998). Further investigation revealed that the true position is a complete waiver of duty on the panel but the panels still attract value-added tax. According to officials of MME, the 5% represents the value-added tax payable on panels (MME, 2000). Thus a solar panel imported into Ghana attracts a consolidated 'tax rate' of 5%. All other Balance of System (BOS) components of the solar generating set such as batteries and inverters are dutiable and taxable.

An attempt was made to compare the market situation before and after the introduction of the policy. However, this was not possible because there were no records on PV imports at the harbour, and private dealers were not prepared to disclose business performances. Even if such figures had been available they would not have given a true picture of the effect of the policy on demand because of other exogenous factors such as the energy crisis in 1998 (MME, 2000). This notwithstanding, interviews conducted with key solar dealers by KITE (2002) pointed to the fact that the policy instrument has not been very effective if the overall objective was to increase the usage of solar PVs. They argued that the waiver or tax reduction does not bring about a sufficiently large reduction in the cost of the system. Furthermore, because the policy was vague, it was subject to the interpretation of custom officials (Akuffo, 1998). Most of the dealers suggested that at the least the waiver should have been on all other PV components. It was opined by one dealer in the KITE (2002) report that instead of the waiver, the government could collect the duty and pay it into a fund; this fund could then be used to offer credit on favourable terms to people who cannot afford the high start-up costs of PV systems.

Though the policy exempts taxes on the importation of solar panels, taxes however still applies to the importation of Balance of Equipment (BOE) components. This is because some fraudulent businessmen abused this tax exemption by importing pumps that were for other purposes instead of for SWP BOEs (Personal Communication, 2004). Appropriate policy recommendations are suggested in chapter 8 of this dissertation.

### **3.2.3.2 Tax Instrument**

#### **Petroleum Taxes**

Since the mid 1980s the government has financed sustainable energy projects using small levies on petroleum products (refer to Table 3.3). The levy, which started at 0.3% of the pump prices for petrol and diesel fuel and slightly less for kerosene, was set at one Ghanaian Cedi (¢) per litre (2002 rate). Using the 1998 annual consumption of petroleum products of about 1.2 million metric tons, Tse (1999) estimated that around \$ US 600,000 could be generated annually from the tax. These sums are paid into the Energy Fund and used *inter alia* to promote renewable energy and energy efficient projects (KITE, 2002).

### **3.2.3.3 Financing Scheme**

#### **Energy Fund**

The Energy Fund was established under section 41 of the Energy Commission (EC) Act and fed primarily by a proportion of government levy on petroleum products, electricity and natural gas. The levy on petroleum products (in year 1999) was ¢ 1 /litre and that of electricity is ¢ 1.7 /kWh (i.e. \$ US 0.0001327/litre & \$ US 0.0002257/KWh respectively) [(Tse, 1999)].

Monies generated through the fund are supposed to be used *inter alia* for the promotion of projects for the development and utilization of renewable energy resources and rural electrification. Table 3.3 shows the disbursements made from the fund to the technical wing of the Ministry of Mines and Energy for a three-year period. As evident from Table 3.3, the apportionment of monies from the fund is skewed towards electricity planning (i.e. National Electrification Scheme, NES). Up to about 64% of total disbursement for each year went into electricity with figures rising in absolute terms from about 15 billion cedis \$ US 10,217,984 in 1996 to 24 billion cedis \$ US 10,572,687 in 1998 (KITE, 2002). These figures far exceed the allotments for the development of the renewable energy. Even a comparison

with figures for the promotion and development of LPG, still leaves the renewable energy relatively under-financed.

What could be inferred from the above is the fact that limited financial support from the Energy Fund has gone into the development of renewable energy *vis-à-vis* other programmes being implemented by MME. It also reiterates a point made earlier that the rural electrification programme was a missed opportunity for the renewable energy. Had the programme targeted the renewable energy, more RETs would have been disseminated rather than the money being spent on grid extension from conventional power sources.

Table 3.3 Payments made from the Energy Fund for Projects within the Technical Wing of the Ministry of Mines and Energy (MME).

Details of Expenditure	1996		1997		1998	
	Recurrent (\$ US)	Dev't (\$ US)	Recurrent (\$ US)	Dev't (\$ US)	Recurrent (\$ US)	Dev't (\$ US)
1. Project Monitoring & Management	17,838	-	16,006	-	13,388	-
2. Corporate Planning & Finance	22,703	-	23,647	-	16,740	-
3. Petroleum (including LPG)	9,460	2,762,838	7,994		12,037	2,340,529
4. Renewable Energy	3,960	229,054	45,613	193,162	51,282	-
5. Energy Information Centre	21,608	-	15,105	-	20,022	-
6. Energy Conservation	17,946	1,035	45,447	872,934	111,088	344,934
7. Resources & Environmental Planning	9,432	-	13,009	85,470	14,973	-
8. Electricity Planning	8,784	10,539,324	-	9,512,821	-	10,607,930
<b>TOTAL</b>	<b>98,313</b>	<b>13, 532, 251</b>	<b>166, 821</b>	<b>10, 664,387</b>	<b>239,530</b>	<b>13,293,393</b>

[Source: Technical Wing of the Ministry of Mines and Energy, 1999 with modification (exchange rate as at 1<sup>st</sup> January for each year was used in the currency conversion)].

### **3.2.3.4 Pricing Instrument**

Low electricity tariffs have been cited as one of the main causes of inefficient use of electricity in Ghana. Many African countries including Ghana have tried to overcome this problem through a gradual phase-in of full marginal-cost pricing, especially of grid electricity (Brew-Hammond & Crole-Rees, 2002). This can have a positive impact on the take-up of energy efficiency as well as improving the competitiveness of renewable energy. However, this effect is usually weakened or wiped out by high inflation rates combined with strong public objection to price increase. The government of Ghana accepted the principle of long-run marginal cost (LRMC) pricing for domestic electricity in 1987, but by the end of 1995, residential and bulk supply tariffs had risen only to about 50% of LRMC (KITE,2002). In May 1997 tariffs were increased by some 300% (Akuffo, 1998). The tariff increases were later suspended following a massive public outcry only to be reintroduced a year later in 1998 (KITE, 2002). It is anticipated that this will *inter alia* make the unit price of renewable energy more competitive.

### **3.2.3.5 Other Policy Issues**

#### **3.2.3.5.1 National Electrification Scheme (NES)**

As mentioned earlier, on the Government of Ghana (GoG), in its NES and also Economic Recovery Programme (ERP), committed itself to extending electricity to all communities with population above 5000 by the year 2020. As at 1989, only 478 out of the 4221 such settlements-the overwhelming majority of which are rural-had access to electricity (Ampofo, 1998). The GoG views the electrification of rural areas as a giant leap towards rural agro based industrialization, employment creation, increased incomes and improved standards of living (MME, 2000).

To achieve these objectives, the GoG instituted the NES as the principal instrument of its policy of national electrification. A complementary activity to the NES is the Self-Help Electrification Project (SHEP). Under the SHEP, communities that are 20km from the national grid can bring forward their electrification projects provided they procure all the low voltage (LV) poles required for the LV network and have a minimum of 30% of the houses within the community wired.

Since the inception of the NES, all 110 district capitals in Ghana have been connected to the national grid system. From 1990 to date, 2450 towns were electrified; more than 2000 of

these were connected through SHEP (Ampofo, 1998). The NES has been funded mainly through bilateral and multilateral assistance. In October 1992, the GoG and the IDA concluded an agreement for an IDA syndicated credit of \$ US 185 million to implement the National Electrification Project (NEP) [(KITE, 2002)].

#### **3.2.3.5.2 PURC's Transitional Plan (2000-2002)**

The transitional period was defined as the period from 2000 until end of year 2002 when it was highly expected that natural gas will be available for power generation in Ghana, via the West African Gas Pipeline Project (KITE, 2002). Thus the transitional plan has been linked to the availability of natural gas in Ghana, which was expected to translate into lower end-user tariffs under natural gas fired thermal plant regime. The transitional plan has been couched in a manner that will afford the PURC the opportunity to transit current electricity tariffs with respect to generation, transmission and distribution, to economic rates, without imposing undue financial burden on all classes of customers. The plan is also expected to give ample time to customers to gradually adjust to the economic tariffs and simultaneously, enable the utility providers to cover their operating and maintenance costs and also to make a reasonable rate of return on their average revalued net fixed assets (PURC, 2000).

#### **3.2.3.5.3 Ghana's Poverty Reduction Strategy and its linkage to energy**

The Government of Ghana (GoG) has prepared a Poverty Reduction Strategy Paper (PRSP) referred to as "The Ghana Poverty Reduction Strategy" (GPRS) that aims to increase economic growth and reduce poverty (GPRS, 2002). It focuses on three dimensions of poverty, namely income and consumption poverty, lack of access to basic services and deprivation in human development.

The stated goal of the GPRS was to reduce the national incidence of poverty from 39% in 2000 to 32% by 2004. It identified energy as a major contributor to economic transformation in rural areas but was unable to identify any specific approaches short of stating the intention of GoG to support the development of renewable energy technologies and ensuring that electricity supply to rural areas was capable of being used for production purposes.

Ghana subsequently developed Energy for Poverty Reduction Action Plan under the Global Village Energy Partnership (GVEP) and through a unique partnership between GoG representatives for all the Poverty Reduction Strategy sectors and key energy professionals

from government and NGOs (GPRS, 2002). The draft Action Plan document reflects the energy service needs for the key components of the Poverty Reduction Strategy (with the seven main priority sectors: agriculture; health; education; small and medium enterprises (SME); water and sanitation; environmental management and communication).

### **3.2.4 Summary of Renewable Energy Policy Findings**

Perhaps the greatest legacy that the power sector reform has “bequeathed” to decentralized energy in general and renewables in particular is the “legal status” it has granted to private generation and sale of electricity. Prior to reform the existing laws did not permit any entity, be it corporate or private individual, to generate electricity in Ghana. With this main barrier removed, it is hoped that the scope of application of renewables (and with it the benefits to the environment) will be enlarged since private individual and/or companies can now apply for license to develop and disseminate renewables in remote rural communities where it would be uneconomical to extend electricity from national grid. However, there are other key barriers that will have to be removed before widespread adoption and utilization of renewables can be achieved. Hopefully these barriers will be removed by the on-going DANIDA funded Renewable Energy Development Project (REDP). The REDP was set up under a cooperation agreement between the GoG and Denmark to provide technical assistance to the MME and EC in the management and promotion of renewable energy technologies (RETs) in Ghana. A key component of the REDP is the formulation of the National Renewable Energy Strategy (NRES), which is basically aimed at identifying and removing barriers to RETs in Ghana.

#### **Findings on policies influencing REs in Ghana can be summarized as:**

- Exploitation of Ghana’s renewable energy resources has been carried out under two main policy regimes-PNDC law 62 (1983) and the Energy Sector Development Programme (ESDP). The former established the National Energy Board (NEB) and amongst other things mandated the NEB to direct the development and demonstration of renewable energy projects throughout Ghana while the latter is the policy framework that has been guiding the development of RETs since 1996 till the present.
- Several measures and instruments have been employed in the implementation of renewable energy policies. The main measures used are research and development, information and education, and some normative measures (like the passing of PNDC



law 62 and the Energy Commission law). Some economic instruments (such as subsidies, taxes, pricing, financing and duty waiver/reduction) have been used as well but only to a limited extent.

- Existing renewable energy policy framework is not potent enough to ensure the commercialization and widespread utilization of RETs, that the framework seeks to promote. This is because the policy framework has neither investment plans nor financing mechanisms and relies heavily on government budgetary allocation and donor funding which are not likely to be sustainable (KITE, 2002). The policy framework can also be faulted on the grounds that it discriminates against some forms of RETs (notably small hydro power) by not making provision for their development.

Despite government activities in RE technologies, financial schemes available to entrepreneurs and consumers are still rare and the range of policy instruments narrow. Mechanisms for maintenance of renewable energy equipment are weak and the awareness of RETs is in general not well developed. A low electricity tariff discourages the use of alternative forms of energy production.

## **PART 2: ANALYSIS OF RENEWABLE ENERGY TECHNOLOGIES & DEVELOPMENT OF MODELS FOR FUTURE PROJECTS IN GHANA**

### **CHAPTER 4 BIOMASS ENERGY**

*‘Don’t judge each day by the harvest you reap but by the seeds you plant’.*

*- Robert Louis Stevenson (1850-94).*

#### **Introduction**

This chapter is a detailed analysis of biomass energy resources in Ghana. It first provides a general overview of the technical aspects with regards to biomass and its energy conversion processes. Then follows an extensive analysis of all biomass energy projects commissioned to date in Ghana. Performance evaluation of projects for identification and analysis of success/failure cases was also undertaken. The chapter eventually leads us to a barrier analysis on biomass energy technologies employed in Ghana. A development collaborative model for sustainable bio-energy projects is mapped out in this chapter. The chapter finally ends with suggested recommendations for future projects.

#### **4.1 Technical Aspects of Biomass Energy Resource**

Biomass is any photosynthetically derived material of biological origin (Fischer & Schrattenholzer, 2001). Most of the standing biomass is in the form of woody forest materials, (Klass, 2004) and these forest species store biomass energy for relatively large amounts of time [(Nanguneri & Hester, 1990), (Biomass Program, 2004), (Tsao *et.al.* 1982)]. Conversely, marine biomass has a large productivity but a small reservoir due to the short lifetime of the organisms (Szargut, 2003). In order to improve or develop energy conversion processes for biomass, it is important to understand its composition (Wright & d’Agincourt, 1984). Most land biomass is composed primarily of cellulose, hemicellulose, and lignin [(Klass, 2004), (Yancey & Kadam, 1997)]. Celluloses are carbohydrates composed of a variety of saccharides. Proteins are found in most biomass, but are particularly abundant in herbaceous species (Hall and Rao, 1999). Lignins are the tough fibres giving woody biomass its structural properties [(Farone & Cuzens, 1996a), Broder *et.al.* 1992)].

Several types of biomass are used as an energy conversion feedstock including agricultural and forest product residues, municipal solid waste, and industrial waste. Except for the case of corn derived ethanol, there are currently no large scale efforts to commercially grow crops for energy [(Yamamoto, 1999), (Frank & Lee, 1987)]. It has been proposed however, that fast growing species such as switch grass or sugar cane would be an economical option (Imhoff, *et.al.*, 2002). High quality woody feedstocks such as poplar and pine have also been mentioned (Hoogwijk, 2003) as having immense economic potential. These feedstocks could be combusted, gasified, or biologically digested, depending on the composition of the fuel and the desired energy carrier product (Nanguneri & Hester, 1990). Many species are viable energy feedstocks and can be selected based on their appropriateness to the intended energy conversion process and growing environment (Farone & Cuzens, 1996b).

Biomass has some advantageous chemical properties for current energy conversion systems (Biomass Economy, 2002). It is low in ash, low in exotic trace elements, and high in volatiles and reactivity [(Wilke *et. al.*, 1976), (Lightfoot & Green, 2004), (Kuhad, *et.al.*,1997)]. However, its high moisture, tendency to form tars, and an ash chemistry that leads to the formation of low melting point solids when combusted presents challenges to current conversion methods (Imhoff, *et.al.*, 2002). Some biomass fuels may be high in N and Cl-the combination of both an alkali deposit and high Cl often constitutes a corrosion threat [(Klass, 2004), (Wyman, 1991), (Montenecourt & Eveleigh, 1979). Nitrogen is usually lower in biomass than in coal, although there can be exceptions such as poultry litter and highly fertilized crops (Szargut, 2003). Under some conversion conditions, higher N content may lead to the formation of nitrogen oxides (IPCC, 2001). Sulfur is also typically much less than in coal, decreasing the potential of sulfur oxide creation during conversion.

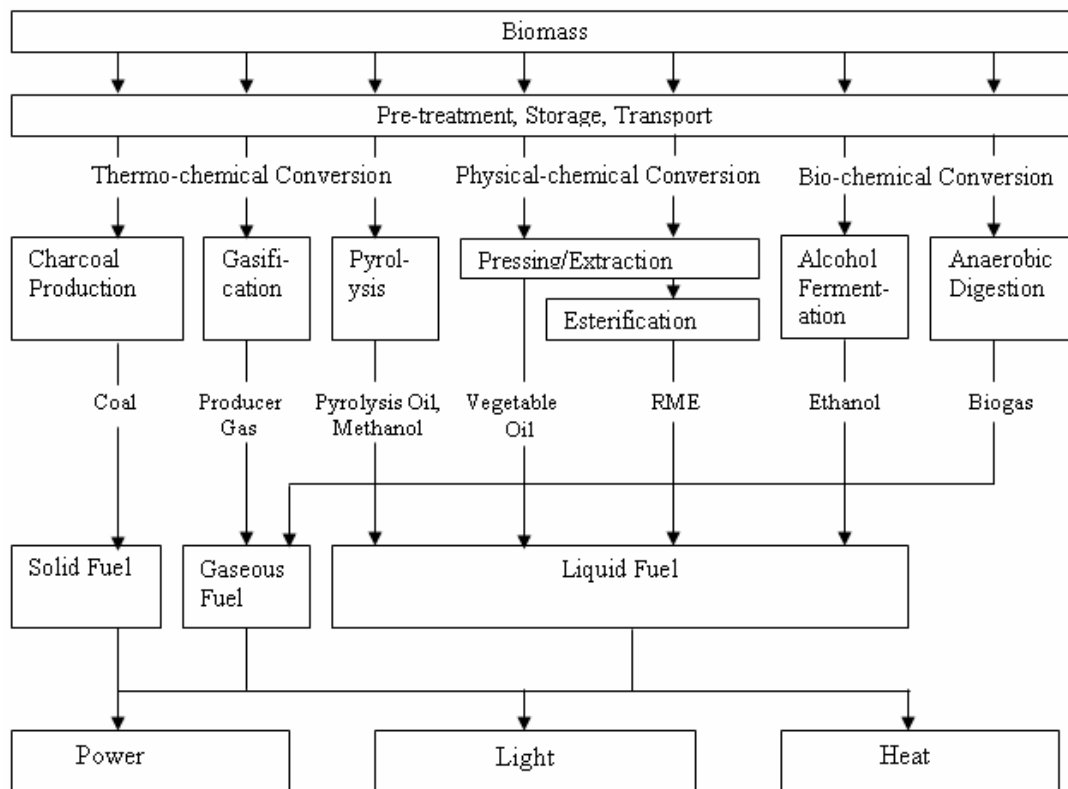
While the elemental composition is important to combustion conversion systems, biomass also has the property that it can be biologically converted through anaerobic digestion or fermentation (IPCC, 2000). The chemical structure of the feedstock determines the fraction of biomass that can be utilized as different types of carbon compounds in the biomass feedstock are more or less available for this type of conversion (Knecht & Goransson, 2004). For example, lignin is resistant to chemical breakdown by the microorganisms and enzymes that digest solid biomass-although they are hampered by incomplete utilization, these biological conversion processes may be simpler and less capital intensive than thermo-chemical pathways to make gaseous and liquid fuels.

Though both fossil fuels and biomass are ultimately products of the solar resource, the ability to re-grow harvested biomass and recapture the carbon emitted to the atmosphere through photosynthesis allows the possibility of carbon neutrality.

#### 4.1.1 Conversion Routes of Biomass for Energy

Most of the biomass that is already used for energetic purposes is directly combusted to produce heat or electricity (Kaltschmitt & Bridgewater, 1999). Figure 4.1 shows the most promising biomass energy conversion options that are currently pursued globally.

Figure 4.1 Conversion routes of biomass upgrading.



(Source: Kaltschmitt & Bridgewater, 1999).

According to Kaltschmitt & Bridgewater (1999), the different conversion routes can basically be divided into three main platforms; thermo-chemical, physical-chemical and bio-chemical conversion (Figure 4.1). The thermo-chemical conversion platform comprises of charcoal production, gasification and pyrolysis. The physical-chemical platform consists of the

pressing and/or extraction and an optional esterification. The energetically most relevant biochemical conversion routes are alcohol fermentation and anaerobic digestion.

In each of the three conversion platforms, biomass is upgraded to secondary solid, liquid or gaseous biofuel that offers better qualifications for a clean and efficient utilization.

#### **4.1.1.1 Thermo-chemical Conversion**

This is mainly based on the decomposition of biomass by means of heat. Depending on the process conditions, solid (charcoal), liquid (pyrolysis oil) and gaseous (producer gas) products are obtained.

##### **4.1.1.1.1 Charcoal Production**

Charcoal is the solid residue consisting mainly of carbon obtained by the destructive distillation of wood in the absence of air [(Adapted from U.N., 1994), (SEI, 1999), (Smith, 1987)]. It is produced by thermal decomposition of wood. Wood residues and/or woody energy crops are the preferred feedstock. Feedstock availability is relatively high. Unlike pyrolysis and gasification, this technology is established on the market in many countries and has been optimized for decades (Härdtlein & Kaltschmitt, 1996). The cost reduction potential is low due to the fact that this technology has already been used for a very long time (Eurostat, 1995).

##### **4.1.1.1.2 Gasification**

Gasification of biomass is the thermal conversion of (solid) biomass to a gaseous fuel mainly by converting solid carbon into gaseous carbon monoxide; the producer gas, which can be used for various applications similar to natural gas (Kaltschmitt, 1996). A wide range of biomass (i.e. residues, energy crops) can be used as a feedstock (also organic waste, e.g. sewage sludge, which, is already used to a certain extent) [Kaltschmitt, 1994]. Therefore feedstock availability is relatively high. The major challenge of biomass gasification is the production of electricity or combined heat and power (CHP) production with a high electrical efficiency using engines (Härdtlein & Kaltschmitt, 1996). There had been only a small number of gasifiers for thermal application under commercial operation in Europe (Kaltschmitt & Bridgewater, 1999) and similar trend can be observed today as compared to other RETs such as wind installation capacities. This is mainly due to technical problems on

the one hand and the relatively high costs of this conversion technology on the other hand (Eurostat, 1995).

#### **4.1.1.1.3 Pyrolysis**

Pyrolysis of biomass is the thermal decomposition with the objective of obtaining as much liquid fuel (pyrolysis oil) as possible. This oil can be used in various ways to substitute crude oil; preferred niche markets could be CHP in small cogeneration plants or the transportation sector. However, this conversion technology is, apart from some positive exceptions, still in the stage of development and the pyrolysis oil is not stable during storage in an oil tank (Härdtlein & Kaltschmitt, 1996). Due to the early stage of development, the costs of this technology are still very high and have to be reduced significantly to achieve market introduction (Härdtlein & Kaltschmitt, 1996).

#### **4.1.1.2 Physical-Chemical Conversion**

The physical-chemical conversion platform leads to the production of a liquid biofuel based on biomass that contains vegetable oil. This technology is similar to the conversion routes for the production of vegetable oil in the food industry.

##### **4.1.1.2.1 Production of Vegetable Oil**

Vegetable oil is produced by pressing and/extracting the oil from the seed. Thus, only those plant species containing adequate amount of oil can be used here such as rape, sunflower and jatropha. Most of these energy crops can only be cultivated in certain regions and require relatively high agricultural efforts (Kaltschmitt & Bridgewater, 1999). The production of vegetable oil is state-of-the-art since decades (Kaltschmitt, 1994). The utilization of vegetable oil for energetic purposes is connected with high environmental benefits in certain niche applications due to the fact that vegetable oil is easily decomposed (Kaltschmitt & Bridgewater, 1999). This might render vegetable oils it as an important fuel to power ships and boats that ply on drinking water bodies.

##### **4.1.1.2.2 Production of Oil Methyl Ester**

The production of oil methyl ester (like the production of vegetable oils) requires oil-containing crops which can only be cultivated in certain regions and require relatively high agricultural efforts. In addition to the above mentioned vegetable oil production, an

esterification step is necessary to produce a liquid fuel that can be used in conventional diesel engines (Härdtlein & Kaltschmitt, 1996). Despite the high need for cleaner transportation fuels, the high energy costs of vegetable oil methyl ester and low area specific yield is huge barriers to successful market diffusion (Kaltschmitt & Bridgewater, 1999).

#### **4.1.1.3 Bio-chemical Conversion**

Bio-chemical conversion is based on the decomposition of biomass by means of microorganisms. This can be realized in presence or absence of oxygen. The most important processes for providing energy are the alcohol fermentation and the anaerobic digestion (Kaltschmitt & Bridgewater, 1999).

##### **4.1.1.3.1 Alcohol Fermentation**

With regards to alcohol fermentation, only biomass that contains sugar or starch can be used (Kaltschmitt, 1996). Fermentation of cellulose is not common as that technology is very complex and not yet entirely available [UN(Ed.), 1996]. The technology of alcohol production from sugar or starch containing biomass is state-of-the-art and has been used for food production since centuries (Härdtlein & Kaltschmitt, 1996). As an admixture to gasoline, alcohol can easily be used in the transportation sector (Kaltschmitt, 1996). The potential of alcohol to contribute to energy demand and reduce energy based emissions is low since the amount of available arable land for growing energy crops is limited and the energy balance is poor respectively (Kaltschmitt & Bridgewater, 1999). The energy costs of alcohol fermentation technology are high and the cost reduction potential is low due to the fact that the conversion technology has been optimized since years (Eurostat, 1995).

##### **4.1.1.3.2 Anaerobic Digestion**

Despite some still given technical problems, biogas production can be considered state-of-the-art at the global level (Kaltschmitt & Bridgewater, 1999). However, the main task of the anaerobic digestion conversion route is to treat organic waste or residues to improve their further utilization; the production of energy is only a by-product (Kaltschmitt & Bridgewater, 1999). Biomass residues or organic waste with high moisture content can be effectively used as feedstock (i.e. in most cases significantly more than 90% water) [Härdtlein & Kaltschmitt, 1996]. After cleaning the produced gas mixture, which are primarily methane (CH<sub>4</sub>) and Carbon dioxide (CO<sub>2</sub>), biogas can easily be used in engines and boilers. The potential of

anaerobic digestion to contribute to the energy supply e.g. in Europe is low due to still unresolved disposal routes of the treated feedstock (Kaltschmitt, 1996). Additionally, the efficiency of the conversion process is quite low. That notwithstanding, there are some environmental benefits connected with this technology such as reduction of offensive smell (which is a nuisance) and the improvement in environmental hygiene (Kaltschmitt, 1996).

## **4.2 Biomass Energy Resource Assessment in Ghana**

Recall from Chapter 1, that biomass forms the dominant source of energy accounting for 66.7% of the total national energy consumption (Atakora & Brew-Hammond, 1999). 70% of Ghana's population of rural Ghanaian dwellers and a significant percentage of urban dwellers depend on fuel wood and charcoal for all their domestic and other commercial activities that require heat (Nketia, 1992).

Assessment of biomass energy resources currently utilized in Ghana yielded the following four main categories; forest resources, logging residues, wood processing residue and crop residue /animal waste.

### **4.2.1 Forest Resources**

The forest resources in Ghana are categorised into the open (savanna) and the closed (high forest) zones. The savanna zone covers an estimated total area of 9.6 million hectares of which 2.9 million hectares is bush fallow (Nketia, 1992). The remainder is degraded savanna. The closed forest zone covers a little more than a third of the country's total land area and has a size of about 8.2 million ha, 20% of which is demarcated either as forest reserves or fuel wood plantations (Nketia, 1992). Altogether forest reserves in the country cover about 2.47 million ha, which constitute about 10.5% of the total land area. The reserves are categorised into production reserves, covering 1.2 million ha and protective reserves, covering 1.3 million ha. The production reserves are managed for sustainable production of timber, and non-timber forest products and the protective reserves are managed solely for environmental protection, thus closed to timber exploration. About 680 tree species have been identified in Ghanaian forests. The estimated national growing stock of wood in 1986 was 322 million tons with a gross mean annual increment of 12.3 million tons (Nketia, 1992).



#### **4.2.2 Logging residues**

The merchantable wood material extracted from the forest is principally the fairly straight, sound bole volume part of the tree, which constitutes about 49.6% of the total volume of tree. All other parts of the plant such as the stump, butt-end, off-cut and branch wood are considered as logging waste and left in the forest by loggers. In 1990 an estimated 688,262 tons of residue was generated from logging activities alone. The logging residues are sometimes used for particle board and fibreboard production and sometimes as raw material for the manufacturing of products such as flooring, tool handles, wood crates and pallets. However in a great majority of cases only a small percentage of logging residues find any use at all.

#### **4.2.3 Wood Processing Residue**

The processing of timber into products as lumber, veneer, plywood among others, generate a lot of residue or waste. For example, out of 806,000 cubic metres of log equivalent processed in Ghana in 1993, 518,000 cubic metres (representing some 51.8% of the annual allowable cut) went to waste (FPEB, 1993). Wood processing can be classified into 'solids' and 'fines'. Examples of 'solids' include barks, slabs, and edgings, off cuts, veneer waste and cores. The 'fines' include sawdust, planes, shavings and other sander dust. The 'solids' constitute a greater percentage of wood processing residue produced in Ghana. In 1988, 79% of processing waste was 'solids' and 21% 'fines' (UNDP/ESMAP, 1988). Table 4.1 shows production of sawmill residue in Ghana from 1990 to 1994 in cubic metres of solid weight equivalent.

Table 4.1 Sawmill residue production (m<sup>3</sup> SWE)

Year	Slabs & edging	Off-cuts	Sawdust	Total
1990	38,220	393,120	158,340	589,680
1991	35,490	365,040	147,030	547,560
1992	39,935	410,760	165,445	616,140
1993	41,510	426,960	171,970	640,440
1994	38,850	399,600	160,950	599,400

(Source: Forestry Commission, 1995).

From Table 4.1, off-cuts (a solid) are the most abundantly produced sawmill residue. In 1994, for example, 399,400 m<sup>3</sup> SWE out of a total of 599,400m<sup>3</sup> SWE of wood residue generated in sawmills were off-cuts. This represented about 67% of total residue for 1994. Sawdust (a fine) represented about 27% of the residue generated in 1994 with the remaining 6% going into slabs and edgings (solids). The percentages are no different from the other years.

More than half of the wood-processing residue generated is used off-site. Of the residue used offsite, about 30% is used directly as firewood for food preparation, and about 70% converted to charcoal in earth mound kilns. Most of the solids have economic values and are normally sold as domestic, industrial fuel or construction material. On the contrary, the fines (mainly sawdust and shavings) are usually considered as waste material and normally pose disposal problems to the wood industry in Ghana. The residue is considered as possessing a negative resource value as people are employed to burn the material on site or transport to disposal sites elsewhere. Burning of the residue (waste) generates a great deal of pollution and is a nuisance to the general public.

#### 4.2.4 Crop residue and animal waste

Agriculture is the backbone of the Ghanaian economy contributing about 42% of GDP (Nketia, 1992). The sector is also the main source of employment to the over 65% of the country's population living in the rural areas (KITE, 1999a). All kinds of tropical crops are cultivated in Ghana, which generate a lot of post-harvest residue suitable for the production of biomass energy. Examples of agricultural residue include maize cobs, rice husks, palm branches, shells and nuts. The residues are normally popular fuels that burn rapidly; they are usually used in relatively small quantities to supplement or augment ignition when the main

fuel is forest wood or charcoal. There are many instances where they are used exclusively for heating purposes such as in traditional palm oil processing, fish smoking, small scale smelting and palm kernel oil processing. Table 4.2 below shows the production of some major crops and their residue in Ghana in 1990.

Table 4.2 Production of some major agricultural residues in Ghana.

<b>Crop</b>	<b>Residue</b>	<b>Residue production (t/crop)</b>	<b>Total crop production '000 tons</b>	<b>Residue production '000 tons</b>
Maize	Cob	1.00	553	553
Oil palm	shells	0.45	429	193
Paddy rice	Husk	0.23	81	19
Sorghum	Stalk	1.00	136	136
Millet	Stalk	2.00	75	150
Groundnut	Shell	0.50	113	56
<b>Total</b>			<b>1,387</b>	<b>1,107</b>

(Source: Hagan 1997)

Another form of energy that can be derived from agricultural waste is in the form of animal waste. Livestock rearing is a major occupation of people living in the northern parts of Ghana. In addition there are abattoirs and slaughterhouses in many cities and towns in the county and a lot of dung is generated. Biogas (mainly methane) is the product of the biological action of certain bacterial on organic matter such as dung. The resulting combustible gaseous product can be used like LPG in stoves for cooking, gas lamps for lighting and be used to provide motive for water pumping and grain milling applications.

### **4.3 Case Study Analysis of Biomass Projects in Ghana**

Biomass conversion technologies currently being used in Ghana are very inefficient with as much as 89% of the biomass going to waste [(KITE, 1999b), (Malvar et. al., 1980)]. Seven main technologies covering all biomass projects undertaken in Ghana is being considered and reviewed in this section. The section also contain results from barrier analysis for four of these technologies: biomass dryers saw dust briquetting, saw dust stoves and biogas.

#### **4.3.1 Biomass-fired Dryers**

The technology considered under this category is locally produced equipment for use by farmers for drying their crops. Identified projects are; a GTZ support programme at the Agricultural Engineering workshop of the KNUST and Duela Ventures, a private enterprise (MME, 2000). The manufactured dryers are used for drying agricultural produce such as maize and also for drying poultry feed. The technology has not yet been commercialized.

##### **4.3.1.1 Evaluation and lessons learnt**

The design and manufacture of the dryers are done locally. About four main units have been disseminated so far and they are all functioning very successfully.

##### **4.3.1.2 Barrier Analysis**

The two main barrier analyses to be undertaken are technological and economic.

###### **4.3.1.2.1 Technological/Technical**

Biomass dryers have so far been proven to be technically ready for the commercial and industrial sectors of the country (AFREPREN 2001). Current users have not experienced any major technical problems although users think some improvements to the size and finish of the product would be appreciated (KITE, 2002).

###### **4.3.1.2.2 Economic**

The workshop unit of the Agricultural Engineering Department, KNUST, is the pioneer in locally manufactured biomass dryers. The other known manufacturer is Duela Ventures. From a survey by KITE, (2002), it was found out that there was no other manufacturer large-scale biomass dryer. Despite being manufactured locally, the biomass dryers contain imported components, which are expensive; additionally the cost of local components of the dryers was also expensive. This makes the unit cost of the dryer (\$ US 900 at the time of the survey), expensive and unaffordable to farmers who are the main target group (KITE, 2000). There are no financing mechanisms currently available to support the manufacture and acquisition of the dryers.

###### **4.3.1.2.3 Crosscutting**

###### *Information*

Although farmers are one of the main targets of this product, only a few have any idea of its existence (KITE, 2002). The two manufacturers have so far made little effort to get

information about the dryers to the targeted groups. In the case of the Agricultural Engineering Workshop at KNUST, the dryers are only manufactured upon request from who are already using the technology.

#### *Institutional*

Energy-related research and development institutions in the country are biased towards particular technologies; unfortunately biomass dryers are not one of these technologies. Even though the ESDP sought to develop the biomass resources of Ghana, it did not consider biomass dryers. Hence there are no institutions in Ghana promoting widespread adoption of biomass dryers.

### **4.3.2 Sawdust Briquetting**

The largest sawdust briquette project was a 2200 tons/year plant producing uncarbonised sawdust briquettes (Hagan, 1997). This was a private effort by a Taiwanese entrepreneur and a Ghanaian partner at Akim Oda in the Eastern region of Ghana. The plant operated for 5 years (1984-1989) before it collapsed (MME, 2000). A new private plant is known to be in operation in Kumasi but products from this plant have not as yet entered the market; specimens are still being tested (KITE, 2002). Apart from manufacturing briquettes, there are plans by management to design a special residential cook stove that will use the briquettes produced.

#### **4.3.2.1 Evaluation and lessons learnt**

The briquettes produced by the Akim Oda plant were found to be too expensive, furthermore they could not be used in the domestic sector since no cook stoves were designed for briquettes (Atakora & Brew-Hammond, 1999). They were mainly targeted at commercial consumers like brick makers and bakers and the demand for the briquettes were very high (in spite of the cost), in some case far outstripping the supply. Nevertheless, there were some problems, which included operational inefficiencies, inadequate sawdust drying capacity and poor storage facilities for the sawdust. The main problem however was poor management, which eventually led to the closure of the plant in 1989 (MME, 1998).

#### **4.3.2.2 Barrier Analysis**

Sawdust can be found in abundance near wood processing firms around the country. The amount of sawdust generated in the country annually is at least 200,000 m<sup>3</sup> solid wood equivalent (MME, 1998, 2001). Less than a tenth of this finds any use at all; the rest are

simply incinerated on site. There is sufficient sawdust being generated at sawmills to feed any briquette plant more so as wood processing activities are not seasonal and subsequently the production of sawdust. Sawdust can be obtained free of charge and transported in trucks from nearby sawmills to nearby briquette plants. A study by KITE (2002) revealed that the properties of sawdust are favorable for the production of briquettes.

#### **4.3.2.2.1 Technological/Technical**

From the case study analysis, major technical problems were encountered by one of the briquette plants (Akim Oda briquette plant) which eventually led to the closure of the facility. Before the closure of the facility, operational inefficiencies were such that the 2,200 tons/year capacity plant was only producing 1,100 tons of uncarbonised sawdust briquettes in a year (KITE, 2002). One major factor for the poor performance of the plant was the inadequate drying of sawdust processed. The flash tube used at the plant was not insulated and the sawdust was being stored in the open where it was exposed to rain. It came out from an expert meeting that the feasibility study carried out before the setting up of the plant was seriously flawed (Atakora & Brew-Hammond, 1999). The expert realised that the energy required to make the briquettes when the facility was functional was more than what the plant provided (MME, 2000). There is at present no research and development on promoting the technology further.

#### **4.3.2.2.2 Economic**

Experience from the defunct Akim Oda plant indicates that the sawdust briquettes produced were mainly used as a substitute for fuelwood consumption in the industrial and commercial sectors, where the premium qualities of briquettes are valued. The products from the Akim Oda plant were mainly sold and used by commercial bakers in the Accra/Tema metropolis and the Ankaful Brick Factory near Cape Coast in the Central Region of Ghana. The potential demand for briquettes from bakers and brick manufacturers alone was estimated to be 45,000 tons annually (Hagan, 1994). Other potential users identified include fish smokers, local restaurants and institutional kitchens. It was estimated by Hagan (1994) that the potential demand for briquettes would increase to 500,000 tons/year if fish smokers and restaurants were to switch from firewood consumption to briquettes.

The cost benefit analysis for sawdust briquette is based on a feasibility study carried out in 1994 for a 30,000 tons/year sawdust briquette plant (Hagan 1994). The total capital cost of the project was estimated to be \$ US 3 million, comprising 75% debt and 25% equity financing. It was assumed that loans were to be raised from development banks in the USA and Ghana at interests of 10 and 25% respectively. It was estimated that 58,000 tons/year of sawdust supplemented by 3,600 tons/year of off-cuts would be required at the cost of \$ US 1 per ton to produce 30,000 tons of briquette annually (MME, 2000). It was further estimated that the briquettes would be sold at \$ US 72 per ton throughout the entire life of the project, which was assumed to be 10 years (Hagan, 1994, MME, 1998). Based on these estimations and assumptions, the financial analysis of the proposed briquette plant was conducted under two scenarios—the best case and worst case scenarios.

In the worst case scenario, the project was classified as ‘priority area of investment’ under section 12 of the Ghana Investment Code thus entitled to the following benefits and incentives (MME, 2000):

- Exemption from payment of custom import duties on plant, machinery and equipment, and accessories imported for the project;
- Depreciation of 40% in the year of investment and 20% in subsequent years
- Reduction of 15% on company income tax payable owing to the proposed location of the project outside Accra; and
- Investment allowance of 7.5%

In the best-case scenario, the project was classified under the ‘areas of special priority’ by the Ghana Investment Code (Areas of Special Priority Instrument), 1991 and thus entitled to all the benefits above in addition to the following (Hagan, 1994, MME, 1998, 2000):

- Five years tax holiday; and
- 50% rebate on company income tax thereafter

Table 4.3 contains a summary of the financial analysis for Sawdust Briquetting

Table 4.3 Summary of Financial Analysis of Sawdust Briquetting Plant.

	<b>Worst Case</b>	<b>Best Case</b>
Average annual profit in year 2-10,\$ US	339,338	478,872
Net present value, NPV @ 25%, \$ US	273,194	486,529
Internal rate of return, IRR in %	30	34
Discounted payback period @ 25% in years	4.2	4.0

(Source: Hagan, E.B. 1994).

According to Hagan (1994), in the event of a 10% increase in production costs, IRR of the project in the best-case scenario reduces to 28% with a discounted payback period of 5.2 years. In the worst case, the IRR reduces to 26% with a discounted payback period of 5.5 years. In the event of a 10% decrease in the estimated total revenue for the project and production costs remain unchanged, the IRR of the venture, in the best case, reduces to 23% with a discounted payback period of 7 years. In the same situation, the IRR in worst case reduces to 21% with a discounted payback period of 7.2 years. Consequently it can be concluded that the project was more sensitive to reduction in project revenue than an increase in production cost. The project on the whole was adjudged to be financially viable, especially in the best-case scenario.

### **Consumers' Perspective**

A consumer making a decision to use briquettes will be interested to find out how the price of briquettes compare with the alternative fuel source it will be replacing (in this case perceived to be firewood). Current market estimates indicate that firewood is sold at an average price of \$ US 45 per ton while the briquettes are to be sold at \$ US 72, a price differential of \$ US 27 per ton (MME, 1998). With this difference in price firewood and briquettes, no consumer would opt for briquettes unless there are other benefits associated with the use of sawdust briquettes.

Meanwhile according to Hagan (1994), interviews with several of the users of the briquettes from the Akim Oda plant indicated their strong preference for the products over firewood because of the former's technically superior quality. Bakers interviewed by Hagan (1994) indicated that they would be willing to pay up to 20% premium over the energy content adjusted price of fuel wood for the better characteristics of briquettes. Similarly, brick



manufacturers also indicated their willingness to pay between 10-20% premium over the energy price adjusted price of fuelwood for the operational advantages of sawdust briquettes (Hagan, 1994).

### **Financing**

Briquetting is a large-scale venture, which requires substantial capital for investment. Initial plant costs are very high and usually require external funding. Donor funding and/or support from national and international financial institutions however is not usually forthcoming (Atakora & Brew-Hammond, 1999). Almost all the components of the plant can be sourced on the international market and import taxes and other duties prohibitively expensive. Agencies and private investors involved in the technology are often unaware of how to approach financial institutions and are poorly informed on the financial instruments that are available and well suited for their requirements. National and local financial institutions are biased towards more conventional energy options; there is generally poor awareness amongst conventional financial institutions and government-sponsored bodies of the opportunities offered by briquetting technologies. Financial mechanisms such as loans, subsidies, delayed payment arrangements and hire purchase that could allow low-income groups to patronize environmentally benign sawdust briquettes are woefully absent. Access of briquette to international markets is nil and even internally the addition of transportation costs hikes up the price of briquettes making it uncompetitive with other fuel options.

#### **4.3.2.2.3 Crosscutting**

##### *Information*

The briquettes produced were aimed at a few industrial and commercial consumers and knowledge of the product among these types of users in the country is generally low (KITE, 1999b). Only little efforts have been made to get information about briquettes to a wider portion of the population and there is no mechanism for getting the views of customers already using the product (Hagan, 1994).

##### *Institutional*

The MME is not known to have any briquette projects in their immediate plan (KITE, 2002) and their involvement in the development of this technology has been rather on the low side.

Other research institutions in the country are also not particularly interested in briquettes. Many of the activities seen to date have come from private commercial entrepreneurs.

#### *Policy*

Although there are specific policies on the development and deployment of briquettes in Ghana, on the contrary, existing government policies, such as the Ghana Investment Code, favour briquetting projects [(Hagan, 1994), (MME, 1998)]. The Ghana Investment Code, 1991 classifies projects that are related to indigenous energy supply under the 'areas of special priority'. Special priority rated projects are exempt from the payment of corporate tax for the first five years of operation. This provision under the Code offers an attractive incentive to many indigenous energy projects including briquetting. As can be seen from the financial analysis in section 4.3.2.2 the economics of briquettes becomes attractive with the introduction of tax holidays.

### **4.3.3 Improved Sawdust and Charcoal Cookstoves**

The Ministry of Mines and Energy is the pioneer of the dissemination of improved charcoal cook stoves popularly known as the Ahibenso in Ghana (Ampofo, 1998). The ministry's project started in 1989 and dissemination began in 1992 and it is still on going. Another project being carried out involves sawdust cook stoves which commenced in 1983 and is being managed by the Agricultural Engineering department of KNUST with support from GTZ (Nketia, 1988). The BRRI and other private entrepreneurs have been identified to have various designs of cook stoves on the local market (Oteng-Adjei, 2000).

#### **4.3.3.1 Evaluation and lessons learnt**

The technology is only effective in the urban areas where income levels are not so low and where stoves are already being bought. About 30,000 Ahibenso and 5000 sawdust stoves are known to have been disseminated (MME, 1998). Benefits of improved stoves range from savings in amount of fuel to reduced cooking time, reduced accidental burns and cleaner, more hygienic conditions. Problems with sawdust stoves and other improved cook stoves are principally lack of funds for promoting agencies, social acceptance of these stoves and poorly organized marketing strategies (RDREG, 2002).

### **4.3.3.2 Barrier Analysis**

#### **4.3.3.2.1 Technological/Technical**

All stoves are manufactured locally and are quite durable. The main problems are the voluminous amounts of soot and smoke that characterize the use of the stoves. Some end-users interviewed by KITE (2002) in a survey, mentioned this as an important reason that has discouraged the use of sawdust stoves. Also the stove is not very reliable in terms of its usage in cooking the different Ghanaian dishes e.g. banku, akplen, kokonte. Sale of the stoves comes without any operating manuals; buyers are only instructed orally on the method of operations.

#### **4.3.3.2.2 Economic**

The Agricultural Engineering Department of KNUST is the only recognized market outlet for the stoves (KITE, 2002). The department has so far disseminated a total of 5,000 stoves (Hagan, 1994). The department only produced on order and has no retail outlets or supply channels. Apart from the Agricultural Engineering Department, some wayside metal working artisans were identified as manufacturers of the stoves. These artisans have neither an organized retail outlets nor supply channel; their wares are basically displayed in front of their workshops for interested customers to make their purchases. Another 5,000 pieces of the stove are estimated to have been sold by these artisans (Nketia, 1998). Given the potential number of users of the sawdust stove that is all households within the vicinity of the sawmills. It can be concluded that the total estimated sale of 10,000 pieces is on the low side (KITE, 1999a, 1999b, 2002). This could be due to the marketing strategy being used to sell the products and the fact that no conscious effort has been made to promote the widespread adoption of sawdust stoves.

The financial analysis of sawdust stove under three different scenarios is presented below (KITE, 2002). The three scenarios considered were:

- a complete switch from the use of traditional charcoal stoves to sawdust stove;
- a 100% switch from improved charcoal stoves to sawdust stoves;
- a 50% switch from traditional firewood stoves to sawdust stoves.

The following are the assumptions used in the analysis:

The average daily charcoal consumption of a household (with an average size of five person) using the traditional coal pot in Ghana is about 2.5 kg per household which then translates into annual consumption of 913kg per household. This consumption rate will be reduced to about 557 kg per household if the household switches over from the use of the traditional coal pot to the improved charcoal stove, popularly referred to as 'ahibenso', which has efficiency 39%. Average weekly consumption of firewood per household is estimated to be 40kg and sawdust assumed to be free. The cost of the sawdust stove is \$ US 14 [approximately 50,000 cedis], 'ahibenso' is \$ US 7; the cost of traditional coal pot is US\$ 3; the price of charcoal is US\$ 63/ton; and price of firewood is \$ US 45/ton.

*Scenario 1:* 913 kg of charcoal could be saved per family per year with a monetary value of \$ US 58. Payback period here is 88 days for the household.

*Scenario 2:* Annual charcoal savings for a family using an Ahibenso improved stove is 356 kg, which translates to \$ US 22. Payback period for this scenario is 232 days (approximately 8 months).

*Scenario 3:* About 1040kg of firewood could be saved per family per year translating to annual monetary savings of \$ US 47. Payback period here is 108 days.

Where the sawdust technically capable of performing the same functions as the traditional coal pot, *scenario 1* which has the shortest payback period-would have been adjudged the best case. However recall that the sawdust stove is technically 'handicapped' when it comes to the cooking of many Ghanaian dishes. Consequently, *scenario 3*, where the household reduces its firewood consumption by 50% is recommended as the best-case scenario.

It is worth mentioning that there are no low cost, long-term financing schemes for manufacturers of sawdust stoves. This leaves the traditional banking sector as the only source of financing for manufacturers wanting to go into large-scale production of the stove. With the commercial and merchant banks charging high interest rates on loans (between 45%-50% per annum) it is unlikely that the artisans and even KNUST can afford to take loans from the banks.

### *Environment*

Environmental consideration (finding use for the abundant sawdust) rather than economic is the primary reason for the introduction of the sawdust stove on the Ghanaian market. As much as 21% of all timber processed turns out as sawdust waste, which finds very little or no use (UNDP, 1988). Only a handful of wood firms use their generated sawdust. Sawdust usually poses environmental problems as it is disposed of by dumping in landfills, on open land or burning. Sawdust abounds in areas where sawmills are concentrated but absent in other areas. Wood processing activities are not seasonal and sawdust is not always available in large amounts throughout the year in the appropriate areas (RDREG, 2002).

Although sawdust is so far free and available in large quantities to those who are near sawmills, it is plausible if not likely, that a price may be tagged to it once the technology become very popular and more stoves get disseminated.

#### **4.3.3.2.4 Cross-Cutting**

##### *Information*

Only a small percentage of potential end-users are aware of the presence of the product on the market despite representation of KNUST at, at least two exhibition/ trade fairs in Ghana (KITE, 1999a, 1999b). The initial impression that sawdust could be obtained freely makes its use appealing to many prospective users. Information on the stove's usefulness, performance, costs and others is very low. Manufacturers have not made any efforts to get information about the stoves to a wider portion of the population and there is no procedure for getting feedback from people already patronizing the stoves.

##### *Institutional*

It was found out from a survey (KITE, 2002) that the institutional capacity in the country is adequate except that there was a lack of collaboration between manufacturers. This could be due to the fact that some products on the market could not be traced to their producers and the known producers had little idea about the operations of their competitors. Government institutions such as MME are not known to have been involved with sawdust stoves (KITE, 2002). Facilities exist for the training of personnel on the technology and at KNUST many technicians have acquired the technical know how for the manufacture of the stoves.

#### 4.3.4 Biogas

A number of interesting biogas projects is currently on-going in Ghana. These include:

- A 100m<sup>3</sup> digester capacity plant utilizing human waste commissioned by Guinness Ghana limited and Water for life (UK). Gas generated is used for community lightning, cooking in a local school and to run a community corn mill.
- The Ministry of Mines and Energy's (MME's) bio-toilet at Ofori-Panin Secondary School. The facility produces gas for lighting the toilet and the surroundings of the school.
- Mampong Hospital Biogas Project: This is a 45 million cedi project, which utilizes liquid domestic waste to produce methane gas for electricity generation.
- The Institute of Industrial Research (IIR)'s and MME's demonstration project at Appolonia (Figure 4.2). This is a biogas-diesel hybrid in mini-grid producing 12.5kW electricity. The gas produced is used for direct cooking in 27 homes. A visit was made to this facility to examine the current state and performance as part of the study (Figure 4.2).



Figure 4.2 Electricity Generator Facility in Appolonia (myself left with one of the technicians-right).

##### 4.3.4.1 Evaluation and lessons learnt

Biogas technology can facilitate decentralized electricity generation and also serves as a low cost and environmentally friendly waste management process. Studies undertaken by MME (1994) showed that electricity generation cost from biogas is 14 times higher than that of hydro. Secondly, the utilization of biogas as cooking fuel is very unpopular in Ghana.

#### **4.3.4.2 Barrier Analysis**

Although the projects were implemented in areas with a high cattle and other livestock population, dung was quite scarce at certain times. This is a result of the combination of free range/semi confined system of livestock rearing where the animals are sent out to graze several kilometres away during the day and are returned to their pens at night. In many cases dung has to be sought for, collected and transported to biogas plants. Transportation of dung to use points is often a serious problem in remote communities. Human excreta transported by sanitary trucks from nearby cities can be employed in times of dung shortage. This however occurs at high cost to the system and is only possible in centralized sewerage system.

It came out from a survey by KITE (2002) that several biogas facilities were not in use due to dung and water shortages in certain seasons which should not have been the case if proper feasibility studies had been undertaken prior to the commencement of the project.

##### **4.3.4.2.1 Technological /Technical**

No technological limitations were identified with the operation of biogas plants installations. A similar study however found out that there was a complete absence of operational manuals for users of biogas installations (KITE 2002). Servicing of systems was not a common phenomenon even though there were a few trained local people to carry out this task.

##### **4.3.4.2.2 Economic**

The major economic obstacle facing this technology is its high cost. The communities for whom this technology is suited are most often poor. Many of the demonstration units had the service been provided for free but even then, the small monetary contribution needed from the users, that is to cater for cost for transporting dung to points of use, to supplement government or donors efforts, could not be paid by the poor users (MME, 1998, 1999). As a result many of the systems are not operating due to a shortage of dung.

Based on the cost of equipment at the prevailing dollar rate in Ghana, the generation cost per cubic meter of biogas is calculated under four different scenarios in Table 4.2 below for the Appolonia biogas project:

Table 4.4 Production Cost of Biogas

	<b>Scenarios for Biogas Production Options</b>	Biogas Cost [\$ US/m <sup>3</sup> ]
1	Free supply of feedstock but digester and O&M cost considered	0.26
2	Feedstock (cow dung & water) supplies, digester and O&M cost considered	0.93
3	Human excreta from cesspit truck, digester and O&M cost considered	0.51
4	Cost of bio-latrine system with digester and its operation cost considered	0.28

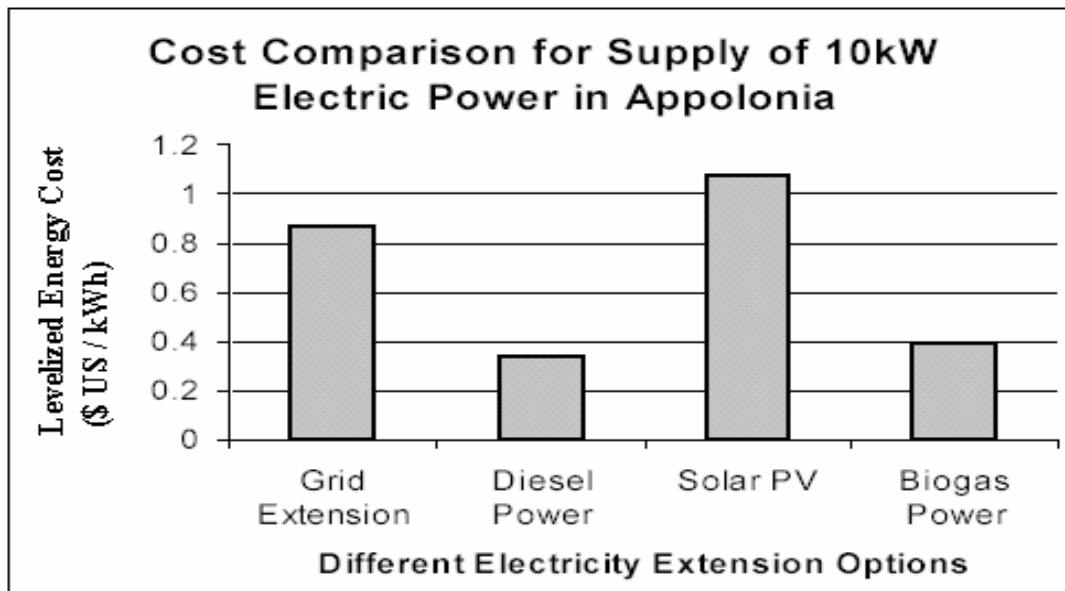
(Source: KITE 2002).

Labour costs for collecting and transporting dung to the digester is the largest cost component. This is seen in *scenario 2* which turned out to be the most expensive option. Cost of water used in mixing the cow dung is another important component; on the average 1kg of water is required per kg of cow dung. *Scenario 1* where the supply of feedstock to the location of digester is free (as in the case of a waste disposal site) turned out to have the lowest biogas production cost.

A graphic representation of the cost of supplying Appolonia with 10kW electric power for 12 hours daily by four different options is shown in Figure 4.3 below. The analytic basis for the comparison pivots around the economic concept of levelized energy cost / (LEC) and is on the basis of financial cost only. Other indirect costs and benefits such as sanitation control, environmental issues, reliability, etc are not considered here. It must be noted that production of electricity by biogas ranked second only to diesel in this case and that cost of grid power extension is distance dependent and only competitive to biogas power for distances below 6km from the nearest grid line. The financial analysis presented here is however not very conclusive as a lot of issues would have to be considered on a detailed economic analysis. Producing electricity from biogas is highly inefficient and could be economic only in very peculiar cases.



Figure 4.3 Chart of the different electrification options for Appolonia



(Source: KITE 2002).

The total cost of installation of biogas systems is very high for rural dwellers, who are the principal end-user. Profitable businesses cannot exist without loans and/or equity and the low involvement of the financial institutions in the production of biogas systems does not augur well for its dissemination throughout Ghana. Information on procedures and requirements for attaining loans are not readily available to producers and consumers of the biogas systems. Other financial obstacles affecting wider utilization of biogas include lack of:

- investment incentives e.g. accelerated depreciation and grants;
- production incentives e.g. production tax credits and direct cash payments per kWh produced;
- fiscal incentives e.g. property tax and land-use waivers;
- net metering and
- power purchase obligations for utilities.

#### **4.3.4.2.3 Crosscutting**

##### *Information*

Consumer awareness is very high in areas where there are biogas projects and very low in areas where there are no biogas projects. Results from a MME (2002) survey indicated that end-user acceptance of the technology is high. Acceptance is however low in areas where there are no biogas projects and people have many misconceptions about the technology. Although consumers are aware about the usefulness and performance characteristics of biogas systems, they have very little idea about the cost involved since systems are supplied free of charge in most cases.

##### *Institutional*

Biogas is a technology that has received considerable attention from the MME and agencies promoting RETs in the country (Atakora & Brew-Hammond). Biases within the energy sector favour this technology. There is enough private sector participation and adequate evaluation of social and environmental externalities for implementation of biogas programs. The single institutional barrier identified and that could have impeded any embryonic planning of large-scale biogas project is lack of interest of power utilities to bring on board any technology that does not have comparable costs to conventional systems in the country (Hagan, 1997).

#### **4.3.4.2.4 Stakeholders' Perspectives of Key Barriers to Biogas Technologies**

Opinions obtained from stakeholders in biogas with regards to key barriers affecting the business were mentioned as: *unfavourable policies, raw material availability, the right financing arrangements, absence of market and lack information* (KITE, 2002).

##### *Alternative to Overcoming Raw Material Barrier*

To overcome the raw material barrier biogas plants must be sited only at studied sites where resource availability is proven to be adequate at all times and where the focus is more on solving an environmental problem rather than an energy problem. Specific sites mentioned included abattoirs, public latrines, schools and hospitals. Dumping sites in cities/urban centres for domestic liquid waste have also been identified as appropriate centres for the siting large biogas plants.

#### *Managing the Financing Barrier*

Biogas projects in Ghana can benefit from funds from multilateral institutions e.g. Global Environment Facility (GEF), African Rural Energy Enterprise Development (AREED), United Nations Framework Convention on Climate Change (UNFCCC).

#### *Overcoming the Social Acceptance Barrier*

Involving the benefiting local communities early at the plant development phase can help overcome the social acceptance barrier that the technology tends to face in Ghana. Communities should as much as possible be encouraged to manage the project. This would not only help in acceptability, but also enhance sustainability of the plant once external support is no longer available.

Educating and creating awareness amongst the future beneficiaries of biogas projects can also be employed to tackle the social acceptability problem. This can be done by dissemination of information on existing projects to communities unfamiliar with the technology and provision of site visits to leaders of future project beneficiary communities.

#### **4.2.4.2.5.8 Recommendations**

Biogas projects might attract investment from a wider audience if programmes are packaged for sanitation or agricultural rather than energy programmes. Projects should be linked to institutions like boarding schools and hospitals to solve principally waste disposal problems. Biogas obtained can be employed to meet energy requirements for cooking and possibly lighting. Use of biogas for cooking is about 60% efficient compared to the 12% efficiency if it were used for electricity production (KITE, 2002). The residue which is a rich organic manure can be used on the institutions farms if any or sold to other farmers.

#### **4.3.5 Other Biomass Energy Technologies**

This section briefly examines two further biomass energy technologies namely: pyrolysis and cogeneration in use in Ghana. Detailed analysis was however not undertaken for these technologies primarily due to lack of data.

##### **4.3.5.1 Pyrolysis**

A six-ton pyrolytic plant fuelled on sawdust was set up to provide alternative fuel oil for brick kilns at the Building and Road Research Institute (BRRI) in Kumasi in 1980 (MME,

2000). BRRRI had financial assistance from USAID and teamed up with personnel from Georgia Institute of Technology (GIT), USA to set up this plant. This demonstration plant, which was only 6% to 13% efficient, is no longer in operation (Hagan, 1997).

#### **4.3.5.1.1 Evaluation and lessons learnt**

Problems encountered included poor supply of raw materials, inefficient drying of sawdust and manual process control leading to low yields. Lack of funds for major repairs and modifications was also a major problem.

#### **4.3.5.2 Cogeneration**

Two sawmills namely, AT&P (Samreboi) and Mim Timbers STP (Kumasi)-have been reported to be simultaneously producing heat and power using their processing waste (Atakora & Brew- Hammond, 1999).

#### **4.3.5.2.1 Evaluation and lessons learnt**

Firstly, low electricity tariffs prevailing in Ghana have been responsible for the extremely low level of this technology in the country (RDREG, 2002). All studies to date indicate that where electricity is priced at full economic cost, the economics of cogeneration is very attractive (KITE,1999b). For an example, a study by KITE (1999a) established that Maxwell Owusu Timbers could generate 1 MW of electricity all from their own wood processing residues, having an internal rate of return 21-27% with a discounted payback period of 5-7 years. Secondly, there are virtually no financial or fiscal incentives neither are there regulatory requirements encourages generation and sale of electricity into the grid.

#### **4.3.6 Energy Crops**

The main energy crop to be considered here is the *Jatropha Curcas*. In the future other energy crops can be considered and introduced depending on appropriate advice from ecologists as care must always be taken with the introduction and cultivation of foreign energy plant species into a locality. Experience has shown that certain plant species previously thought of as not being invasive proved otherwise and disrupted the ecosystem into which they were introduced (Henning, 1994).

The *Jatropha Curcas* is a drought-resistant perennial, living up to 50 years and growing on marginal soils (Henning, 1996). *Jatropha* seeds contain about 35% of non-edible oil. The production of seeds is about 0.8 kg per meter of hedge per year, with an oil yield of 0.17 litres (Henning, 1994). *Jatropha* hedges do not only protect farmlands and gardens from hungry livestock but also reduce damage and erosion from wind and water. It may be used as a check against desertification (Burn & Coche, 2001). Traditionally, in some African communities (e.g. Mali, Burkina Faso, Malawi, Zimbabwe and Ghana), the seeds are harvested by women and used for several purposes e.g. for running milling machines, lighting, medical treatments and local soap production. Recent research undertaken by the University of Hohenheim, Germany has led to the development of a *Jatropha* stove (Henning, 1998). Rural communities in Ghana and other parts of Africa with the *Jatropha* resource will be able to cook their food using these stoves thus meeting their energy needs and simultaneously protecting against the harvesting of already scarce woody bio resources for fuel.

This was especially selected because the plant is already found growing in the wild in Ghana. The *Jatropha* plant is not an invasive specie (Gübitz *et.al.* 1999) and permits the growth of other plants in its vicinity so it does not negatively affect the ecosystem but rather because it grows on marginal soils (where other plants can not thrive) it exert a positive impact by being pacesetters for the re-vegetation of otherwise barren soils.

#### **4.3.6.1 Comparison of the Physico-chemical properties of Diesel and *Jatropha* oil**

As shown in Table 4.3, with the exception of their solidifying points, flash points and percentage of sulphur, *Jatropha* oil is very comparable to diesel oil. The minute amount of sulphur present in the biofuel is environmentally preferable to that of diesel as sulphur dioxide emissions from the biofuel are very low. Biodiesel has a higher cetane rating than diesel, which improves engine performance. In its principal use, the biofuel is a potential replacement for conventional diesel. In contrast to conventional diesel, which is derived from a depleting energy resource, in the form of a fossil fuel, *Jatropha* grown in a sustainable manner could be seen as a potential renewable source of energy, which offers prospects for reducing the emissions of carbon dioxide (CO<sub>2</sub>) which, as a greenhouse gas (GHG), is implicated in global climate change.

Table 4.5 Physico-chemical properties of Petroleum Diesel and Jatropha oil

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

(Source: Schrimppf, 2002).

#### 4.3.6.2 The Jatropha and Economic Development Opportunities

It is important to investigate the possibilities of directly linking the renewable energy projects to prevailing economic activities in the benefit community. A typical example will be to link the Jatropha system to agriculture, where the biofuel will be employed to power irrigation systems. The cost of petroleum diesel in Ghana, is \$ US 0.64/litre at 2005 rates (Ghana's Official website, 2005). The production cost however for Jatropha oil is quoted between \$ US 0.45-0.60 [(Schrimppf, 2002), (Protzen, 1997)]. The higher cost of diesel coupled with its frequent unavailability due to the remoteness of a community might have contributed to the unattractiveness of any particular locality to consider an irrigation system that will have to run on diesel. Farming in most Ghanaian communities still depends solely on rainfall, which is not reliable, and the unpredictability of rainfall patterns is very frequent. Quantity and quality of harvest has been severely affected as a result.

Jatropha oil extraction can either be done domestically or industrially (Figures 4.4 & 4.5) using locally manufactured press [(Kandpal & Madam, 1995), (Openshaw, 2000)]. The extracted oil may be utilized by milling houses and light food industries in the processing of low cost fortified foods to meet nutritional needs of weaning children in particular (Ackom *et. al.*, 1998) as well the entire community on the whole.

Figure 4.4 Simple Home Based Jatropha Oil Press.



Figure 4.5 Locally manufactured Industrial Jatropha oil Press.



Improving the economic power of the rural Ghanaian communities will eventually lead to the next two points: (a) ability to pay for the investment that might lead to sustainability of project and the development system; (b) possibly stimulate environmental protection awareness. It can be said that most impoverished rural African communities, do not see the environmental protection as a need and thus not of significant importance as compared to economic empowerment, healthcare, food security and access to potable water. Therefore any energy programme to be introduced should really be targeted at helping alleviate some of

the above mentioned factors in addition to meeting energy needs other than crippling already impoverish communities with the burden of paying back for the investment cost of extremely expensive energy technologies having a rather low profitability index.

#### **4.3.6.3 Collaborative Development Model for Sustainable Jatropha Project**

In this model, the farmers need to form a local co-op to produce the energy in jointly owned facilities. The approach can increase profits by achieving economies of scale and scope in production and by gaining access to low-cost financing. It can also help strengthen rural communities.

#### **Development Model**

My development model is based on the working relationship between the community benefiting from the Jatropha project, a local technical NGO and a foreign development agency. Each entity has its respective and important roles that complement, harmonize and support one another leading to the ultimate success and sustainability of the project.

#### **The Role of the Foreign Development Agency**

The direct main responsibility of the development agency is to the local NGO (Figure 4.6) and must occasionally visit the community and projects. Their main role will be:

- a) To provide seed money and matching grants that can initiate and support the efforts of the NGO to raise the money needed for a project and/or provide capacity grants which help to build their organizational capacity.
  
- b) To popularize the NGO achievements in developing sustainable Jatropha energy systems and related environmental protection plans through the media, internet, and other written and visual sources (Sluijs & Bode, 2001). This will lead to support for more community-based biofuel projects internationally and give credence to the NGOs involved [(Sluijs & Bode, 2001), (Henning, 1996, 1998, 2000)].
  
- c) To facilitate trainings for NGOs such as; community surveys of power demand and potential usage, site selection, the budget process, choice of appropriate technology, environmental assessments, feasibility studies, civil design, operational & fiscal

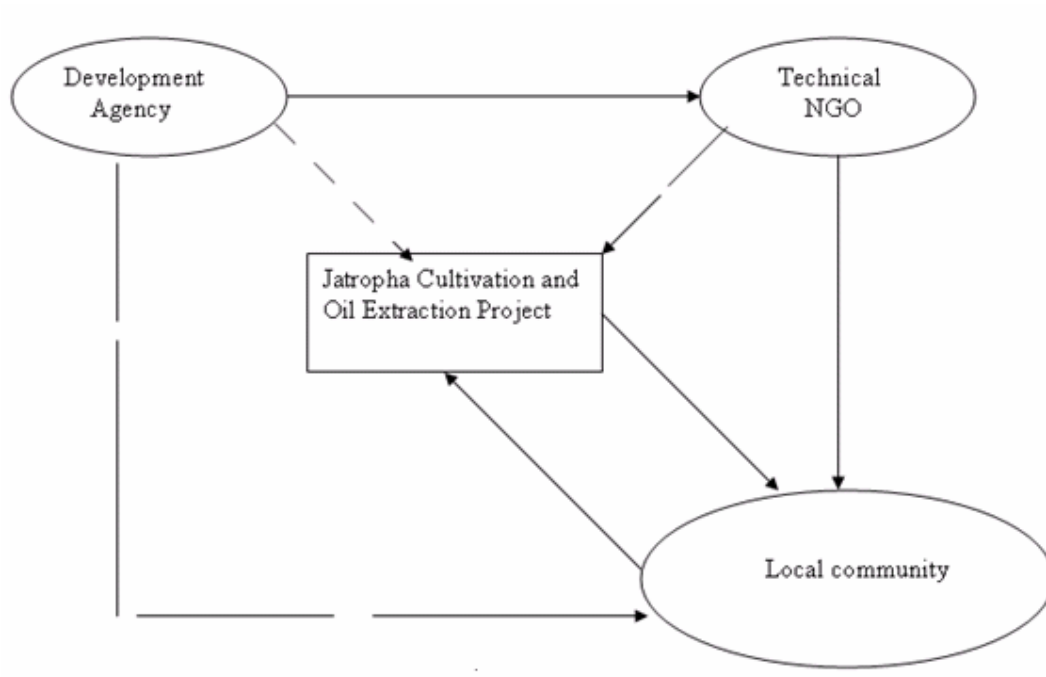


management, micro-enterprise development, long term planning, and grant writing (Sluijs and Bode, 2001).

**The role of the NGO**

The local NGO is directly responsible to the community in this model (Figure 4.6) but more directly involved in the energy crop cultivation and oil extraction than the development agency (as indicated by the number of broken lines in the diagram). This NGO must be able to assess the communities’ organizational capacity and their potential to complete and manage an energy project. The NGO should be able to provide technical, organizational advice, support and training to the community. It must determine the best source from which to buy project equipment for the community (Sluijs and Bode, 2001).

Figure 4.6 Development model for establishing sustainable Jatropha biofuel projects in rural African communities.



Ackom & Ertel, 2004

Key. — —> Partial responsibility\*  
 — —> Direct responsibility

\*The number of breaks in each arrow is indicative of the degree of responsibility.

**The role of the community**

The local community possesses direct responsibility towards the day-to-day running of the biofuel project (Figure 4.6). The commitment from the community includes: The need and

desire for the use of Jatropha to meet their energy needs. Even though involvement of both genders in a community is possible in this model, it however emphasizes particularly on the socio-economic empowerment of women, thus women groups will be specially utilized to manage the project as they are also the main gender responsible for the provision of energy needs in rural African communities. The role of the community should therefore be:

- Provision of land for Jatropha plantation and site for the establishment of the oil extraction unit.
- Experience (Sluijs and Bode, 2001) has shown that when development packages are given on a '*silver platter*' to local communities they sometimes fail to see the value of such projects and consequently relent in their commitment.
- Responsibility for the day-to-day management of plantation, including, cultivation, harvesting, extraction and sale of the oil.
- Commitment of human resources for project development such as unskilled labour (to handle farmlands), access to skilled labour (to repair broken down equipments etc).

In order to help the community in their quest towards sustainable development, it is very important that they should be the main recipient of all benefits accrued from the project.

Concluding, the Jatropha system can bring about major economic empowerment by providing income and employment opportunities to the rural communities. The system has successfully been promoted in Mali. Other countries such as Ghana, Burkina Faso, Malawi, Zimbabwe, Egypt, and India have also started to test the applicability of the Jatropha system to their locality. For example in Egypt, Jatropha is being cultivated on a 500 000 hectares of desert land which is irrigated by treated sewerage water (Jatropha, 2004). The Jatropha system can be utilized as a crucial element to stimulate a circular system combining ecologic, economic, and income-generating effects (Henning 1994), especially in drought prone rural African communities such as Ghana. The system promotes four main aspects of development which combine to help achieve a sustainable way of life for village farmers in terms of provision of renewable energy, erosion control, economic empowerment through job creation and poverty reduction. With appropriate assistance, communities will be able to generate sustainable economic opportunity locally and develop the bio-diesel resource.

## **CHAPTER 5 SOLAR ENERGY TECHNOLOGIES**

This chapter first of all explains the basic technical operating mechanism of three identified solar technologies namely, solar air heating, solar water heating and solar water pumping that are of potential economic importance to the situation. Detailed analysis of all commissioned solar energy/PV projects then followed with the goal to evaluate project performance and to learn from their success/failure experiences. Barrier analysis on these main solar energy technologies was undertaken. The chapter finally concludes with suggested recommendations for future projects based on models developed from RETScreen.

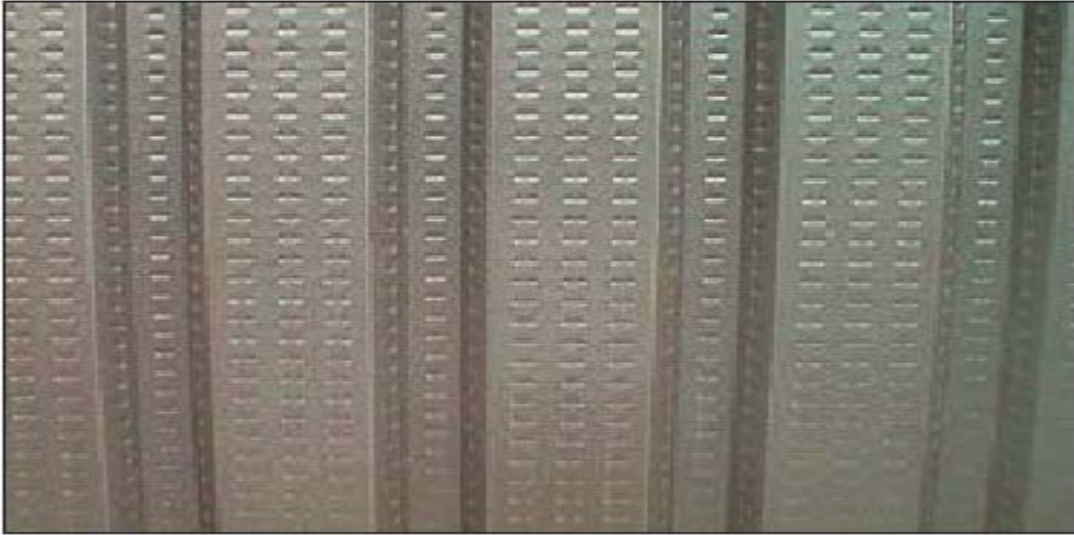
### **5.1 Basic Operating Mechanism of Solar Air Heating, Solar Water Heating and Solar Water Pumping.**

#### **5.1.1 Description of Solar Air Heating System-Industrial Application**

The solar air heating system consists of two parts: a solar collector mounted on the side of the building facing the equator and a fan and air distribution system installed inside the building.

A unique feature of the solar air heating system is that it uses a perforated plate (or transpired-plate) as the solar collector (Figure 5.1) eliminating the need for a glass cover, common in most other solar collectors used for heating purposes (IEA, 1999). Air is drawn through small holes in the dark coloured solar collector plate and is warmed as it passes over and through the plate. The air collects in a cavity between the solar collector and building wall and is ducted into the building (EMR, 1985). High-efficiencies are possible because the solar collector plate is only a few degrees warmer than the outdoor air (Carpenter *et.al.*, 1999). Therefore, there is little heat loss and most of the solar radiation is transferred to heat the air.

Figure 5.1 Transpired plate solar collector.



Solar process air heating systems are similar to ventilation air preheating systems (Duffie & Beckman, 1991). The perforated plate absorber is located in any convenient location that has good exposure to the sun. Sloped roofs as well as walls are suitable mounting structures. A constant flow of air is taken through the collectors and is ducted into the air intake of the process (IEA, 1999). If necessary, additional heat can be added from auxiliary sources to deliver the desired air temperature and some or all of the process air can bypass the collectors if the air is above the desired temperature (Carpenter *et.al.*, 1999).

As depicted in Figure 5.2, the solar air heating system interior components consist of a constant-speed fan, a recirculation damper system and a fabric distribution-duct. Perforated fabric ducting is a low-cost method of delivering make-up air throughout the building (IEA, 1999). A recirculation damper system incorporated into the fan compartment mixes warm indoor air with cooler solar collector air to maintain the constant delivered air temperature. The ratio of indoor (recirculated) air to solar air heating system (outdoor) air varies continuously with changes in the solar collector outlet air temperature, while a duct thermostat operates the damper system (Carpenter *et.al.*, 1999).

Drying of agricultural products is a good application for solar energy, as the required temperature rise must be kept relatively low to prevent damaging the crops. Those crops that are harvested continuously over the year are well suited because all the available solar radiation can be used. Solar systems can also serve as a preheater to (high temperature) industrial drying systems.

Figure 5.2. Solar Air Heating System Schematic.

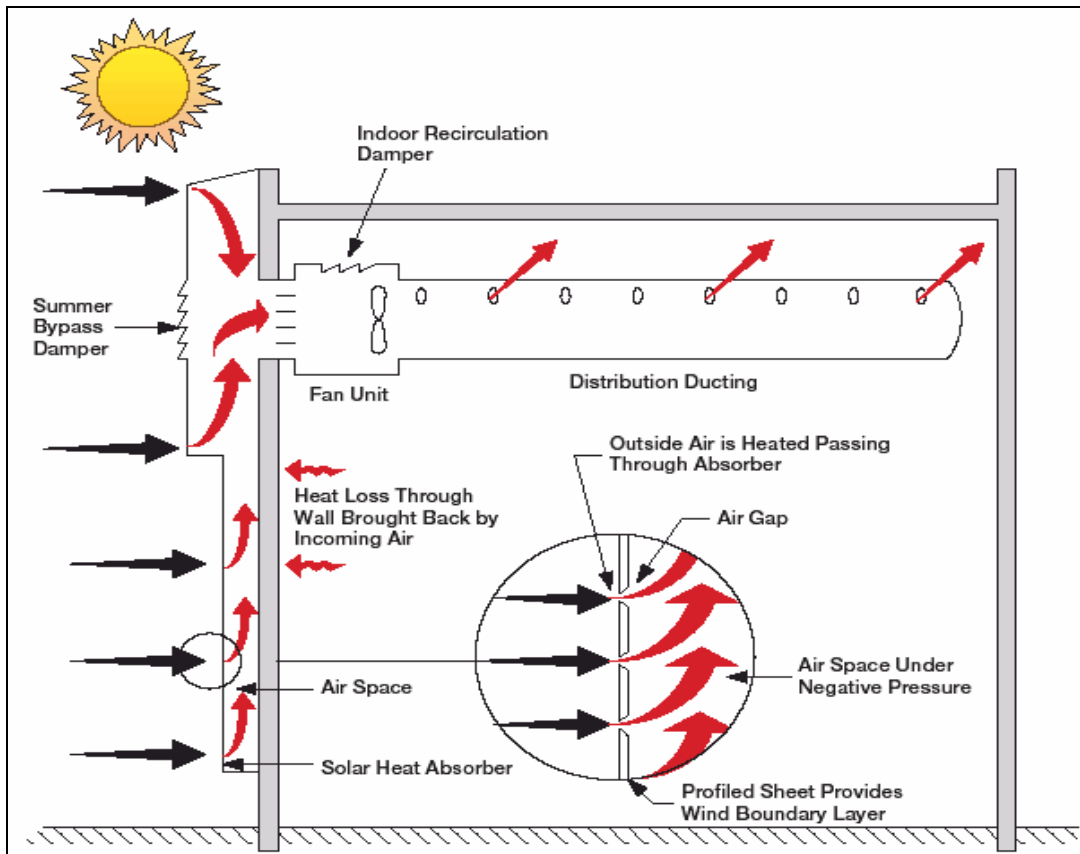


Photo credit: Enermodal Engineering

### 5.1.2 Description of Solar Water Heating Systems

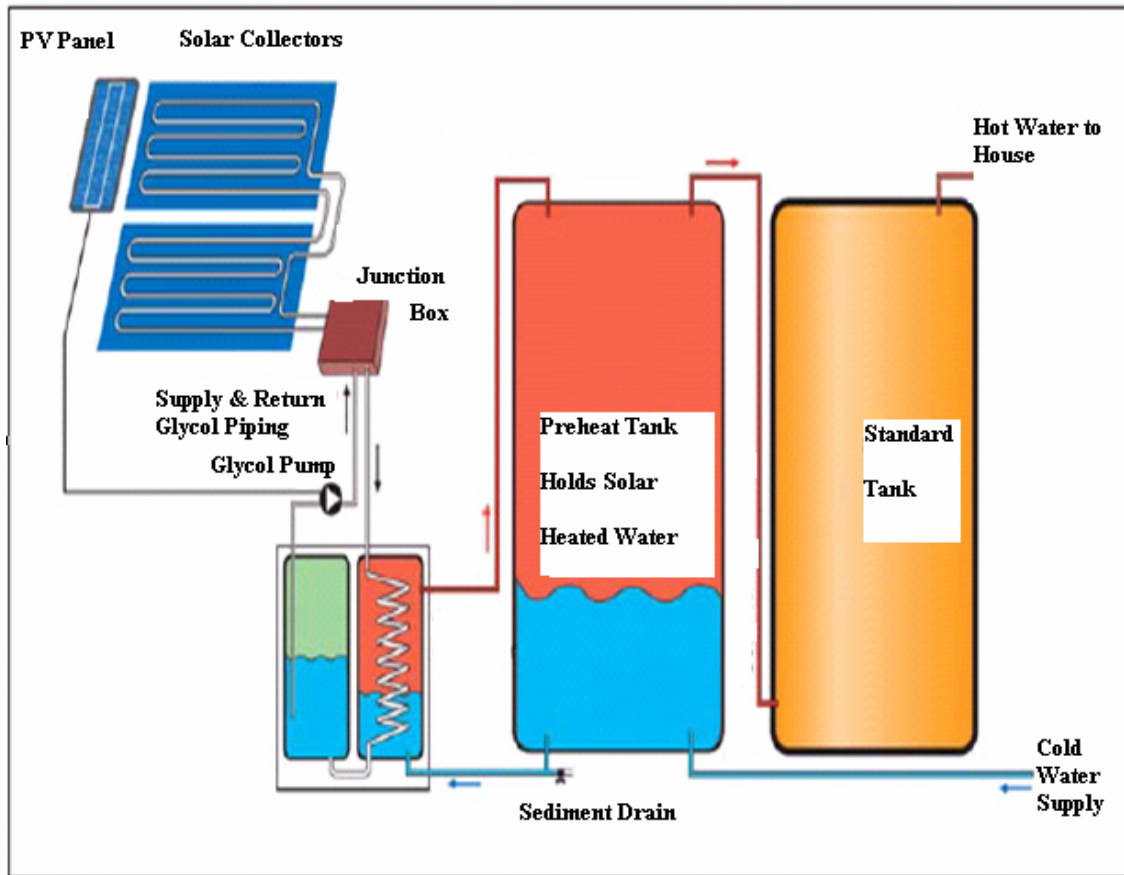
Solar water heating systems use solar collectors and a liquid handling unit to transfer heat to the load, generally via a storage tank. The liquid handling unit includes the pump(s) [used to circulate the working fluid from the collectors to the storage tank] and control and safety equipment. When properly designed, solar water heaters can work when the outside temperature is well below freezing and they are also protected from overheating on hot, sunny days. Many systems also have a back-up heater to ensure that all of a consumer's hot water needs are met even when there is insufficient sunshine. Solar water heaters perform three basic operations namely collection, transfer and storage as shown in Figure 5.3.

**Collection:** Solar radiation is “captured” by a solar collector;

Solar energy (solar radiation) is collected by the solar collector's absorber plates. Selective coatings are often applied to the absorber plates to improve the overall collection efficiency. A thermal fluid absorbs the energy collected Figure 5.3. There are several types of solar

collectors to heat liquids and election of a solar collector type depends on the temperature of the application being considered and the intended season of use (or climate). The most common solar collector types are: unglazed liquid flat plate collectors; glazed liquid flat-plate collectors; and evacuated tube solar collectors.

Figure 5.3 System Schematic for Solar Water Heater.



**Transfer:** Circulating fluids transfer this energy to a storage tank; circulation can be natural (thermosiphon systems) or forced, using a circulator (low-head pump); and

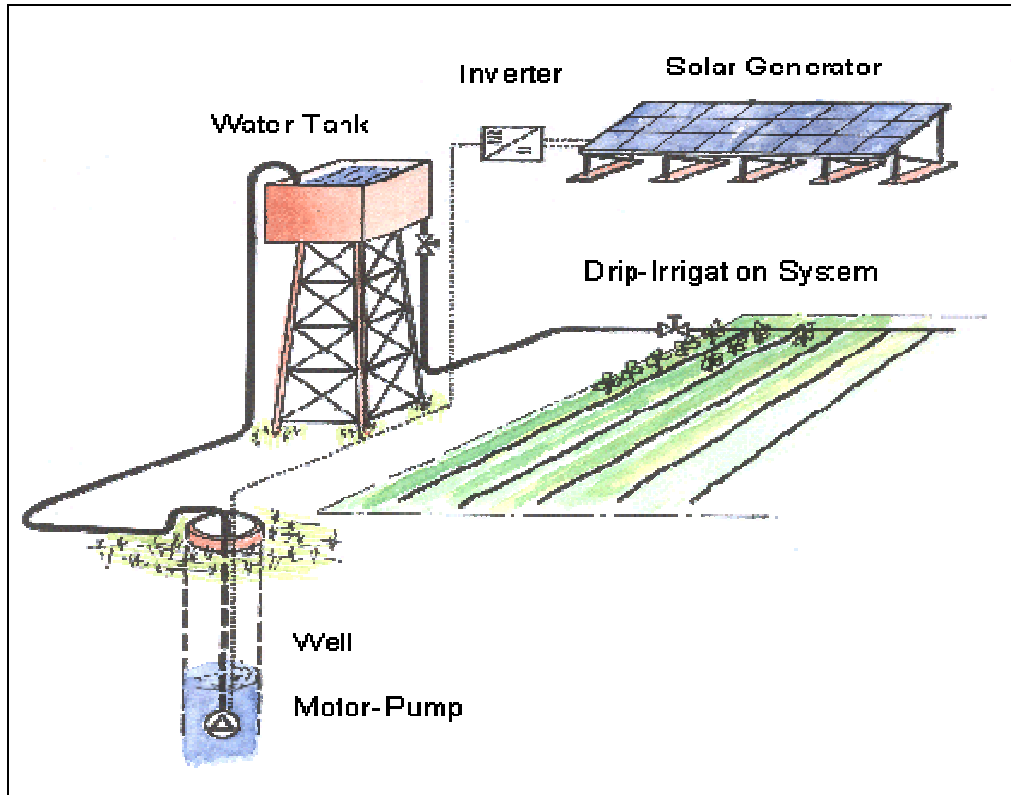
**Storage:** Hot water is stored until it is needed at a later time in a mechanical room, or on the roof in the case of a thermosiphon system.

### 5.1.3 Functional Principle of Solar Water Pumping

The functional principle behind any photovoltaic irrigation system is illustrated in Figure 5.4. The solar generator provides electricity for driving a submersible motor pump, which in turn

pumps water into an elevated water tank. The water tank bridges periods of low insolation and supplies the pressure needed for the irrigation system. One major advantage of solar pumps is that they do not require electrical batteries which are expensive and need a lot of maintenance. Force of gravity causes the water to flow from the tank to the fields.

Figure 5.4 Functional principle of a solar water pump system.



Drip irrigation enables the economical use of water, and its relatively low operating pressure makes it particularly well-suited for combination with photovoltaic pumping systems.

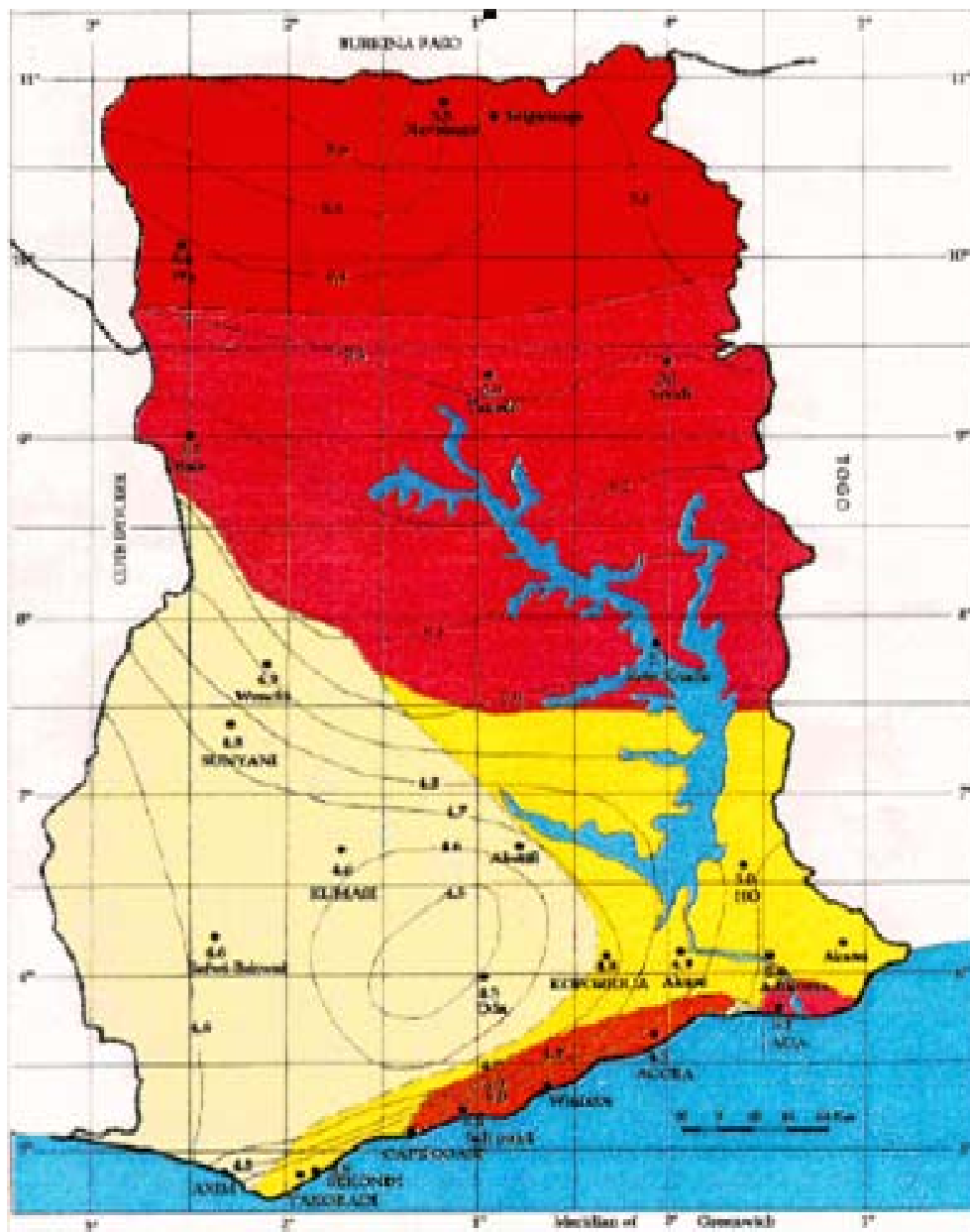
## 5.2 Solar Resource Assessment in Ghana

As mentioned in Chapter 1, Ghana is a tropical country located between latitude  $4^{\circ}$  and  $12^{\circ}\text{N}$  and longitude  $30^{\circ}\text{W}$  and  $1^{\circ}\text{E}$  and is well endowed with solar energy resources, receiving daily solar irradiation of between  $4$  and  $6\text{kW}/\text{m}^2$  and a corresponding annual sunshine duration of 1800-3000 hours.

The Ministry of Mines and Energy has developed a solar map for the Ghana and this is useful for the design and installation of solar systems. The map (Figure 5.5) shows that most of the Southern parts of the country have very high diffuse radiation levels (over 45%) with the North having moderate levels of diffuse radiation (between 32 and 45%).



Figure 5.5 Solar radiation map of Ghana.



**LEGEND**

<div style="display: flex; flex-direction: column; gap: 10px;"> <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; background-color: red; margin-right: 5px;"></div> <div>Very low Diffuse Radiation (32%)</div> </div> <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; background-color: pink; margin-right: 5px;"></div> <div>Low Diffuse Radiation (36 -40 %)</div> </div> <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; background-color: brown; margin-right: 5px;"></div> <div>Moderate Diffuse Radiation (41-45 %)</div> </div> </div>	<div style="display: flex; align-items: center; margin-bottom: 10px;"> <div style="width: 20px; border-bottom: 1px solid black; margin-right: 5px;"></div> <div>Global (Total) Radiation (kWh/m<sup>2</sup>/day)</div> </div> <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; background-color: yellow; margin-right: 5px;"></div> <div>Very Diffuse Radiation (45-48 %)</div> </div> <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; background-color: lightyellow; margin-right: 5px;"></div> <div>Very High Diffuse Radiation (48-55 %)</div> </div>
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(Source: KITE, 2002).

## **5.3 Study Analysis of PV/Solar Technologies in Ghana**

### **5.3.1 Solar Thermal Systems**

#### **5.3.1.1 Evaporative Cooler for Food Storage**

This project, managed by the Department of Mechanical Engineering at KNUST, utilized passive cooling techniques (evaporative cooling) for preserving agricultural produce. The project was conceived in 1974 by two members of the department and received funding in 1979 from the Cooperative Programme in Alternative Energy Resources. Sponsorship was also received from the Federal Republic of Germany through the German Agency for Technical Cooperation, *Gesellschaft für Technische Zusammenarbeit* (GTZ).

The primary object of the project was to design, construct and test systems, which utilise alternative energy sources. The second object was to select and develop promising models into prototypes for field demonstration and evaluation.

##### **5.3.1.1.1 Findings and lessons learnt**

The results of the project indicated that even under humid tropical conditions, the passive evaporative cooler could be successfully employed to inhibit the ripening rates of matured green plantain and tomatoes. The quality of chamber-ripened items was better as compared to those ripened naturally. However, the cost of the materials required for the construction of the unit was too high for the ordinary farmer. It was recommended by Akuffo & Kwame (1983) that the cost of the system can drastically be reduced by substituting the galvanized sheets with locally available materials such as bamboo platforms.

##### **5.3.1.2 Ministry of Mines and Energy's (MMEs) Solar Thermal Projects**

The MME installed two pilot scale solar crop dryers. These systems worked successfully and are currently being utilized by a private company Cashpro, which dries crops for export. Effective strategies are being formulated to diffuse the technology and encourage its commercialization (MME, 1998).

The Ministry has also embarked on pilot projects to demonstrate the feasibility of deploying Solar Water Heaters (SWH) in the commercial and domestic sectors of the economy. This effort is expected to lead to the formulation of a comprehensive information database on hot

water generation and utilization patterns in Ghana. An educational institute, the Abetifi Vocational Institute, was then contracted to produce and install 30 SWHs with a total capacity of 2,100 litres in 4 hospitals in Ghana (Tse, 1999).

#### **5.3.1.2.1 Evaluation and lessons learnt**

The SWHs manufactured by the local institute produced hot water of average temperature 49<sup>0</sup>C in the afternoons and 35<sup>0</sup>C in the mornings. The maximum temperature recorded was 63<sup>0</sup>C. Unfortunately no hot water was produced by the system during cold days, the output of hot water in the mornings is low, very much to the disappointment of users.

#### **5.3.1.3 The Cyliandro-Parabolic Solar Collector Project at KNUST**

The solar energy laboratory of the Department of Mechanical Engineering, KNUST, in collaboration with STEVEN Foundation of the USA embarked on a project, which involved the construction and testing of cyliandro-parabolic solar collectors. These concentrator collectors were meant to generate steam and ammonia for a solar pump and refrigerator respectively.

#### **5.3.1.3.1 Evaluation and lessons learnt**

The device could provide 4 hours of pumping on a clear day and could also be used for cooking within the period of 11am and 4pm. The project failed to make any major impact on the society possibly due to the fact that the technology was sophisticated and expensive (Obeng *et. al*, 1986), additionally it might also have been due to the fact that they were not reliable in terms of being able to meet the cooking needs when most needed.

### **5.3.2 Solar PV Systems**

Projects employing PV technology in Ghana include:

#### **5.3.2.1 The DANIDA/Ministry of Health (MOH) Solar Project**

Main beneficiaries for this project were remote areas, particularly in the Upper West Region in Ghana. Under this project, the MOH received solar energy units in hospitals and clinics in 9 regions of the country. The project installed 15 solar refrigerators, 4 solar water pumps and 14 solar water heaters and solar powered communication devices in 29 different sites. In addition most of the sites were equipped with 3 portable solar powered lights, each comprising a 14W panel and a rechargeable fluorescent light. The project is wholly

supervised and implemented by DANIDA personnel in close collaboration with Danafco Engineering (DENG), a local firm.

#### **5.3.2.1.1 Evaluations and lessons learnt**

The impact of this project has been felt very strongly on storage of vaccines remote communities (Ampofo, 1998). This has provided strong supports for Ghana's vaccination campaign, which include mobile programmes where ice packs are needed to preserve vaccines. The solar pumps and heaters installed so far have almost been problem-free (Akuffo, 1998). Three different solar heaters have been installed. These are Solarhart, Alpha and DENG. In terms of efficiency, the Solarhart system has proven to be the best, and then is Alpha. The main problems encountered in this project are bad co-ordination, poor installations and lack of consistent leadership (Akuffo, 1998). There is also lack of co-ordination between technical advisors and administrators of the project; a commonly identified situation was equipment purchasing and sub-contracting (MME, 1998). This has resulted in many faulty and poor installations by incompetent contractors resulting in frequent equipment failures. Frequent change and /or transfer of leadership have also created distortions in manning and supervision (KITE, 2002).

#### **5.3.2.2 CIDA-University of Regina/UST Renewable Energy Project.**

The project started in 1992 with an overall goal of strengthening the capacity and capability of KNUST to respond more effectively to national developmental priorities and aspirations, particularly the practical implications of rural development as well as the need for self sustaining economic growth (Catania and Kessey, 1988). This project is a combined effort between the University of Regina, Canada and KNUST, Ghana with funding provided primarily by the Canadian International Development Agency (CIDA). The purpose of the project was to transfer essential skills through teaching, on-the-job training, field training and developmental research activities in areas of biomass, biogas, solar, energy policy and planning, socio-cultural-economic and environmental issues, as well as extension and community outreach programmes.

The project has established Solar Service Centres (SSC) in three communities in the country. The following are the major achievements of the project (AFREPREN, 2002):

1. The project has designed and installed solar battery charging services including solar distilled water plants at the SSCs in the three communities. Small solar home lighting

systems (SOHLS) and battery operated home systems (BOHS) have also been sold under a hire purchase scheme to people in the pilot areas.

2. The project has designed, manufactured and sold nearly 100, 18W fluorescent lamps, 100 battery cut-outs (LVD) and 60, 5W halogen lamps. The traditional kerosene lantern has been modified to operate on solar charged batteries (K-electric lantern).
3. Following the success story of the pilot centres, the MME in 1997 and 1998 contracted the project team to build two SSCs at Appolonia in the Greater-Accra Region and Wechiau in the Upper West Regions of Ghana. The Wechiau centre has battery charging facilities, lights, TV, radio, fan, and solar distillation units. Forty-one domestic homes at Wechiau have also been equipped with BOHS on hire purchase basis.
4. In collaboration with NGOs such as the Energy Research Group (ERG) and Ghana Solar Energy Society (GHASES) and with the support of MME, the project has organized training workshops for technicians, engineers, entrepreneurs and some 'solar enthusiasts'.

#### **5.3.2.2.1 Key findings and lessons learnt**

The project established that using solar PV to charge batteries for TV and radio operation was financially profitable and therefore carried out the installation of centralized battery-charging stations. However, the earnings from the battery charging centre was very low even with 2 lines each capable of charging a 50AH battery daily (AFREPREN, 2002). It was found that this was due to the fact that nearly all the batteries were old unserviceable car batteries (KITE, 2002). The project therefore decided to offer hire purchase scheme for co-operative members to acquire new batteries.

#### **5.3.2.3 TU-Berlin/UST Solar Pump Project**

The mechanical engineering department of KNUST in mid 1995 received a GTZ grant to construct, install, test and evaluate the performance of a PV radial flow centrifugal water pump in collaboration with the Technical University of Berlin, Germany (AFREPREN Data Base, 2000). The aim of the project is to identify and recommend a suitable solar powered irrigation pump for rural communities. The research team has so far designed and fabricated a centrifugal pump, which is being run in a test tank on a 330W DC motor. A 600W PV

array supplies power to the motor and also to electronic measuring devices and data loggers (William, 1998).

#### **5.3.2.4 The Wechiau Project**

This is a National Solar Energy Programme to assess, demonstrate and evaluate the technical, economic and social viability of appropriate solar technologies to support the government's rural development programmes. The project is demonstrating and evaluating the concept of integrated solar power in Wechiau, a village in the upper west region through a government fund worth \$ US 11,149.90 [using 2002 exchange rate of \$1 US = ¢ 7,533.70]. The project was implemented with the support of KNUST.

#### **5.3.2.5 The Spanish Solar Project**

The Spanish government offered MME a concessionary loan of \$ US 5 million to implement off-grid solar electrification in 10 villages. As at 1998, 975 home systems had been installed in 5 villages. A total of 1600 home systems, 5 school systems, 4 community systems, 2 solar pumps and 200 streetlights were expected to be installed (MME, 1998). The systems are being offered to households on fee-for-service basis (KITE, 2002).

#### **5.3.2.6 The UNDP/GEF Project**

The project involves preliminary studies for using solar energy to electrify 13 remote villages in the Mamprusi East District in the Northern region through encouraging the adoption of new technologies. Primarily PV and PV/diesel hybrid power systems are being employed. These technologies are used for individual applications and centralized electrification of off-grid communities not technically or economically viable for electrification through the national grid extension. GEF is providing a grant of \$ US 2.5 million whilst the Ghanaian government is contributing \$ US 0.5 million (MME, 1998). The project was conceived as a pre-investment project, designed to spearhead future investments by private sector or in public-private partnership, in rural energy and infrastructure service companies. The project is scheduled to be implemented over a four-year period, i.e. 1996-2000 (MME 1998; Abavana 1999).

It is anticipated that the impact of the project will include the establishment of Africa's second private sector renewable energy-based rural energy services company (RESCO), to

provide electricity services to off-grid communities for household, community, and economically productive issues (Akuffo, 1998).

Computer simulations have been conducted at the National Renewable Energy Laboratory (NREL), USA using local climatic data to design various electric generators. The household energy/economic survey indicated that the inhabitants of the selected communities are willing and capable of paying for a variety of desirable and useful energy services (Abavana 1999). This survey however raises several interesting questions especially with regards to how the investment was going to be paid and as to whether the local community is really able to pay for the service. One can easily recollect the Ghanaian government rural electrification project where the grid was extended to very remote communities which turned out that they were not even able to pay for the service,

#### **5.3.2.7 Streetlight Projects**

Forty-six solar streetlights have been installed on three university campuses by MME to determine the feasibility of using them to replace conventional streetlights (MME, 1998).

#### **5.3.2.8 The Thermiosiphon Solar Water Heater Project at KNUST**

The solar energy laboratory of UST constructed and tested a thermiosiphon solar water heater. The average temperature obtained was about 55<sup>0</sup>C between 8am and 4pm and the heat loss during the night was not significant (MME, 1998). An analytical model was further developed to predict its long-term performance and hence its economic viability (Tse, 1999). The project failed to make an impact on the commercial sector due to the fact that it was set up purely for academic purposes (Akuffo *et. al.*, 1988).

#### **5.3.2.9 The Ministry of Health's Solar Refrigeration Project**

The Ghana Supply Commission in 1987 signed an agreement with the Swiss company RJM to supply 30PV refrigeration systems (PVR) to the Ministry of Health (MOH) [(KITE, 2002)]. The equipment was supplied that same year but the company RJM wound up its activities and operations in 1989 and appointed the local agent RELTUB to do the installation however, three months after the installation of the PVRs, they all ceased to function (Williams, 1999). A consultant appointed by the WHO to review the systems recommended that parts of the PVRs be replaced with new ones. Through the World Bank, MOH requested UNICEF to order new replacements (Pupulampu, 1992). The main causes of the PVR failures were found to be due to low quality equipment, wrong installations, and poor user

training to handle the equipment. Measures taken by the MOH to rectify the problems yielded great dividends due to improved supervision and a proficient technical framework to support such a project (MME, 1998).

#### **5.4 Barriers Analysis for Solar Technology**

Out of the many solar technologies reviewed earlier in this chapter, three in particular-Solar Crop Dryers (SCDs), Solar Water Heaters (SWHs), and Solar Water Pumps (SWPs) have been selected for detailed barrier analysis. All three solar technologies were selected on the basis of their potential contributions to economic development and the fact that a substantial amount of work has already been done by various stakeholders on these technologies.

SCD were selected on the basis of their potential contribution to the development of Ghana's agricultural sector while SWH were selected for their potential contribution in helping reduce electricity demand associated with water heating in the residential, commercial, and industrial sectors of the economy. SWP were also selected in view of the crucial need for cost-effective water supply systems in rural as well as urban communities.

##### **5.4.1 Solar Crop Dryers (SCD)**

Most harvesting of crops take place in the wet season, which is characterized by high humidity levels and therefore a major challenge to SCD since the reduction of moisture is the key factor in crop drying.

###### **5.4.1.1 Technology**

SCD are immature technologies are still undergoing R&D by researchers. There remain quite a number of intrinsic technical challenges of SCDs as compared to conventional drying systems (KITE, 2002):

- The relatively large area-to-energy ratio of SCD present challenges where land area is a limitation;
- SCD are generally slower than conventional systems such as gas dryers. This is especially true of small dryers. Large dryers (3 tons and above) have a scale advantage but require more land space and effective air circulation techniques;
- Forced convection SCD normally employed on large systems require auxiliary power supply such as electricity from solar panels. These types of dryers are



needed in humid environments of the rain forest area, which happen to the major farming areas;

- The durability of most SCD is threatened by compromising robustness with cheaper materials;
- The type of SCD selected for a particular purpose is crucial. Potential users in Ghana are however not exposed to a reasonable range of SCD types;
- There is no proper framework to provide expert technical services to users and potential users.

A survey on users of locally manufactured SCDs found a technical flaw with the KNUST dryers in that they had poor ventilation and absorber system (MME, 1998), which permitted microbial infestation of produce being dried in the SCD. However the flaw was minor and the entrepreneur was able to modify the design to improve performance with the help of local carpenters. A large cash group marketing company, employing large-scale KNUST SCDs, with a capacity of 2-5 tons for drying pepper was generally satisfied with the dryer when interviewed by KITE (2002). He however identified three main barriers including technology itself and suggested the addition of heat absorbers and a fan to improve the technology.

#### **5.4.1.2 Economic**

There is very little market dynamism, in terms of the demand and supply for this technology. There is lack of demand, which stems mainly from various bottlenecks associated with the barriers discussed above. The supply side is also virtually non-existent, with only a few research institutions undertaking prototype tests and limited field of demonstrations.

#### **Cost-Benefit Analysis**

There has been limited analysis of the costs and benefits of Solar Crop Dryer in Ghana (KITE, 2002). For the purposes of this study, cost benefit analysis (CBA) for a 5 ton KNUST solar crop dryer was undertaken (Table 5.2). The capital cost of the dryer is \$ US 3,185.69. The rate of drying of pepper and maize was assumed to be 2 days per maxi-bag capacity. Based on this and taking care of contingencies, we assumed that 100 batches of dried produce would pass through the dryer yearly. If ¢ 27 is charged for each kg of produce [\$ US 0.003584/kg], annual revenue will be ¢ 13.5 million. With operating and maintenance

charges of \$ US 318.60 (assumed to be 10% of capital cost), the annual profit will be \$ US 1,473.38, yielding a simple payback of a little over 2 years.

Table 5.2 Financial Analysis of a 5-tonne KNUST Solar Crop Dryer

Capacity of dryer = 5,000 kg

Cost of Drying Crop = \$ US 0.003584/kg (27 ¢/kg)

Capacity cost of Dryer = \$ US 3,185.69

Discount rate = 36 %

Annual O & M = \$ US 318.60

Annual Profit = \$ US 1,473.38

IRR = 36 %

NPV @ 36 = 36 %

Year	0	1	2	3	4	5
Revenue (\$ US)	-1,473.38	1,473.38	1,473.38	1,473.38	1,473.38	1,473.38

[Source: KITE, 2002 (with modification)]

The 2002 (January, 1<sup>st</sup>) exchange rate of \$1 US = 7, 533. 70 Ghanaian cedis (¢) was used for the currency conversion. 36 % is the discount rate offered by local banks on loans (KITE, 2002).

Similar results of a highly viable investment were obtained from RETScreen analysis for SCDs (refer to Solar Crop Dryer, Kumasi Appendix). In this analysis net present value (NPV) of \$ US 995 762, pre-tax internal rate of return (IRR) of 190.3% and a profitability Index of 16.93 were obtained even at a high discount rate of 36%. These results indicate that SCD are very viable with promising prospect in the Ghanaian environment.

With regards to other barrier analysis, it was found that there were no social problems with regards to acceptability of SCDs in areas where they are utilized. However, it was found out that limited information was known of SCDs in most rural communities (KITE, 2002). It was also found out that there was capacity limitation in terms of manning even the very few field SCD installations.

A recent survey (KITE, 2002) to determine awareness of SWH in hotels came out that most of the hoteliers interviewed were not aware of SWHs let alone to understand the immense benefits of SWHs towards energy saving retrofitting.

#### **5.4.2 Solar Water Heaters (SWH)**

Solar water heating systems fall into two basic categories; passive and active. SWHs can be an effective way to produce over 60% of a household's yearly hot water needs in a tropical country such as Ghana (Akuffo, 1998). Modern SWH are capable of providing reasonable services for most parts of the year. The demand for hot water in Ghana is highest in the mornings and evenings when the weather is relatively colder. This implies that an insulated storage tank is necessary to compensate for the demand and resource availability mismatch. A battery system can also be couple to the SWP to store the electricity generated during the day and to release it for water heating at nights and early mornings when irradiation is low.

Another limitation to the resource is that, the supply of hot water goes down during the rainy season because insulation is low. A doctor at a hospital in the Upper Region who was interview identified this to be a real problem because the hospitals hot water needs are not met during these periods (KITE, 2002).

The northern regions of Ghana have the best year-round solar radiation and provide the best opportunities for the utilization of stand-alone SWH. SWH face a bigger challenge down south (with the exception of the southern fringes) especially in the forest zones where high humidity and cloudiness result in a lot of diffuse solar radiation.

##### **5.4.2.1 Technology**

Locally manufactured Solar Water Heaters (DENG), compete favourably with foreign ones like ALPHA and Solarhart [(Tse, 1999), (Fagbenle, R., 2001)]. On the manufacturing side, local expertise and materials exist for producing thermosiphon heaters (Tse, 1999). These SWH are easy to construct but look cruder and bulkier than imported ones. Also, regular maintenance is required on the copper-pipe plumbing systems, which are susceptible to corrosion and blockage due to mineral deposits. Other newer technologies like multi-cross flow channels, employed in the Solarhart SWHs required more sophisticated production techniques and repair skills (KITE, 2002).

Another barrier worth noting is the general lack of perception on how to integrate SWH into existing water heating systems. By providing preheated water, for instance, SWH can achieve substantial energy savings in commercial and domestic kitchens but there is limited expertise in the design and construction of such integrated systems.

#### **5.4.2.2 Economic**

The market for SWH is yet to gain momentum (Akuffo, 1998) in Ghana since alternative sources of energy for heating water are relatively cheaper and readily available. The current high cost of SWH is also a major deterrent to its market penetration. Market penetration of SWH for domestic usage has potential amongst the middle and upper classes of society (MME, 1998, 2000). The technology has not been tested in industrial and commercial sectors of the economy where it could either replace existing systems based on conventional energy or serve as pre-heaters. However one of the very first commercial sector application of SWH (Figure 5.6) is underway to supplement hot water needs of a three star modern hotel, the Golden Tree (located at the HIPC Junction, Tetteh Quashie Roundabout, Accra) in Ghana.

The biggest barrier to SWH is the high upfront costs and there are currently no financial incentives to promote their development. Demand for SWHs is marginal and will continue to be so till the cost drops and or tariff goes up. A cost-benefit analysis was prepared for a 200-litre DENG SWH to give an idea of the economic performance of SWH (Table 5.3).

Figure 5.6 One of the very first commercial applications of SWH in Ghana.



(Photo credit: Ackom, 2004)

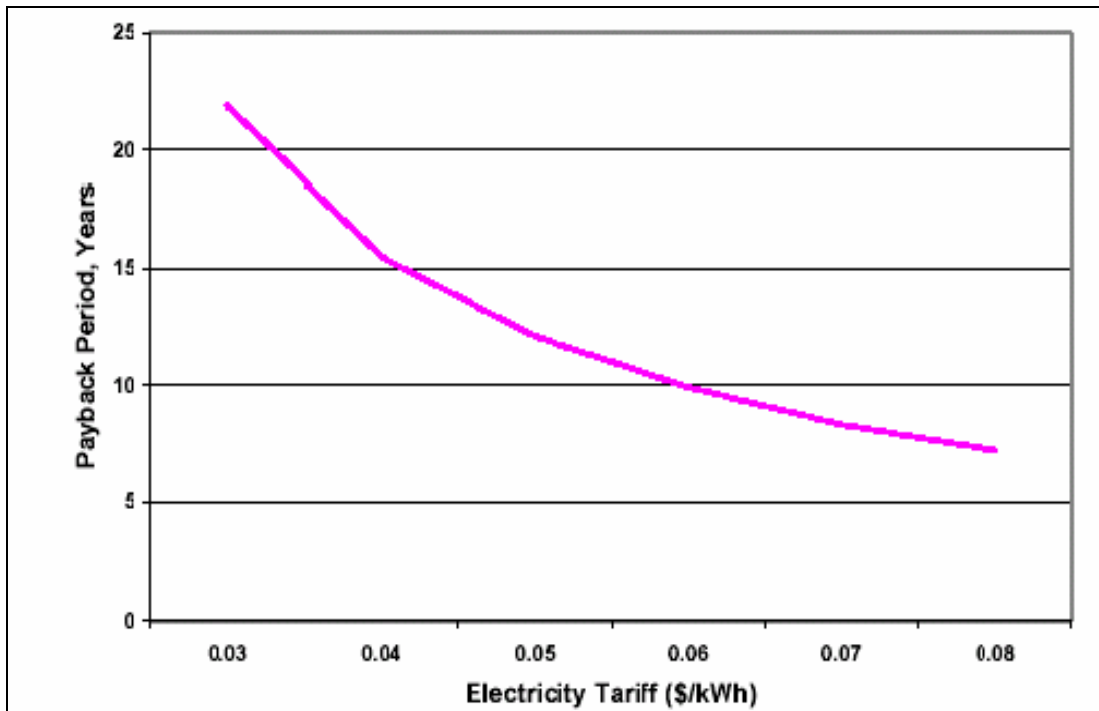
Table 5.3 Cost Benefit Analysis of 200-litre DENG Solar Water Heater

Wattage of Conventional Water Heater	2 kW
Operating time	4 hours/day
Energy Savings due to SWH	70 %
Average installed costs	\$ US 1,100
Electricity tariff, cents/kWh	\$ US 0.04 /kWh
Annual O&M (1% of capital cost)	11
Annual costs of heating water	87.6
Annual gross savings,	\$ US 61.3
Net savings	\$ US 50.3
<b>Payback period</b>	<b>22 years</b>

(Source: KITE 2002).

As can be seen from Table 5.3, the payback period of the DENG SWH is about 22 years, which is too long from a purely economic standpoint. The payback period will however decrease with increasing tariffs as shown in Figure 5.7. Thus higher tariffs can significantly increase the attractiveness of SWH to potential investors.

Figure 5.7 Payback curve for DENG Solar Water Heater.



(Source: KITE, 2002).

Pertaining to other barrier analysis of SWHs, it can be said that social acceptability of SWH varies according to the degree of exposure to the technology by end-users. Because of the high initial upfront cost, market for SWH in residential homes may exist only among high class citizens. The poor to middle class will not be attracted to SWH since cost of electricity and also for an electric heater is really cheap. Besides the cost aspect there is also the low awareness level of the public to SWHs. Additionally there is capacity limitation to handle SWHs. Some of the institutional barriers associated with SWH have been identified by KITE (2002) as

- There are no representatives of MME at district levels to initiate, coordinate and monitor SWH
- Low budgetary allotment
- Insufficient support from government policies

The lack of commitment by the government to SWHs may possibly be due to the fact that it does not see the viability of SWHs in the Ghanaian energy mix and which is very logical.

### **5.4.3 Solar Water Pumping**

Solar Water Pumping can be used during the day to pump water for agriculture; to livestock and or irrigational needs. Prudent agricultural knowledge has it that it is better to irrigate farmlands in the mornings or evening when temperatures are relatively lower. This is due to the fact that during the afternoons in a hot tropical country, the soil is heated by the scorching sun and drops of water from irrigation activity on the hot soil will subsequently lead to release of heated vapour, which cooks the crops and its roots thus killing them. However it is during the day that the system receives enough radiation from the sun to pump out water and to irrigate farm lands. The electricity generated during the day can be stored in the back up system i.e. battery and the energy released when needed, that notwithstanding the transfer of electricity between the two systems is associated with significant losses.

Additionally demand for water for domestic usage is highest in the mornings and evenings when radiation from the sun is low. This characteristic often necessitates a storage tank to compensate for the demand and resource availability mismatch. Thus storage tanks are needed for both situations.

#### **5.4.3.1 Technology**

Though there are no limits to how large a solar pump can be built, smaller installations generally require low capital outlay and are easier to install and maintain and requires less skills. Larger pumps on the other hand have more sophisticated components such as inverters and switches and require specialised skill for maintenance and installation. This skill may be lacking in the rural areas where the technology might have a niche. There has been a number of local R&D on SWP, however this has not had much impact on the dissemination of SWP in Ghana.

#### **5.4.3.2 Economic**

There is little development of the SWP market which involves only one company. Most SWP in Ghana were provided through donor support. The market situation might positively change when SWP is packaged together with other viable end use activities e.g. in agriculture for pumping water to irrigate crops. This integrated energy/agriculture system will ensure a bumper harvest, subsequently leading to improved economic status for farmers, who then will be able to pay back the energy investment. Since low operation and maintenance cost are associated with solar technologies in general, more revenue will be accrued in the

medium to long term of the 25-30 year life span of the project, which can be re-invested to expand the system-this eventually might lead to sustainable development at the rural community level. That notwithstanding however, considering the high upfront cost and lack of capacity in rural communities, other low cost systems (Jatropha) may be preferable options to consider (as explained in chapter 3).

### **Costs and benefits analysis**

A CBA comparative study of two kinds of SWP available on the local market gave different outcomes as shown in Table 5.4. The small pump is economically viable at a tariff rate of 7 cedis/litre (< \$ US 0.01/litre) while the medium SWP is viable at a 4 cedis/litre (< \$ US 0.01/litre) tariff as in Table 5.4.

The analysis revealed that the larger SWP system was more viable as the cost per unit for pumping a litre of water using the small pump was much higher and may be too expensive for consumers.

Table 5.4 Comparative cost benefit analysis for two sizes of SWPs

<b>Various parameters</b>	<b>Small solar pump for a community of 60 people</b>	<b>Medium pump for a community of 200</b>
Flow rate (litres/day)	3,000	10,000
Usage (days/year)	300	300
Capital cost (\$ US)	1 327.37	2 946.76
Economic tariff (\$ US/litre)	0.0009292 (7 Cedis)	0.0005309 (4 Cedis)
Annual operating and maintenance cost (\$ US)	318.60	477.85
Annual revenue (\$ US)	930.22	1,841.06
Profit (\$ US)	611.65	1 363.21
Discount rate (%)	36	36
NPV (\$ US)	4.77	38.67

(RDREG, 2002)

The discount rate of 36% being the rate offered by Ghanaian local banks was used in the analysis above. In an interview with a senior official of the Ghana Water Company (GWC)



by KITE (2002) it came to light that the GWC will consider SWP only as the very last option due to the fact that SWPs do not fall into the viable water pumping technology options.

Additionally other barriers influencing the dissemination of SWP include that of information limitation on awareness of the technology and the lack of commitment to SWP by the energy institution. Recall from chapter 3 that, though there is policy that exempts taxes on the importation of solar panels, taxes still applies to the importation of Balance of Equipment (BOE) such as pumps, batteries, inverters and other accessories. Appropriate policy recommendations are suggested in chapter 8 of this dissertation.

## CHAPTER 6 SMALL HYDRO POWER

This chapter first provides an overview of technical aspects of Small Hydro Systems (SHS). Identification and assessment analysis of studies on all potential SHP sites in Ghana was undertaken. Follow by an in-depth analysis of the status quo in Ghana involving technical & financial viability evaluation of existing projects. Barrier analysis with regards to the development of SHP was also done. Concluding this chapter are developments of models for future projects employing the use of the RETScreen technical and financial analytical tool.

### 6.1 Technical Aspects of Small Hydro Systems

Hydropower can be classified into large, small, mini, micro, and pico, depending on capacity of energy that can potentially be generated. There is no universally accepted definition of the term “small hydro” which, depending on local definitions can range in size from a few kilowatts to 50 megawatts or more of rated power output (Wilson, 2000). Installed capacity, however, is not always a good indicator of the size of a project. For example, a 20 MW, low-head “small” hydro plant is anything but small as low-head projects generally use much larger volumes of water, and require larger turbines as compared with high-head projects.

Table 6.1 Classification of Hydro Systems

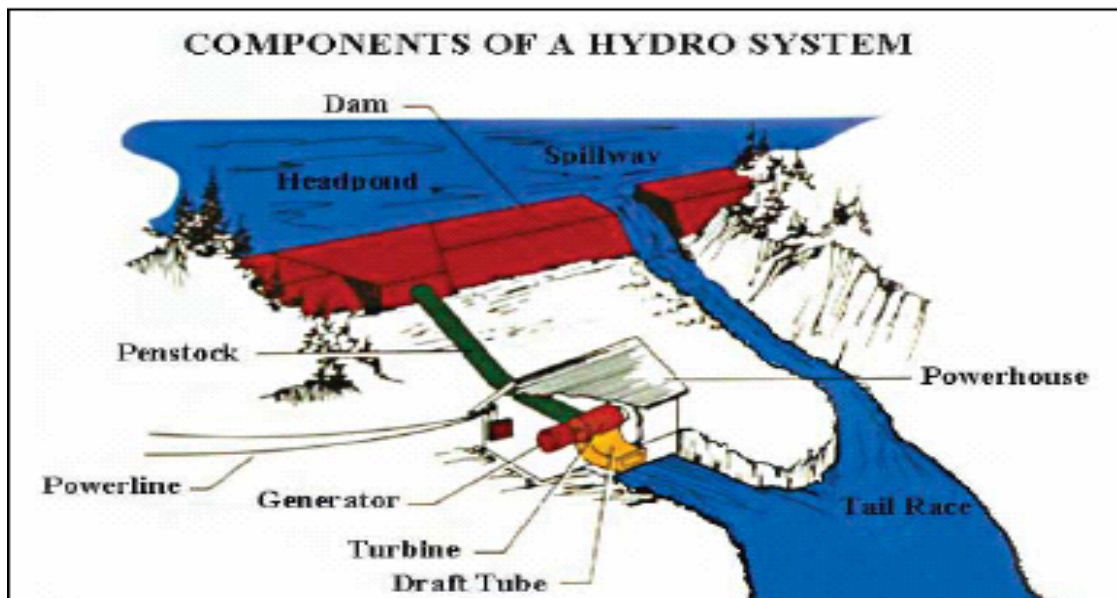
Hydro Classification	Capacity
Large	$\geq 500\text{MW}$
Medium	$<500\text{MW}$ and $>10\text{MW}$
Small	$<10\text{MW}$
Mini	$<500\text{kW}$
Micro	$<500\text{kW}$ and $10\text{kW}$
Pico	$<10\text{kW}$

(Source: KITE, 2002).

From the classification above, it can be said that mini, micro and pico hydro are all subdivisions of small hydro since they fall within the  $<10\text{MW}$  upper limit. As mentioned earlier in Chapter 1, the term ‘small hydro’ as used in this research applies to all hydro systems less than  $10\text{MW}$  which incorporates mini, micro and pico hydro systems.

A small hydro generating station can be described under two main headings: *civil works*, and *electrical and mechanical equipment*. Refer to Figure 6.1 & 6.2 below for a schematic of a typical small hydro power plant.

Figure 6.1 Small Hydro Project System Schematic.



(Source: RETScreen, 2005).

### 6.1.1 Civil works

The main civil works of a small hydro development are the diversion dam or weir, the water passages and the powerhouse as depicted in Figure 6.3. The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet. The water then passes through the turbine, spinning it with enough force to create electricity in a generator (Gulliver & Arndt, 1991). The water then flows back into the river via a tailrace. Generally, small hydro projects built for application at an isolated area are run-of-river developments, meaning that water is not stored in a reservoir and is used only as it is available. The cost of large water storage dams cannot normally be justified for small waterpower projects and consequently, a low dam or diversion weir of the simplest construction is normally used (Gordon, 1989). Construction can be of concrete, wood, masonry or a combination of these materials. Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable.

Figure 6.2 Civil Works for a 700kW Mini Hydro Project.

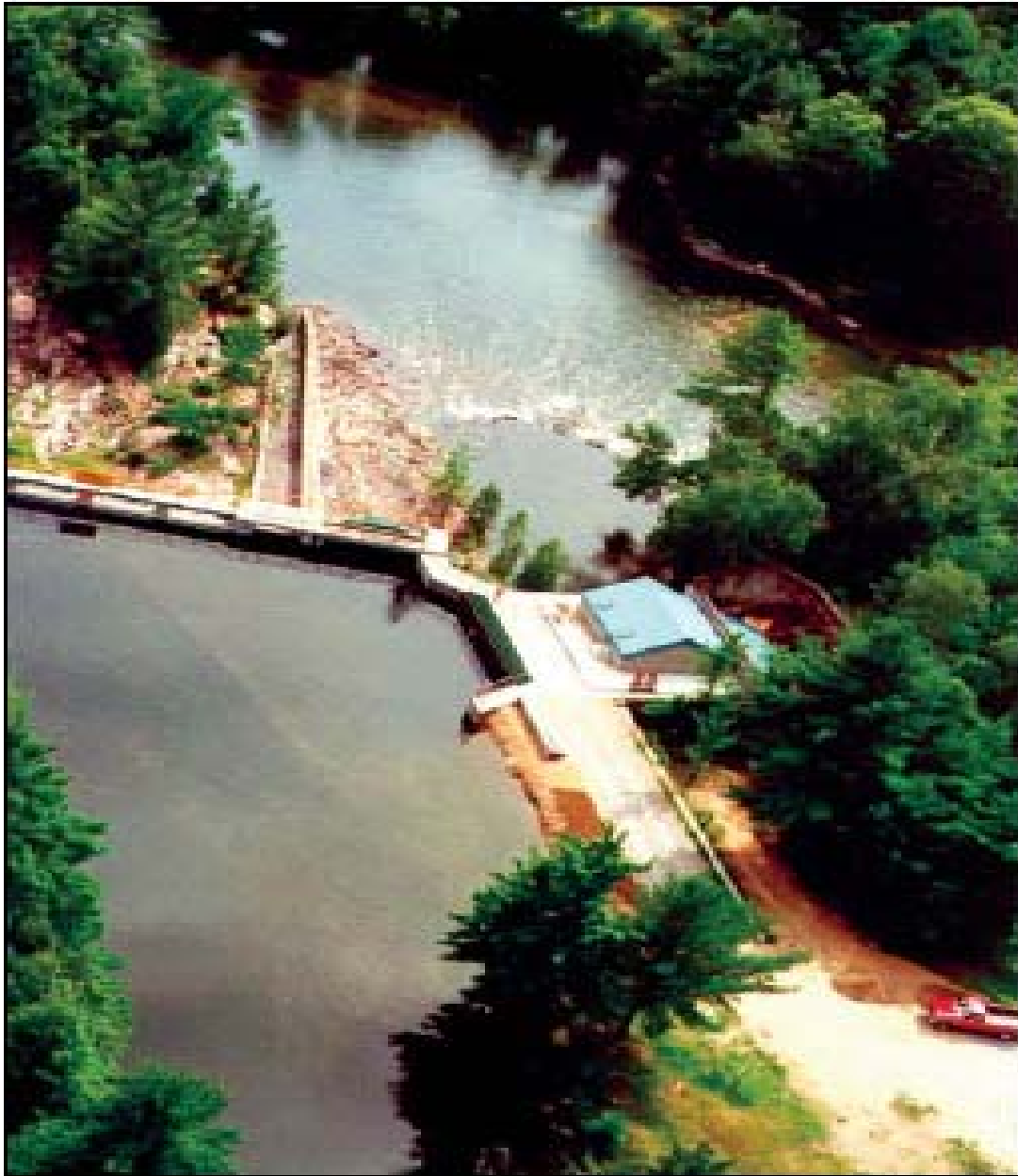


Photo credit: Ottawa Engineering

The water passages of a small hydro project comprise the following:

- An intake which includes trashracks, a gate and an entrance to a canal, penstock or directly to the turbine depending on the type of development. The intake is generally built of reinforced concrete, the trashrack of steel, and the gate of wood or steel.
- A canal, tunnel and/or penstock, which carries the water to the powerhouse in developments where the powerhouse is located at a distance downstream from the

intake. Canals are generally excavated and follow the contours of the existing terrain. Tunnels are underground and excavated by drilling and blasting or by using a tunnel-boring machine. Penstocks, which convey water under pressure, can be made of steel, iron, fibre glass, plastics, concrete or wood.

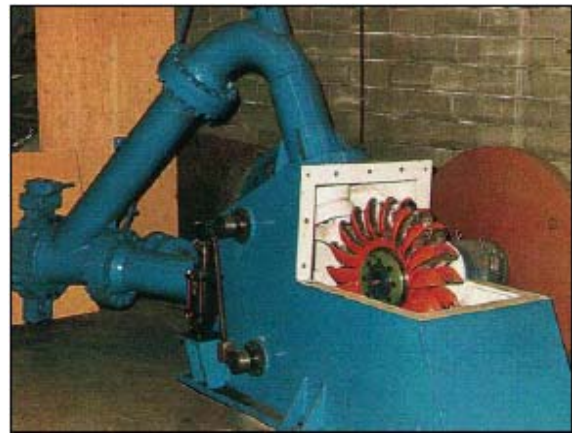
- The entrance and exit of the turbine, which include the valves and gates necessary to shut off flow to the turbine for shutdown and maintenance. These components are generally made of steel or iron. Gates downstream of the turbine, if required for maintenance, can be made of wood.
- A tailrace, which carries the water from the turbine exit back to the river. The tailrace, like the canal, is excavated.

The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment as depicted in Figure 6.3. Small hydro powerhouses are generally kept to the minimum size possible while still providing adequate foundation strength, access for maintenance, and safety (Gulliver & Arndt, 1991). Simplicity in design, with an emphasis on practical, easily constructed civil structures is of prime concern for a small hydro project in order to keep costs at a minimum.

Figure 6.3 Francis Turbine.



Figure 6.4 Pelton Turbine.



*Photocredit: PO Sjöman Hydrotech Consulting*

### 6.1.2 Electrical and mechanical equipment

The primary electrical and mechanical components of a small hydro plant are the turbine(s) and generator(s).

A number of different types of turbines have been designed to cover the broad range of hydropower site conditions found around the world (Acres International, 1984). Turbines used for small hydro applications are scaled-down versions of turbines used in conventional large hydro developments. Turbines used for low to medium head applications are usually of the reaction type and include Francis and fixed and variable pitch (Kaplan) propeller turbines (Bennett, 1990). The runner or turbine “wheel” of a reaction turbine is completely submersed in water. Turbines used for high-head applications are generally referred to as impulse turbines. Impulse turbines include the Pelton (see Figure 6.4 above right), Turgo and crossflow designs. The runner of an impulse turbine spins in the air and is driven by a high-speed jet of water (Leopold, 1974).

Small hydro turbines can attain efficiencies of about 90% (Wilson, 2000). Care must be given to selecting the preferred turbine design for each application as some turbines only operate efficiently over a limited flow range (e.g. propeller turbines with fixed blades and Francis turbines). For most run-of-river small hydro sites where flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred (e.g. Kaplan, Pelton, Turgo and cross flow designs).

Alternatively, multiple turbines that operate within limited flow ranges can be used. There are two basic types of generators used in small hydro plants - synchronous or induction (asynchronous). A synchronous generator can be operated in isolation while an induction generator must normally be operated in conjunction with other generators. Synchronous generators are used as the primary source of power produced by utilities and for isolated diesel-grid and stand-alone small hydro applications. Induction generators with capacities less than about 500 kW are generally best suited for small hydro plants providing energy to a large existing electricity grid (Acres International, 1984).

Other mechanical and electrical components of a small hydro plant include (RETScreen Small Hydro Power Analysis, 2004):

- Speed increaser to match the ideal rotational speed of the turbine to that of the generator (if required);
- Water shut-off valve(s) for the turbine(s);
- River by-pass gate and controls (if required);

- Hydraulic control system for the turbine(s) and valve(s);
- Electrical protection and control system;
- Electrical switchgear;
- Transformers for station service and power transmission;
- Station service including lighting and heating and power to run control systems and switchgear;
- Water cooling and lubricating system (if required);
- Ventilation system;
- Backup power supply;
- Telecommunication system;
- Fire and security alarm systems (if required); and
- Utility interconnection or transmission and distribution system.

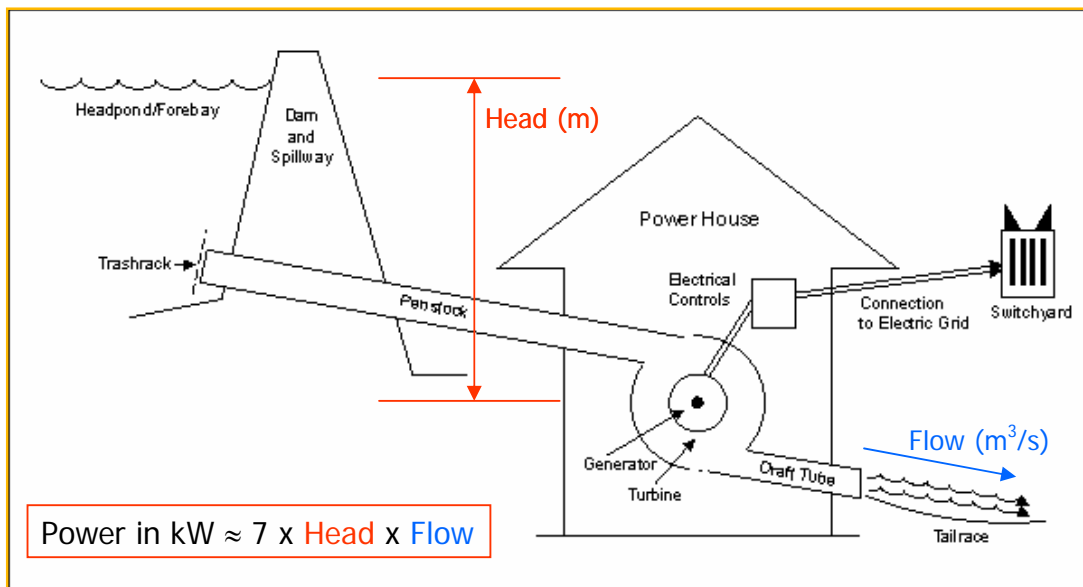
### **6.1.3 Small Hydro Project Development**

The development of small hydro projects typically takes from 2 to 5 years to complete, from conception to final commissioning. This time is required to undertake studies and design work, to receive the necessary approvals and to construct the project. Once constructed, small hydro plants require little maintenance over their useful life, which can be well over 50 years (EMR, 1988). Normally, one part-time operator can easily handle operation and routine maintenance of a small hydro plant, with periodic maintenance of the larger components of a plant usually requiring help from outside contractors.

The technical and financial viability of each potential small hydro project are very site specific (Wilson, 2000). Power output depends on the available water (flow) and head (drop in elevation). The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year. The economics of a site depends on the power (capacity) and the energy that a project can produce, whether or not the energy can be sold, and the price paid for the energy (Gullivers, 1991). In an isolated area (off-grid and isolated-grid applications) the value of energy generated for consumption is generally significantly more than for systems that are connected to a central-grid (Acres International, 1984). However, isolated areas may not be able to use all the available energy from the small hydro plant and, may be unable to use the energy when it is available because of seasonal variations in water flow and energy consumption.

A conservative, “rule-of-thumb” relationship is that power for a hydro project is equal to seven times the product of the flow (Q) and gross head (H) at the site ( $P = 7QH$ ) [see Figure 6.5] Producing 1 kW of power at a site with 100 m of head will require one-tenth the flow of water that a site with 10 m of head would require. The hydro turbine size depends primarily on the flow of water it has to accommodate. Thus, the generating equipment for higher-head, lower-flow installations is generally less expensive than for lower-head, higher-flow plants. The same cannot necessarily be said for the civil works components of a project which are related much more to the local topography and physical nature of a site.

Figure 6.5 Small Hydro Project System Schematic.



### 6.1.4 Small Hydro Project Engineering Phases

According to Gordon (1989), there are normally four phases for engineering work required to develop a hydro project. It is however important to note that for small hydro, the engineering work is often reduced to three phases in order to reduce costs.

Generally, a preliminary investigation is undertaken that combines the work involved in the first two phases described below. The work, however, is completed to a lower level of detail in order to reduce costs. While reducing the engineering work increases the risk of the project not being financially viable, this can usually be justified due to the lower costs associated with smaller projects.



Hydro project engineering phases comprises of the following (Gordon 1998): *Reconnaissance surveys and hydraulic studies, Pre-feasibility Study, Feasibility Study, System planning and project engineering*

#### *Reconnaissance surveys and hydraulic studies*

This first phase of work frequently covers numerous sites and includes: map studies; delineation of the drainage basins; preliminary estimates of flow and floods; and a one day site visit to each site (by a design engineer and geologist or geotechnical engineer); preliminary layout; cost estimates (based on formulae or computer data); a final ranking of sites based on power potential; and an index of cost.

#### *Pre-feasibility study*

Work on the selected site or sites would include: site mapping and geological investigations (with drilling confined to areas where foundation uncertainty would have a major effect on costs); a reconnaissance for suitable borrow areas (e.g. for sand and gravel); a preliminary layout based on materials known to be available; preliminary selection of the main project characteristics (installed capacity, type of development, etc.); a cost estimate based on major quantities; the identification of possible environmental impacts; and production of a single volume report on each site.

#### *Feasibility study*

Work would continue on the selected site with a major foundation investigation programme; delineation and testing of all borrow areas; estimation of diversion, design and probable maximum floods; determination of power potential for a range of dam heights and installed capacities for project optimization; determination of the project design earthquake and the maximum credible earthquake; design of all structures in sufficient detail to obtain quantities for all items contributing more than about 10% to the cost of individual structures; determination of the dewatering sequence and project schedule; optimization of the project layout, water levels and components; production of a detailed cost estimate; and finally, an economic and financial evaluation of the project including an assessment of the impact on the existing electrical grid along with a multi-volume comprehensive feasibility report.

### *System planning and project engineering*

This work would include studies and final design of the transmission system; integration of the transmission system; integration of the project into the power network to determine precise operating mode; production of tender drawings and specifications; analysis of bids and detailed design of the project; production of detailed construction drawings and review of manufacturer's equipment drawings. However, the scope of this phase would not include site supervision or project management, since this work would form part of the project execution costs.

## **6.2 SMALL HYDRO POWER IN GHANA – A DETAILED STUDY**

Until late 1997 and early 1998, virtually all of Ghana's electricity was produced from two large hydro dams at Akosombo and Kpong, which have a combined installed capacity of 1,072 MW.

It is estimated that Ghana has the potential for an additional 2,000MW of hydropower (KITE, 2002). About 1,205MW of this total is expected to be produced from proven large hydro sources while the rest will come from medium to small hydro plants. According to Odai (1999), about 70 SHP sites have been identified in Ghana.

### **6.2.1 Feasibility studies of Small Hydro Power in Ghana**

Preliminary studies to assess the SHP potential of Ghana began in 1979 under the auspices of the then Agricultural Engineering Services Corporation (AESC)-now AESL. About 40 potential small hydro sites were identified based on analysis of available data including topographical sheets (ACRES International, 1991). Subsequently, under a Ghana-India Technical Co-operation Agreement, funds were released for the development of the first pilot SHP schemes at a site near Likpe-Kukurantumi on the Dayi River, in the Volta Region (RDREG, 2002). Unfortunately, this project was never completed.

The government of Ghana issued new guidelines for the energy sector in 1982, which included plans to develop off-grid SHP installations of up to 500kW capacity to provide electricity to remote rural communities (KITE, 2002). To achieve this objective, the Ministry of Fuel and Power (now MME) commissioned AESC to carry out a systematic assessment of SHP potential in selected regions in Ghana.

### **6.2.1.1 Small Hydro Power Resource Assessment in Ghana**

The systematic assessment covered the following areas:

- Analysis of basic data (hydrology, plant parameters, layouts) as well as the assessment of the feasibility and attractiveness of the considered sites;
- An economic assessment of three representative projects;
- An extrapolation of the representative projects in order to assess the small hydro potential of Ghana;
- Development of a work plan for the future comprehensive inventory of Ghana's SHP potential; and
- An outline of technical and technological problems related to investigations, engineering construction, and operation & maintenance (O &M) of SHP projects in Ghana.

ACRES International investigated 16 small hydro sites in their study. Table 6.2 below contains characteristics and potential output of SHP sites studied in Ghana.

Table 6.2 Small Hydro Sites Evaluated in Ghana

No.	Mini-hydro Project	River	Heads (Gross)(m)	Installed Capacity (kW)	Potential output at site (MWh)
1	Wli Falls	Nuboi	264	325	10,747
2	Nuboi River Downstream of Wli Fall	Nuboi	38	45	1488
3a	Tsatsadu Falls I	Tsatsadu	54	100	3343
3b	Tsatsadu Falls II (rapids below falls)	Tsatsadu	38	70	2340
3c	Tsatsadu falls I&II	Tsatsadu	92	170	4683
4	Menu	Menu	7.5	65	2178
5	Ahanmansu	Wawa	6.2	125	4201
6	Dodi Papase	Wawa	9.2	210	7015
7	Asuboe	Wawa	6	100	3340
8	Sanwu falls	Sanwu	80	20	701
9a	Nworannae Falls A	Nworannae	24	12	560
9b	Nworannae Falls B	Nworannae	40	20	933
10	Randall Falls	Pumpum	16	4	422
11	Fuller Falls	Oyoko	15	7	698
12	Kokuma Falls	Edam	27	60	1751
13	Nkoranza	Fia	4.3	35	981
14	Maaban	Kwasu	12.2	15	604
15	Buomfuom Falls	Ongwam	18.5	10	292
16a	Wurudu Falls A (Falls only)	Wurudu	39	30	668
16b	Wurudu Falls B (Falls and lower rapids)	Wurudu	60.5	45	1003
17	Likpe-Kukurantumi	Dayi	-	400-600	-

(Source: KITE, 2002).

ACRES International in their study also came up with a rough assessment of Ghana's SHP potential. The approach used in this estimation was as follows:

- Estimate the number of technically viable sites, which could be developed within a framework of 15-20 years.
- Extrapolate the characteristics (capacity, output) for the already investigated set of representative projects to the technically viable sites identified above.

Several scenarios [i.e. minimal (cautious), maximal (optimistic) and intermediate] were developed-with regards to the viability of establishing SHPs in the investigated sites.

The cumulative potential of SHP (e.g. in simple run-of-river projects), in isolated grid or off-grid situations was estimated to be around 1.2 MW installed capacity for the minimum scenario and 4MW installed capacity for maximum scenario (RDREG, 2002). However, this installed capacity could be increased considerably if the SHP plants would be connected to the national electrical grid, to absorb the excess energy output especially during the rainy season when water levels are high. Under this scheme, the SHP potential of Ghana, for the same sites, was estimated to be around 4MW installed capacity for the minimum scenario and 14 MW installed capacity for the maximum case scenario.

Based on this assessment, ACRES International (1991) described the SHP potential of Ghana as modest. They concluded *inter alia* that the development of small hydro in Ghana could only have a marginal effect on the overall fuel and energy balance of Ghana. They however pointed out that the SHP technology could play a very important role in widening the implementation of rural electrification programmes thereby accelerating the incorporation of otherwise isolated communities into the mainstream of economic and social development.

### **6.2.2 Analysis of the Techno-Economic Viability of SHPs in Ghana**

The AESC arrived at the conclusion from their study that 14 out of 17 investigated sites were economically viable (1985). The AESC report was reviewed six years later by ACRES International. ACRES International concluded from its review process that at least 6 out of 17 sites are technically feasible and economically viable (ACRES International, 1991).

Upon an exhaustive critical analysis of the AESC report it was found out that estimations made in the AESC report was quite unrealistic considering the fact that the water level of

most rivers drops drastically during the dry season and that this season last for almost half a particular year. Some rivers even dry up completely during the dry period.

It is certain that most of the identified SHP sites will not be economically viable during the drying season unless in hybrid systems. The back-up system generates the needed electricity during the drought period. Notwithstanding, it must however be emphasized that SHP has an excellent economic profile during the rainy season. The issues raised above might be the main reason why none of the sites identified has ever been developed fully to date.

The closest Ghana has come to developing its small hydro sites is the Likpe-Kukurantumi project on the Dayi River. After initial preliminary investigation and the construction of a dam, a 100kW turbine unit was imported from India. Unfortunately, this generating facility was never installed and it is to date lying at the Electricity Company premises in Accra. No reason was given for the abrupt termination of the project that was almost near completion. The irony of the above case study is that Likpe-Kukurantumi is presently connected to the grid. What an investment waste! This wasted investment could have been utilized profitably in other RE areas. It is quite obvious that proper feasibility work (that considers all the key factors) had not been done prior to undertaking project constructional works.

## **6.3 Barrier Analysis-Small Hydro Power**

### **6.3.1 Resources**

The ACRES report concluded among other things that ‘the development of SHP resources can only have marginal effect on the overall fuel and energy balance of Ghana’ (ACRES international, 1991). They submitted however, that there is a niche market for the technology in the context of rural electrification programmes. The modest assessment for the country’s SHP resources possibly accounts for the reason why not a single SHP has been implemented in Ghana. Year round resource inadequacy is an important barrier to the development of SHP in Ghana.

### **6.3.2 Technological/Technical**

There is no known technological barrier presently that could have impeded the development of SHP sites in Ghana. There is a worldwide consensus that SHP technology is now mature. It has been greatly improved by electronic load controllers, lower turbine cost, the use of

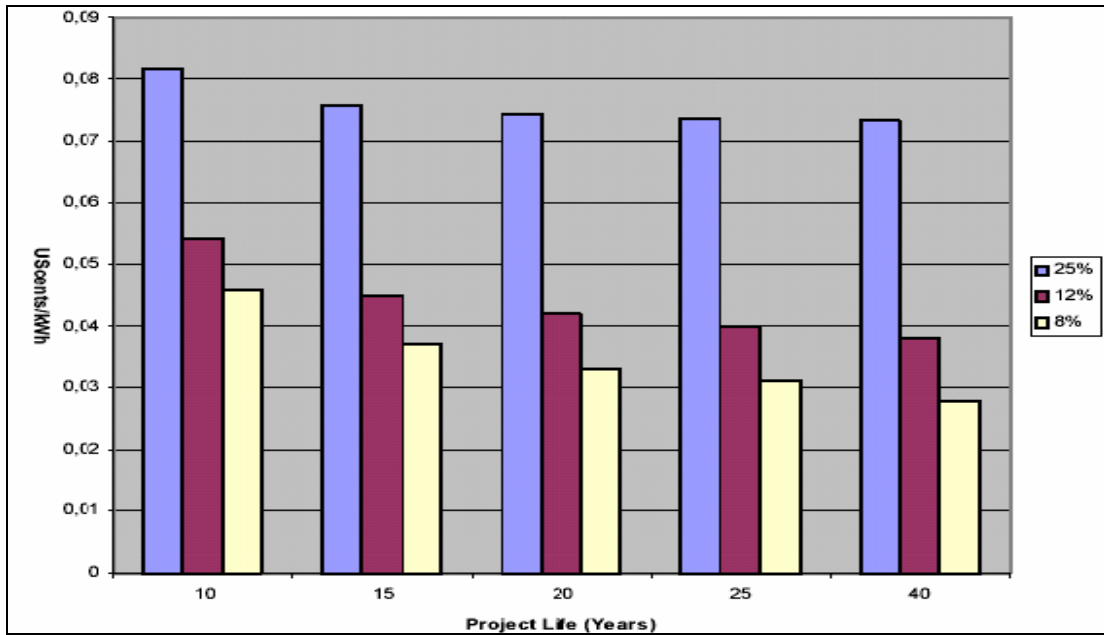
electric motors, and the use of plastics in pipe work and penstocks (Khennas and Barnet, 2000). Continuous improvement in R&D can still bring the cost of generating equipment down. This however does not lie within the purview of the Ghanaian engineer, nor is there any economic justification for embarking on such a venture since other countries such as India and China have a comparative cost advantage so far as the manufacturing of equipment is concerned. The latter point is based on a conclusion drawn by ACRES International (1991) that 'the size of the SHP potential in Ghana does not give sufficient scope for considering domestic manufacturing of the main equipment components (turbines, valves, generators). Project engineering, construction and installation, O&M of SHP plants can be carried out entirely by Ghanaian institutions and expertise (ACRES, 1991).

### **6.3.3 Financial Analysis**

The high initial installation cost for SHP is a potential barrier. An attempt to carry out an independent financial analysis by a local research institution, KITE was unsuccessful (KITE, 2002). The failure was primarily due to lack of cost estimates and more recent hydrological studies of the rivers.

Using the only data available then, from the most optimistic AESC study coupled with some modifications, calculation on the unit cost of electricity production for 2 (out of the 6) sites selected by ACRES International (1991) as viable sites was undertaken assuming a discount rate of 12 %. The discount rate was based on the World Bank guidelines of 8-12 % for such projects (AESC, 1986). The upper limit was chosen for the analysis. The results are indicated in Figure 6.6 which shows the unit cost of generating electric power from the Wli Falls at varying discount rates and project life. Modifications made was to convert the cost estimates in 1986 to US dollars, using the exchange rate prevailing at the time (\$1 to ₵90) and extrapolate the 1986 dollar equivalent to the present assuming an inflation rate of 3 % for the dollar.

Figure 6.6 Unit cost of energy at different project life & discount rate for Wli Falls



(Source: KITE, 2002).

A slightly different analysis was conducted for Tsatsadu Falls as shown in Figure 6.8 which depicts the relationship between plant factor and the unit cost of energy generated at Tsatsadu Falls.

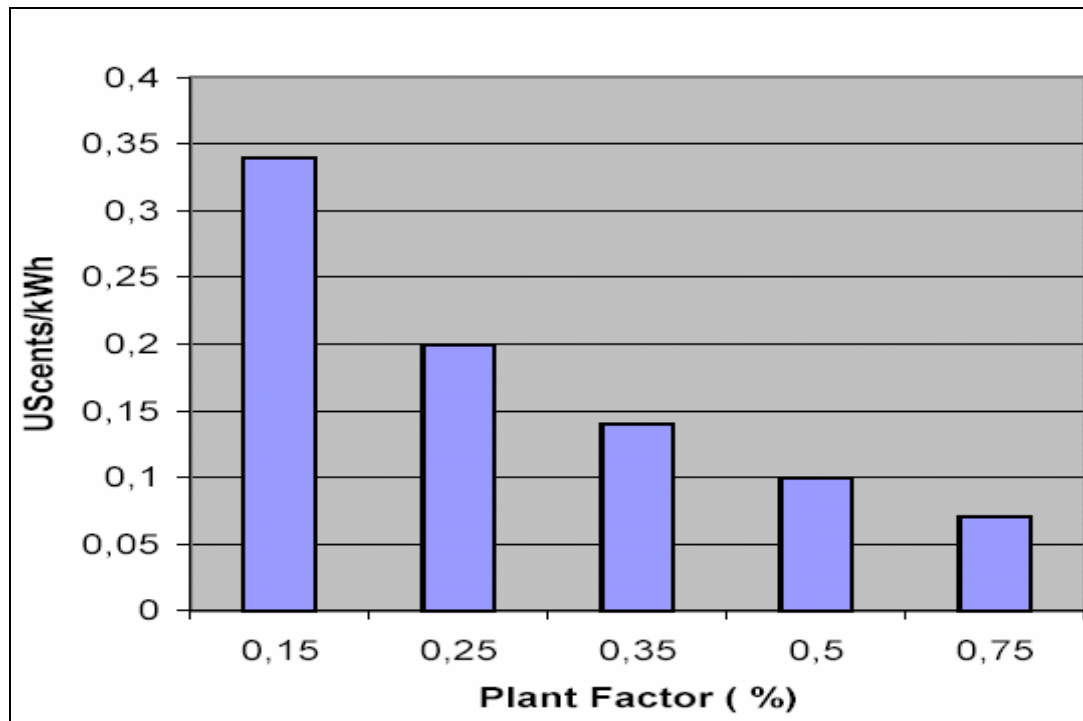
Figure 6.8 shows that for a project life of 40 years, a discount rate of 12% and a plant factor<sup>1</sup> of 75%, unit cost of electric power from Tsatsadu is 9cents /kWh.

<sup>1</sup> The annual capacity factor  $K$  of the small hydro power plant is a measure of the available flow at the site and how efficiently it is used. It is defined as the average output of the plant compared to its rated capacity. Where  $E_{dvd}$  is the annual renewable energy delivered (calculated) and  $P_{des}$  (calculated) is the plant capacity.

$$K = \frac{E_{dvd}}{8760 P_{des}}$$



Figure 6.7 Relationship between plant factor and unit cost of energy for Tsatsadu Falls.



(Source: KITE, 2002).

If the plant factor falls to 15 %, which is the other extreme, unit cost of production rises to 34 cents /kWh. Three major conclusions can be drawn from the analyses done in Figures 6.6 and 6.7, which are:

- The financial viability of a small hydro plant is largely determined by the plant capacity factor and the discount rate;
- The longer the project life, the more financially attractive the small hydro power project is; and
- Using 1986 extrapolated costs, the cost/kW installed and the unit cost of energy for the two schemes falls within the global range.

#### 6.3.4 Environmental

SHP technology is generally an environmentally benign technology compared to large hydro projects (IEA, 1998). However, environmental considerations can potentially impede the development of the SHP sites in Ghana since many of the sites are waterfalls whose scenic beauty may be destroyed should the sites be developed. A typical example is the Wli falls, which came out as the most attractive site among all the sites (RDREG, 2002). Whether or

not the possible negative effect on tourism will constitute a barrier to the development of SHP (in hybrid systems) in Ghana would depend on what is perceived by the government and local community as the best use for the site in question i.e. electricity generation or developing site for tourism.

#### **6.3.5 Social**

There has not been any study to assess the social acceptance of SHP technology by communities within which the SHP sites are located. The AESC study only focussed on the social benefits expected to accrue from the projects. Neither did the project team conduct any study to assess the benefiting communities' acceptance of the potential SHP projects.

An acceptability study should be undertaken even under the most viable SHP hybrid systems. Feasibility studies on potential environmental problems such as flooding, breeding sites for disease causing vectors and social dislocation associated with their larger counterparts (Large Hydro). Even though small hydro produces one the most environmentally benign ways of generating power, their acceptability among local communities should not be over estimated even under the best techno-economic viability situations. Community acceptance of projects/technologies can be enhanced through awareness education. Other conceivable social barriers are cultural or religious issues, especially in cases where host communities attach religious or cultural importance to the sites.

#### **6.3.6 Cross-Cutting Barriers**

The main cross-cutting barriers identified are on: *information, policy and institutional barriers.*

##### *Information Barrier*

It is evident throughout the study that there is a dearth of information on SHP in Ghana. Getting relevant information on SHP was extremely difficult. This has led to a nearly complete lack of information to stakeholders about the usefulness (benefits), prices, resource availability, performance and reliability of SHP in Ghana. There is absolutely insufficient information on which to make an investment decision. A typical case is a situation where a Swedish company interested in developing some of the SHP sites has not been able to move beyond the project concept phase because of the information barrier (KITE, 2002).

### *Policy*

There is no framework in place for the development of SHP in Ghana as explained earlier on in this chapter. Ghana's REDP has made no provision at all for the development of the SHP resources in the country (RDREG, 2002). SHP schemes are not even classified under the renewable let alone provision being made for their development. Development of hydropower has been mentioned briefly under the power sector with emphasis on the development on proposed projects, which are by definition not considered small hydro projects.

Even though there are policies to encourage rural electrification, these are however through extension of the grid. The abrupt end of the Likpe-kukurantumi project can be attributed to the extension of grid electricity to the community even before commissioning of the project. This is clear case of a poor policy intervention. It can be recommended that the Likpe-kukurantumi SHP project be commissioned in any case, and the electricity generated fed into the grid.

### *Institutional Barriers*

There is no institution or body in the country specifically assigned the responsibility of ensuring that the SHP resources in the country are developed. Such an institution, if there was, would not only initiate and implement programmes but also lobby for the policy change required to create an enabling environment of regulation and support for SHPs especially in viable hybrid systems.

## **6.4 Development of Future Small Hydro Projects based on RETScreen Model**

The RETScreen Small Hydro Project Model provides a means to assess the available energy at a potential small hydro site that could be provided to a central-grid or, for isolated loads, the portion of this available energy that could be harnessed by a local electric utility (or used by the load in an off-grid system). The model addresses both run-of-river and reservoir developments and it incorporates sophisticated formulae for calculating efficiencies of a wide variety of hydro turbines.

The Small Hydro Project Model in the software has been developed primarily to determine whether work on the small hydro project should proceed further or be dropped in favour of other alternatives. Each hydro site is unique, since about 75% of the development cost is determined by the location and site conditions. Only about 25% of the cost is relatively fixed,

being the cost of manufacturing the electromechanical equipment (Wilson 2000; ACRES International, 1984).

Seven worksheets are provided in the RETScreen Small Hydro Project Workbook file. These are Energy Model, Hydrology Analysis and Load Calculation (Hydrology & Load), Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis (GHG Analysis), Financial Summary and Sensitivity and Risk Analysis (Sensitivity).

The *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The *Sensitivity* worksheet helps to estimate the sensitivity of important financial indicators in relation to key technical and financial parameters.

### **Validation**

The calculation method employed by the software are empirical and based on data collected for over 20 years in both large and small hydro facilities (Gordon, 1989 & 1991). If used correctly, it can provide a baseline, or minimum, cost estimate for a proposed project. Numerous experts have contributed to the development, testing and validation of the RETScreen Small Hydro Project Model. They include small hydro modelling experts, cost engineering experts, greenhouse gas modelling specialists, financial analysis professionals, and ground station (hydrology) and satellite weather database scientists. Examples of validation exercises include a turbine efficiency curve as calculated by RETScreen in comparison to manufacturer's efficiency data for an installed unit with the same characteristics. Also project costs, as calculated by the software in are comparison to the 'as-built' costs of one small hydro project (RETScreen, 2005). The accuracy of the model, with respect to both energy production and cost estimation, is excellent for pre-feasibility stage studies for small hydro projects.

Detailed algorithms used by the RETScreen Small Hydro Project Model are outside the scope of this dissertation and can be found in the RETScreen e-textbook (RETScreen, 2005).

#### **6.4.1 Development of Wli Falls Small Hydro Project**

Wli was identified from both previous studies as the best SHP site with a water head of 264 m. The proposed project is a run-of- river SHP project. Assuming that based on the results of a reconnaissance study, it was realized from the topography that an above ground canal can be

constructed for about 2.4km through the rocky terrain with an average slope of 30°. A remaining 1.7km will be tunneled due to extremely steep slope. In order to connect the project with the central grid, approximately 6km of 110 kV transmission line will have to be constructed through a relatively flat, open terrain.

A RETScreen analysis on the proposed Wli SHP was made at given discount rates of 8% (minimum value based on World Bank guidelines), 12% (maximum value from World Bank) and 36% based on local Ghanaian bank rates. The prevailing electricity tariff of \$ US 0.04/kWh was used (Figure 6.8). General inflation rate is anticipated to be 2.5% over the 25-year duration. The financial performance of the project was later compared with a \$ US 0.08/kWh electricity tariff scenario (Figure 6.9). Both analyses were done at annual plant capacity factor of 75%. The annual capacity factor is a measure of the available flow at the site and how efficiently it is used. Typical values range from 40 to 95%. 75% was selected for the RETScreen analysis because it represents the best case scenario from previous studies as in Figure 6.7. The total initial cost of the investment is \$ US 10 535 635 and Renewable Energy delivered (in MWh/yr) is 25.039.

As can be seen in Table 6.3, at a Plant Factor of 0.75 the sensitivity analysis is mainly determined by the discount rate and the present cost of electricity. At a discount rate of 8%, the Wli run-of-river SHP project is a viable project with a B-C ratio of 3.02 but at a discount rate of 36% (being the local bank rate) the project is not viable (with a negative NPV and below 1 B-C ratio). The project will however be more attractive to private investors if the prevailing electricity tariff in Ghana is \$ US 0.08/kWh as the resulting B-C ratio from the project will then be 12.08 & 6.84 at 8% and 12% discount rates respectively.

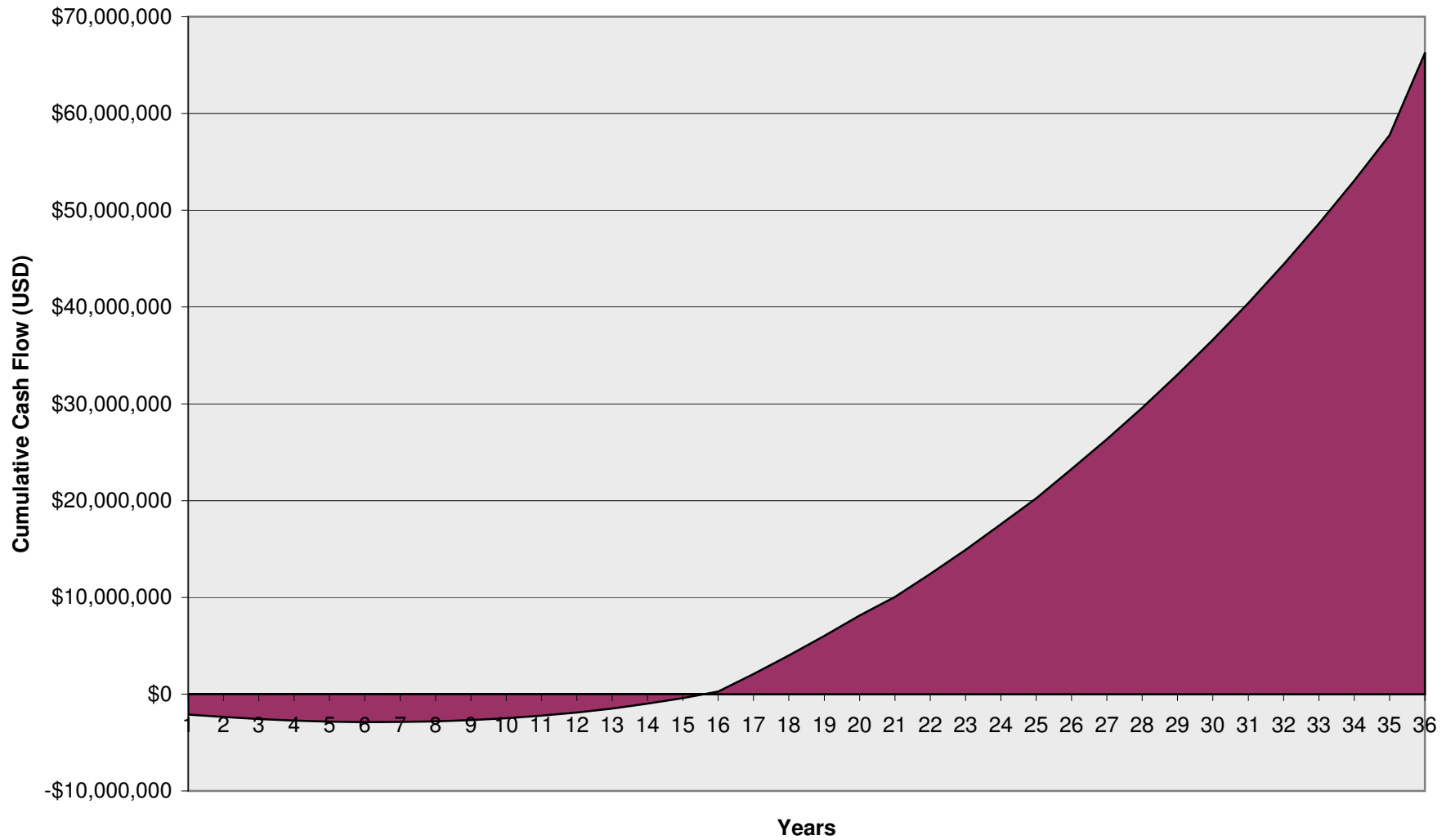
Table 6.3 Summary of RETScreen Analysis of Wli SHP at 0.75 Plant Factor.

Discount Rate (%)	Net Present Value [@ \$ US 0.04/kWh] (\$ US)	Net Present Value [@ \$ US 0.08/kWh] (\$ US)	Benefit-Cost (B-C) ratio @ \$ US 0.04/kWh	Benefit-Cost (B-C) ratio @ \$ US 0.08/kWh
8	4 260 345	23 351 035	3.02	12.08
12	254 502	12 301 776	1.12	6.84
36	-2 499 834	754 988	0.19	1.36

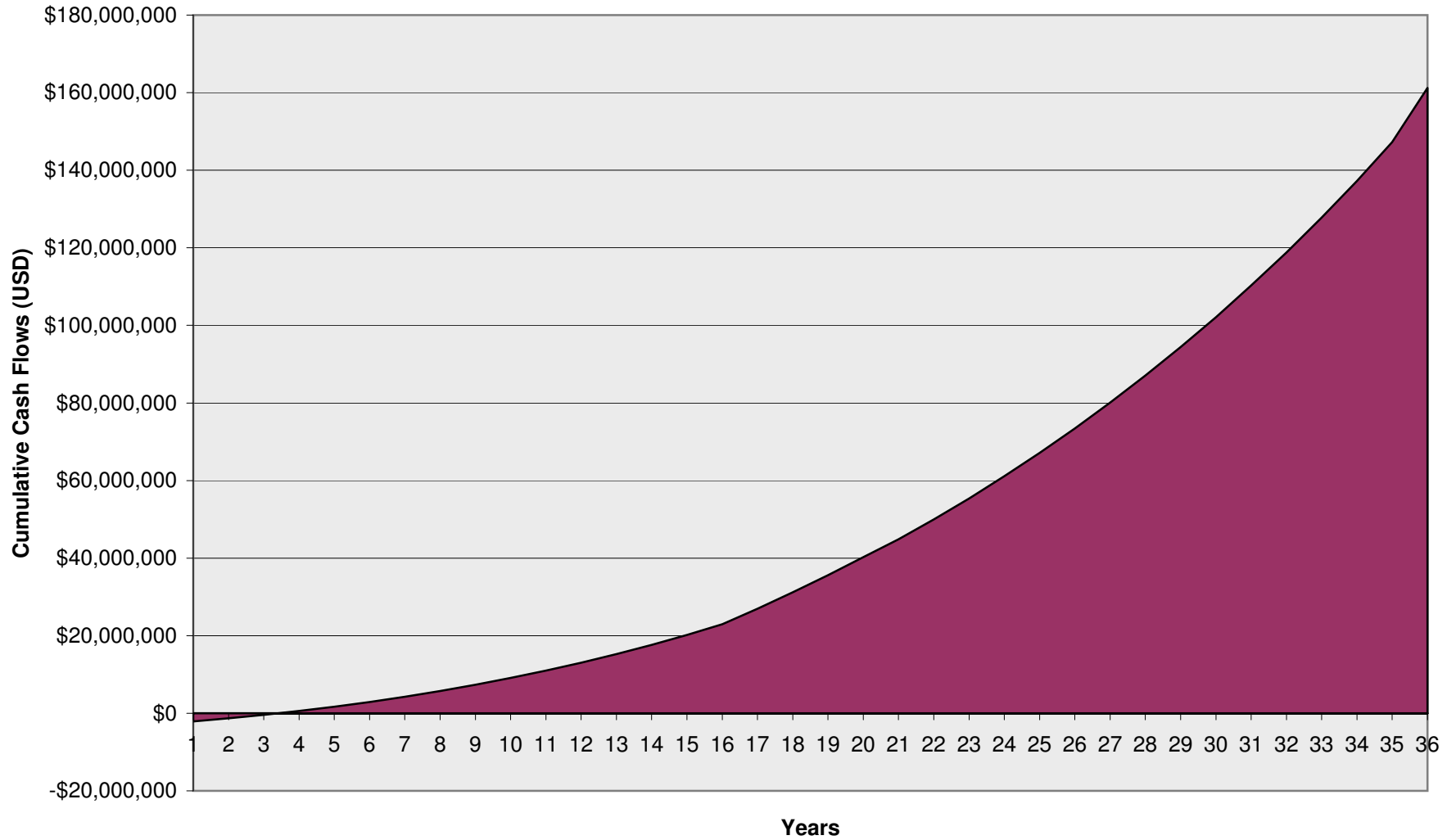
Graphical representation is provided in Figures 6.8 & 6.9 to give clear picture as to how doubling of the current electricity tariff can result in the Wli SHP project being able to contribute to the current energy mix in the country. A Plant factor of 75% and 12% discount rates were used in both analyses. As seen in both graphs, the simple payback period obtained for Figure 6.9 was actually less than half that obtained for Figure 6.8 with values of 6 and 14.1 years respectively. Details of the RETScreen Wli SHP analysis can be found in the SHP Appendix.

Analysis on the Tsatsadu Falls I&II using the RETScreen resulted in a poor outcome (B-C value of -2.35) in terms of techno-economic viability. Net Present Value obtained for this analysis was very low and unacceptable (-\$ US 5 842 242).

**Figure 6.8 Wli Run-of-River SHP Cumulative Cash Flows (@ 4cents/kWh avoided electricity),  
Wli Falls, Ghana.**



**Figure 6.9 Wli Run-of-River SHP Cumulative Cash Flows (@ 8cents/kWh avoided electricity cost), Wli Falls, Ghana.**





### **Concluding Remarks**

From the extensive techno-economic viability analysis conducted on SHP systems, it can be concluded that most of Ghana's SHP sites have poor viability. Making the situation further unattractive is the fact that there are drastic seasonal variations in water levels especially in dry seasons. All these do not render stand alone SHP systems technically and economically viable.

It is however recommendable that the Likpe-Kukurantumi SHP (mentioned earlier on in this chapter) be commissioned, in view of the fact that the project was almost completed when it was abandoned.

## **CHAPTER 7 WIND ENERGY**

Aspects of technical considerations of wind systems are first introduced in this chapter, then follows analysis of the wind resource assessment in Ghana. Data obtained from the only two wind resource assessment studies are utilized to evaluate the techno-economic viability performance of future wind farms based on best and worse case scenarios with the aid of the RETScreen tool. This chapter then examines the sustainability of potential wind energy parks when integrated into a national power grid system. Appropriate barrier analysis could not be done due to the fact there are no wind farms in Ghana.

### **7.1 Technical Aspects of Wind System**

#### **7.1.1 Wind Energy Conversion**

Wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy (Elliot, 1986). The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high to low pressure areas (Le Gourières, 1982).

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. Energy can be extracted from the wind through the creation of either a lift or drag force-or a combination of the two. The principles of drag and lift can be demonstrated by looking at the effects of wind on a spinnaker sail and a Bermuda rig. The spinnaker sail fills like a parachute and pulls a sailing boat with the wind while the Bermuda rig, that familiar triangular sail, deflects with the wind and allows a sailing boat to travel across or slightly into the wind (CanWEA, 1996).

There are five basic features that characterize lift and drag:

- Drag is in the direction of air flow;
- Lift is perpendicular to the direction of air flow;
- The generation of lift always causes a certain amount of drag to be developed;
- With a good aerofoil, the lift produced can be more than 30 times greater than the drag;
- Lift devices are inherently more efficient than drag devices.

Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have

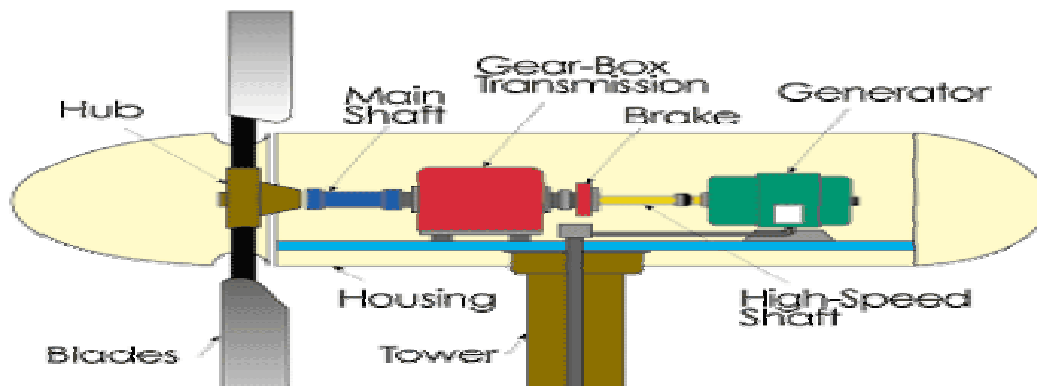
good potential. In spite of these geographical limitations for wind energy project siting, there is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects (Rangi *et. al.*, 1992).

### 7.1.2 Components of a Wind System and other Parameters

The major components of modern wind energy systems typically consist of the following:

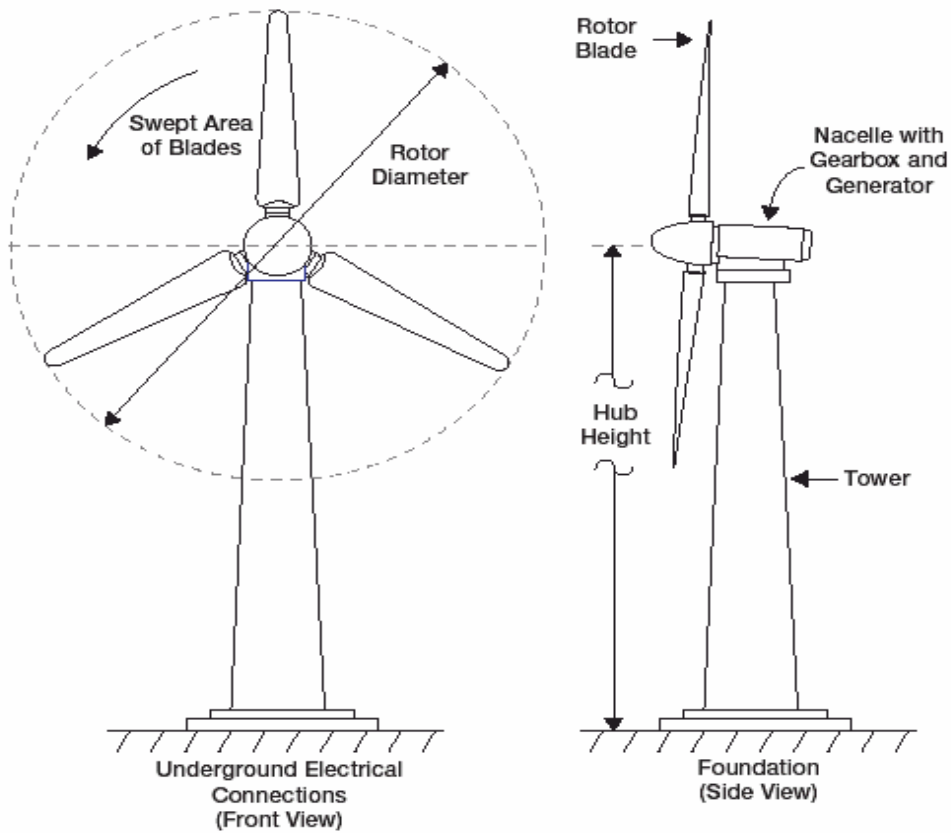
- Rotor, with 2 or 3 blades, which converts the energy in the wind into mechanical energy onto the rotor shaft. The blades are attached to the hub, which in turn is attached to the main shaft (Figures 7.1 and 7.2)
- Gearbox to match the slowly turning rotor shaft to the electric generator;
- Tall tower which supports the rotor high above the ground to capture the higher wind speeds;
- Solid foundation to prevent the wind turbine from blowing over in high winds and/or icing conditions (CanWEA, 1996); and
- Control system to start and stop the wind turbine and to monitor proper operation of the machinery.

Figure 7.1 Components of a Wind Turbine.



(Source: Iowa Energy Center, 2004)

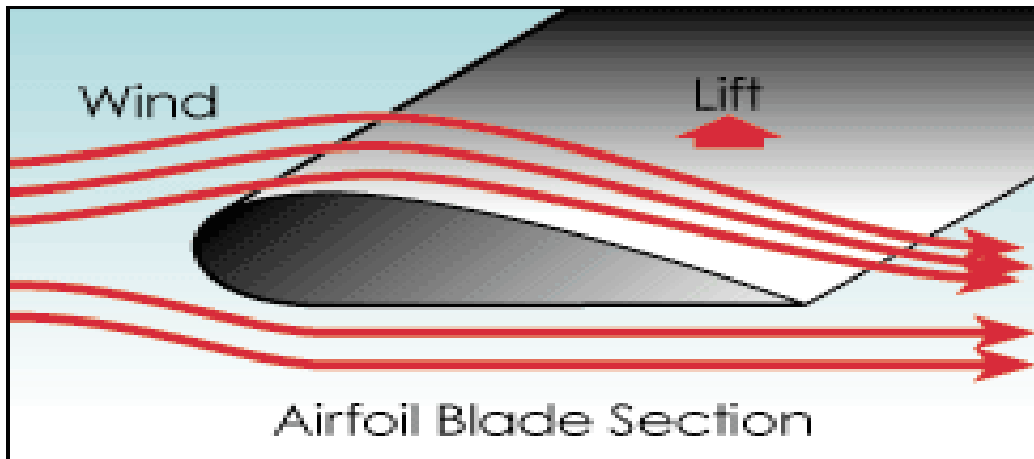
Figure 7.2 illustrates the configuration of a typical “Horizontal Axis Wind Turbine” or HAWT wind energy system.



### Lift Design

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade (Figure 7.3). When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation

Figure 7.3 Lift design mechanism of wind turbines



(Source: Iowa Energy Center, 2004)

### **Tip Speed Ratio**

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1 [(Bergey, 2000); (Brothers, 1993)]. The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it [(Hiester & Pennel, 1981; Vesterdal, 1992)]. This is the main reason why most wind turbines have only two or three blades on their rotors.

### **Generator**

The generator converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades (Gipe, 1995).

## **Wind Power**

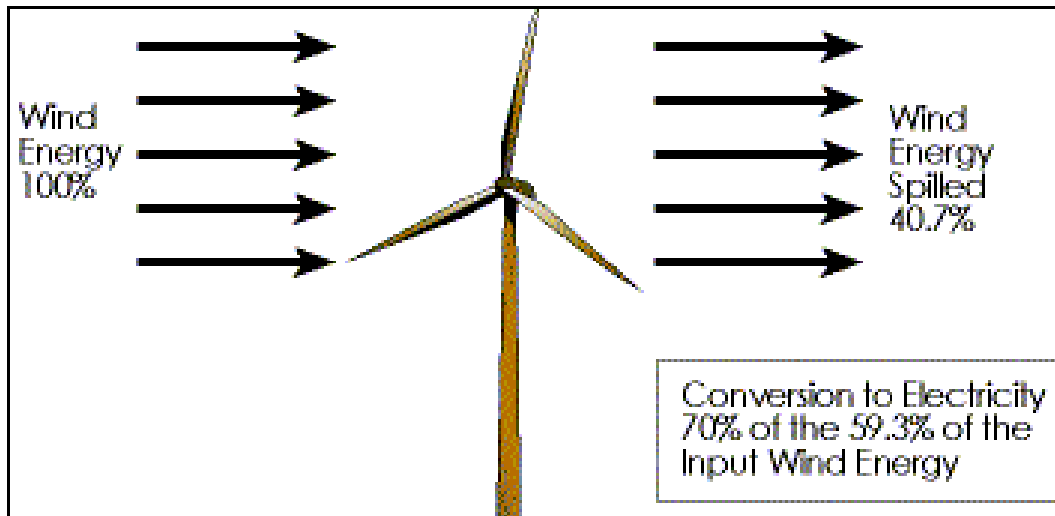
Wind power is a measure of the energy available in the wind. It is a function of the cube (third power) of the wind speed. If the wind speed is doubled, power in the wind increases by a factor of eight ( $2^3$ ). This relationship means that small differences in wind speed lead to large differences in power. The amount of power available in the wind is determined by the equation  $W = 1/2 \rho A v^3$  (Lynette, 1992) where  $w$  is power,  $\rho$  is air density,  $A$  is the rotor area, and  $v$  is the wind speed. This equation states that the power is equal to one-half, times the air density, times the rotor area, times the cube of the wind speed.

This amount of power in available in a wind can also be given by  $0.625 A v^3$ , where  $w$  is power in watts, and  $A$  is the cross-sectional area in square meters swept out by the wind turbine blades (refer to Figure 7.2), and  $v$  is the wind speed in meters per second. Although this power equation shows an exponential increase in wind power as wind speed increases, in practice, the actual power increase in a wind turbine is more linear than is predicted by the equation [(SunMedia, 1999); (Li & Priddy, 1985)]. This is because a wind turbine is not perfectly efficient. The power curve of a wind turbine is actually more significant.

### **7.1.3 Betz Limit**

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59% (Figure 7.4) [CADDET, 2001]. This value is known as the Betz limit. If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%. A more typical efficiency is 35% to 45%. A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will (depending on the model) deliver between 10% and 30% of the original energy available in the wind.

Figure 7.4 Schematic illustration of Betz limit.



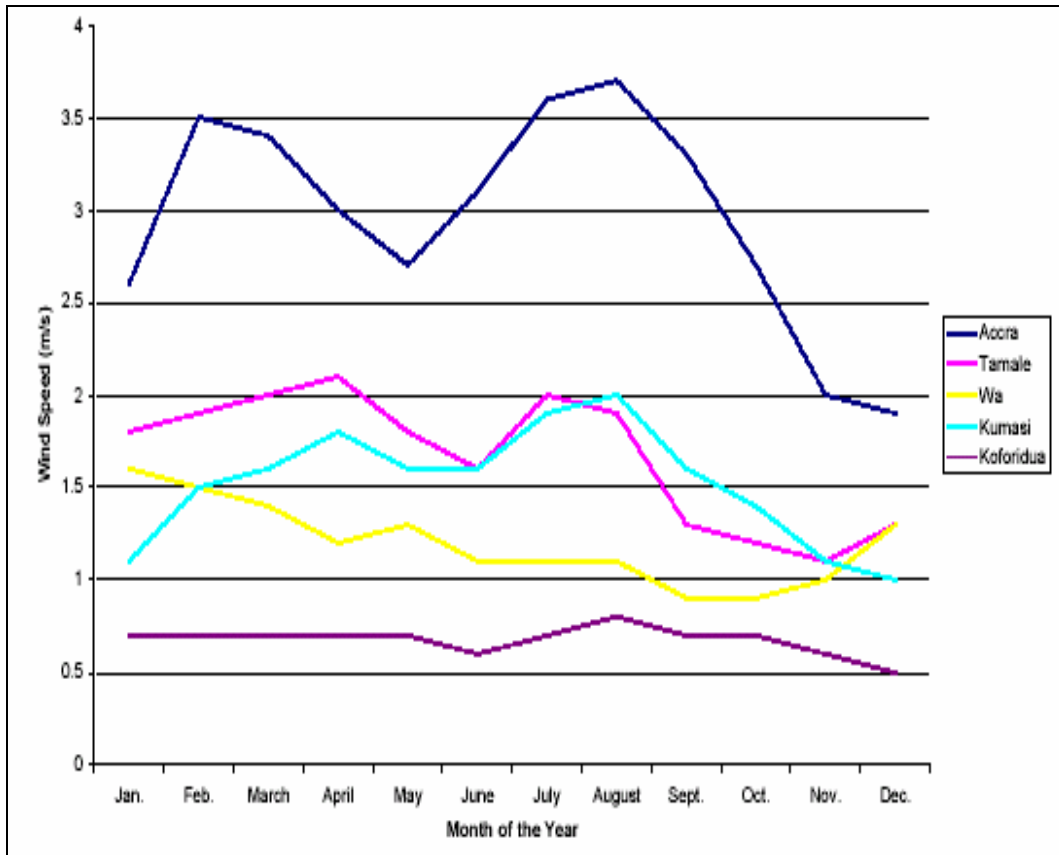
Source: Iowa Energy Center, 2003

## 7.2 Wind Energy in Ghana

Main land wind resource assessment undertaken in Ghana came out with very poor speeds of  $<3\text{m/s}$  (Figures 7.5, 7.6) at 10 metres height for most months in the investigated sites (KITE, 2002). Figure 7.6 was the result the resource assessment feasibility study undertaken by the National Renewable Energy Laboratory (NREL) of the US Department of Energy.

It shows the generally low wind profile observed across the country. Values obtained are not suitable economically and technically for the establishment of wind farms.

Figure 7.5 Wind speeds in some parts of Ghana.

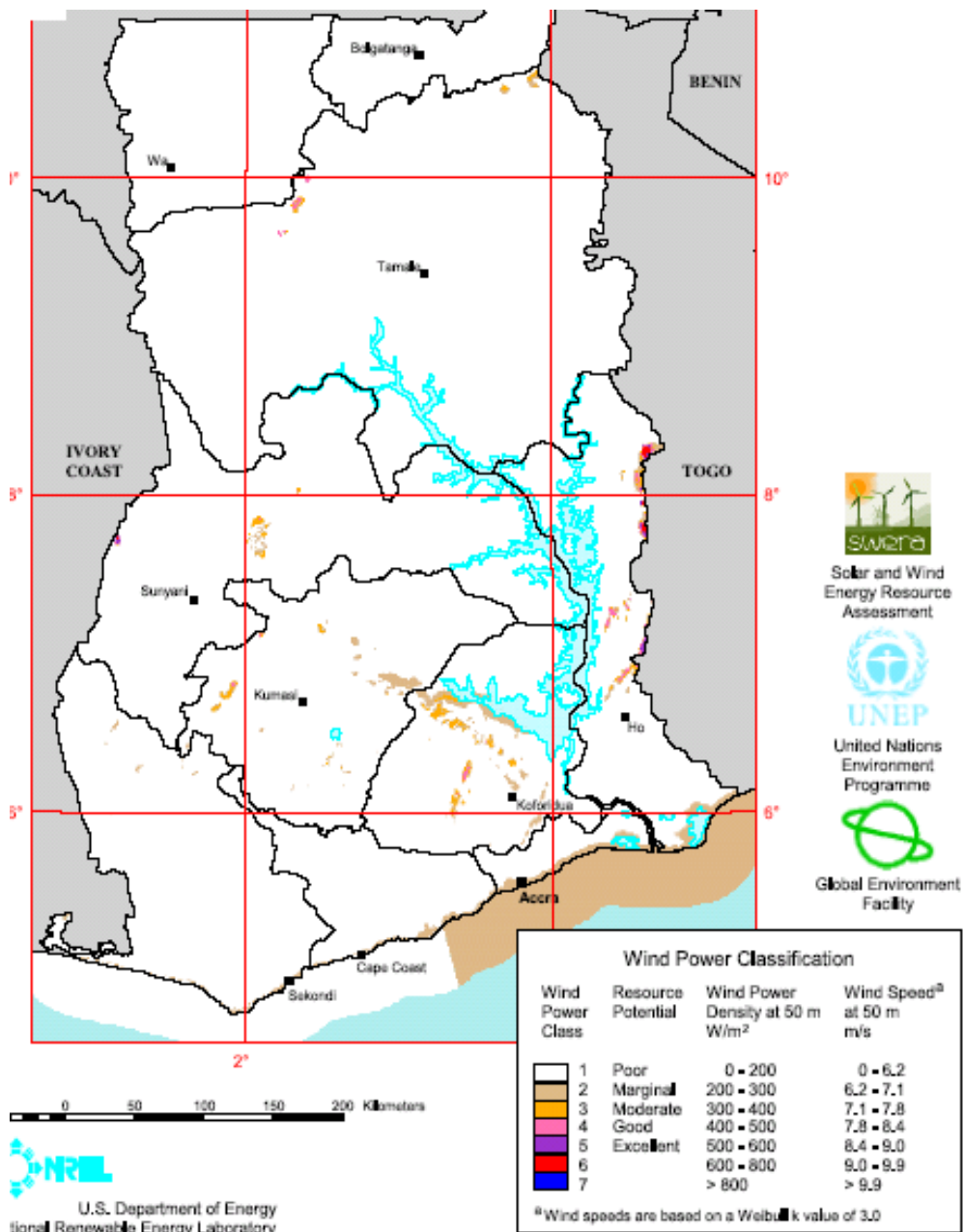


(Source: KITE, 2002)

A personal interview with a resource person from NREL who was involved in the resource assessment study indicated, their study was mainly focused on main land Ghana and that off shore or coastal belt wind speeds which were not done during their study might be encouraging. He also mentioned that wind speeds in certain hilly locations (which were not part of the study) might also yield some good wind speed values.



Figure 7.6 Feasibility Assessment of Wind Resources in Ghana (at 50m).



Source: Courtesy of National Renewable Energy Laboratory (NREL), 2004. Golden, Colorado, USA.

### **7.2.1 Potential Wind Energy Projects in Ghana?**

Two companies, one each from UK and Germany, have signed a letter of intent with the Ministry of Mines and Energy to assess wind energy resources along the eastern part of the coastal belt as prelude to establishing wind farms (MME, 1998). The results of the German study have indicated that with the right technology, heights of measurements and tariff structure the first ever wind farm in West Africa could be in place in Ghana in the near future.

The German wind energy is certainly an impressive example to be emulated. Well over 14,000 MW of wind power installation capacity now sustains 35,000 direct jobs in Germany, where the wind energy industry is now the second largest consumer of steel, behind car manufacturing. This huge growth in the German wind industry is a result of the new German law, which sets fixed prices for environmentally friendly energy, to be subsidized by increases to other electricity bills. The law sets fixed prices for wind power (in addition to solar and biomass power). Targets set in the law includes;12.5 percent of German energy mix coming from renewable sources by the year 2012, and a target of 20% renewable in the energy mix by 2020 (German Renewable Energy Act, 2000).

Recent studies by the Energy Commission and Riso Laboratory, Denmark have identified sites along coastal belt of Ghana with wind speeds adequate for power generation [(KITE, 2002), (RDREG, 2002)]. This discovery has rekindled interest in wind energy in Ghana but so far no wind park has been established in Ghana. This latest resource assessment indicated consistent wind speed values ranging from 4.9-5.0 m/s at 10 metres height (Table 7.1) along the coast line of Ghana.

### 7.1 Wind speeds at selected wind sites from Energy Commission measurements.

Site	Measurement Height (m)	Range of measured Monthly Mean Speeds (m/s)	Mean Annual Wind Speed (m/s)
Pute	10	4.79-6.37	5.0
Aplaku	10	-	4.9
Adafoah	12	4.48-6.43	5.5
Lolonaya	12	4.29-6.71	5.4
Tema	12	4.20-6.67	5.0
Kpone	12	4.07-6.37	4.8

RDREG, 2002

#### 7.2.1.1 Implemented Projects & Studies

There is no implemented wind farm in Ghana and the entire West African sub-region as mentioned earlier in the chapter 1. Based on recent studies, it is likely that the very first wind farm will be established in the very near future in Ghana (RDREG, 2002)

#### 7.3 Barrier Analysis

Barrier analysis undertaken here is mainly based upon other experiences from wind farms globally since there is currently no implemented project in Ghana.

##### 7.3.1 Technological/Technical

Wind turbine technology has reached a mature status during the past 15 years as a result of international commercial competition, mass production and continuing technical success in research and development (R&D). Earlier concerns that wind turbines were expensive and unreliable have largely been allayed. Wind energy project costs have declined and wind turbine technical availability is now consistently above 97%. Wind energy project plant capacity factors have also improved from 15% to over 30% today, for sites with a good wind regime (Rangi *et al.*, 1992). There is presently the existence of 5MW wind turbines that is state of art technology and with the advancement in technical know how, this promise to improve with time.

### 7.3.2 Environmental

The main environmental impacts associated with wind farms are *noise, visual intrusion, land use, bird strike and interference to electromagnetic navigation communications* (Jagadeesh, 1999),

- Noise: there are two major types of noise emitted by wind turbines: aerodynamic which results from the passage of air over the rotating blades and mechanical resulting from all moving parts, particularly the gearbox. Most complaints about wind turbines relate to the mechanically generated noise, specifically where the noise has a strong tonal component [(Eyre, 1995), (Legerton, 1995)]. Noise levels must be controlled by the application of statutory or recommended noise limits at the nearest noise sensitive property. However, if correctly sited, there should be no problem with modern turbines.

Thus appropriate siting of wind parks away from areas of high population and particular land topography is very essential.

- Visual Intrusion: the impact of wind farms on visual amenity is probably the most controversial and difficult to quantify of all the environmental issues affecting wind energy development. The main visual effect is the physical presence of wind turbines themselves and this depends on a number of factors (IEA, 1998):
  - The physical size of the turbine (this governs the zone of visual influence);
  - The distance from the turbines to the observer. Visual impacts is minimal at distances greater than approximately 6 km (Eyre, 1995);
  - The numbers and design of the turbines and layout of the wind farm (Williams, 1998; Rand, 1989);
  - Indigenous population density within the zone of visual influence;
  - The number of visitors;
  - The landscape type and the availability of alternative 'unspoilt' areas;
  - Weather conditions and local topography (land form);

However, the impact of these factors can be minimised by good design and planning and there are some techniques for assessing visual impact, which are frequently used within the planning process for wind farms (Halliday & Jenkins, 1994).

- Land use and Habitat Damage: wind farms are moderately land intensive occupying approximately 6 ha/GWh/year (IEA, 1998). However, the actual area covered by the turbines is much smaller (~ 40 m<sup>2</sup> each), so that together with access roads and other buildings, only about 1% of the area with the wind farm is actually occupied. This allows the land between the turbines to be used for other purposes such as growing crops or grazing animals. When assessed on this basis, wind turbines are the most efficient users of land of all renewables occupying approximately 0.06 ha/ GWh/year (IEA, 1998). Additionally at the end of the operational lifetime, the foundations can be reused and the site restored to its original condition at a relatively low cost. Thus, wind energy schemes are unlikely to have significant impact on land use or habitat damage provided they are sited away from areas of archaeological importance, high conservation and or recreation value or sensitive natural ecosystems.
- Bird Strike: turbines can disturb the behaviour of birds as well as leading to avian mortality through collisions with the rotating turbine blades. Most studies show that there is a little effect on resident bird species [(ETSU, 1995a), (ETSU, 1996a), (RSPB, 1998), (Winkleman, 1990)] but there have been concerns regarding migratory species, due to unfamiliarity with turbine sites. This is especially true where sites have been inappropriately chosen, for an example the Tarifa wind farms in Southern Spain straddle a major migratory route across the western end of the Mediterranean Sea (IEA, 1998).
- Electromagnetic Interference: the rotating blades of wind turbines can scatter electromagnetic signals, causing interference in a range of communication systems. Most of the potential impacts can be avoided or ameliorated (Chignell, 1986:1987):
  - Interference with television signals can be easily corrected using a range of technical measures including: signal amplifiers, active deflectors, relay transmitters and cable television.

- Problems with microwave links can be avoided by assessing sensitive sites (e.g. screening for military and industrial users should be carried out while the site is still in the planning stage).
- Statutory separation zones frequently apply to aerodromes and so problems with aircraft navigation and landing transmissions can be avoided at the planning stage.

### **7.3.3 Social**

Of all the new renewable energy technologies, the potential impacts from wind energy have received the greatest attention from a social point of view. Wind farms sited in areas of tourism, of high population centres and scenic beauty are the greatly opposed.

It is however; very difficult to take into account the subjective perceptions of individuals, with respect to:

- Attitudes to scenery and natural beauty;
- The existing level of visual amenity;
- Attitudes to wind energy.

It is clear that attitudes to wind energy are likely to affect aesthetic judgements about visual amenity. Some surveys indicate the public attitudes to the visual impact of wind farms may be positive and there is evidence that it is only a minority of people who believe turbines spoil the scenery in a typical location (IEA, 1998). Deployment experience has shown reduced perception of visual amenity impacts where the local community can see the benefits of a scheme, either from directly using the wind energy or from seeing existing fossil fuel stations displaced (Halliday & Jenkins, 1994). It is thought that the visual impact is greater if the turbines are still, as the observer does not perceive their usefulness. In addition, attitudes may also be affected by the economic and social relationship between the wind farm and the host community (Eyre, 1995).

### **7.3.4 Economic**

The generated cost of electricity per kWh is currently 3.50 cents which is the result of good policy implementation and improvement in technology in other parts of the world.

Unfortunately however, the drive towards maximizing the economics of wind energy has resulted in some wind turbines being sited in areas of high landscape value, which has provoked opposition to both the original schemes and subsequent schemes in other areas. Further work is required to examine how the economics and visual impact of wind farms could be optimized.

#### **7.4 Development of Future Projects based on RETScreen Wind Model**

##### **Validation of the RETScreen Wind Model**

Numerous experts have contributed to the development, testing and validation of the RETScreen Wind Energy Project Model. Comparison of the RETScreen model predictions against results of an hourly simulation program and against monitored data shows that the accuracy of the RETScreen Wind Energy Project Model is excellent in regards to the preparation of pre-feasibility studies, particularly given the fact that RETScreen only requires 1 point of wind speed data versus 8,760 points of data for most other hourly simulation models (RETScreen, 2005). Detailed validation analysis and algorithms for the programme can be found in the RETScreen Wind Model e-textbook (RETScreen, 2005).

The proposed projects were run using the data in Table 7.2 in central grid systems. The calculations were based on using the current cost of electricity generated from the large hydro (the base case) with the value of \$ US 0.04/kWh as the avoided cost of electricity at a discount rate of 12%. 12% discount rate is the highest limit based on the World Bank's guidelines (KITE, 2002). Results obtained were very impressive (see Table 7.2).

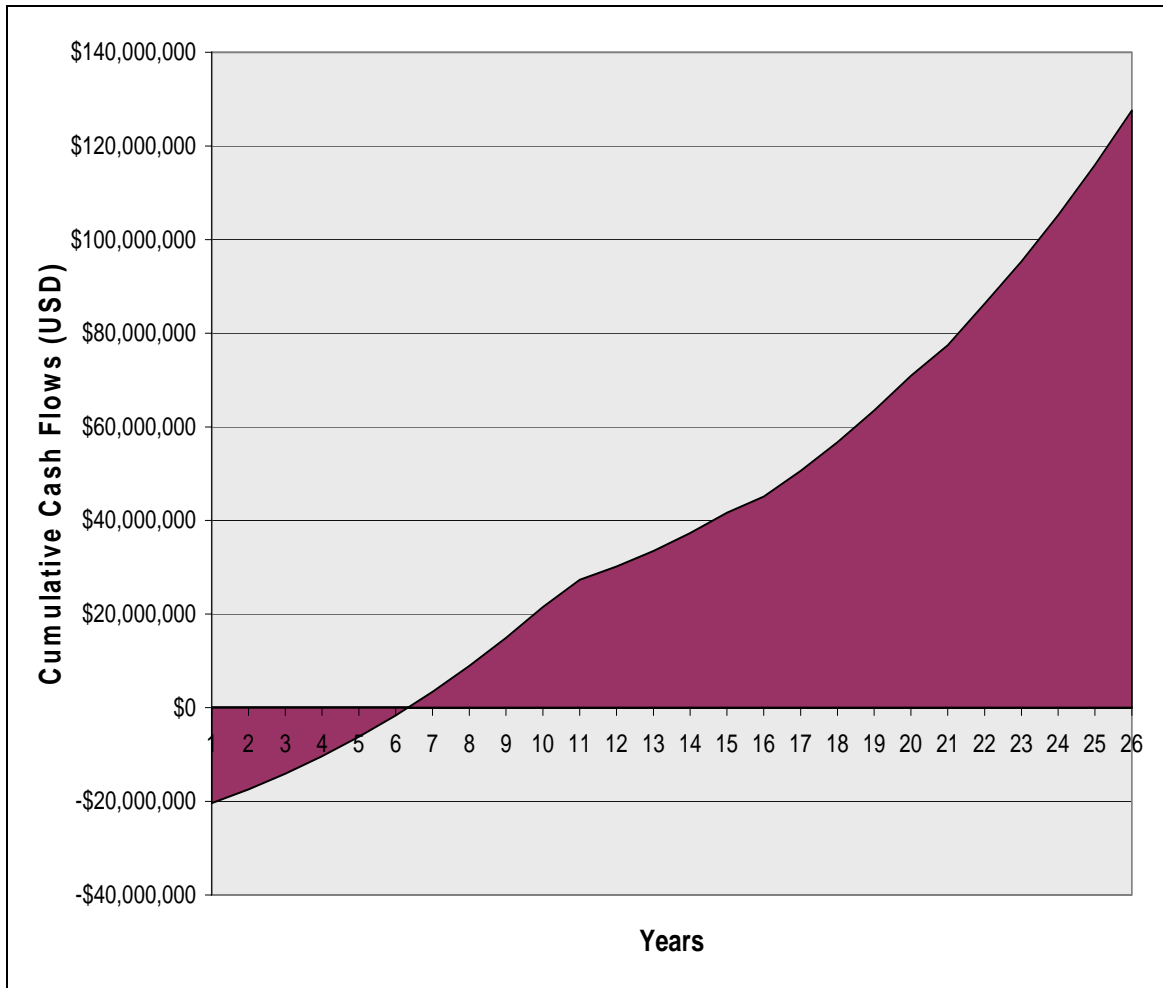
Table 7.2 Summary of financial performance for the proposed wind projects along the coast of Ghana using RETScreen software.

Site	Internal Rate of Return [IRR] (%)	Simple Payback (years)	Net Present Value [NPV] (\$ US)	Benefit Cost (B-C) Ratio
Pute	14.9	8.1	5 401 420	1.27
Aplaku	10.7	9.2	-2 355 598	0.88
Adafoah	20.8	7.2	16 482 553	1.81
Lolonaya	19.1	7.4	13 348 178	1.66
Tema	12.2	8.7	393 862	1.02
Kpone	6.4	10.3	-10 228 466	0.50

As seen in Table 7.2 all the projects are viable (except for Aplaku and Kpone) even at current electricity tariff of \$ US 0.04 /kWh with B-C ratios greater than 1. Investing more money (i.e. by almost doubling the initial investment) to increase the number of turbines from 35 to 70, renders Aplaku viable with B-C ratio of 1.33, IRR of 15.5%, simple payback of 8.2 years and NPV of \$ US 127 637 765 (refer to Appendix, Wind Farm Aplaku). Kpone however still remains unattractive even upon doubling the initial investment cost. With advancement in technology and improvement in turbine efficiency, Kpone might possibly be a viable venture. Adafoah happens to be the most viable project with a NPV of \$ US 16 482 553 and 1.81 B-C ratio. Year to positive cash flow for Adafoah was as low as 5.3 years (Figure 7.7). Detailed RETScreen analysis of all the projects can be seen in the wind farm appendices.



Figure 7.7 Cumulative Cash Flows for Adafoah Wind Farm, Ghana.



In order to avoid the bitter experiences encountered in other countries with the establishment of wind farms, it is recommendable that a social acceptability study should be undertaken on the proposed projects. The study should seek to gather and accept the local populace opinion on the projects as that will go a long way to offset any future problems encountered elsewhere in other countries. Issues of noise, shadows, and routes of migratory birds should be properly taken care of as mentioned earlier on in this chapter. There also the possibility of setting up off-shore wind farms, in case opinion poll from local communities rejects the proposed projects but this however must also be subject to meeting other demands like non-interference with navigation electromagnetic signals.

## **PART 3: CONCLUSION**

### **CHAPTER 8 BEST POLICY RECOMMENDATIONS**

This chapter is a formulation of best policies that can be drawn from the entire study.

Following the results obtained from the entire study it can be recommended that the Ghanaian government must strive in its effort to develop the country's renewable energy resources. The main objective should be attainment of energy security via policies that promotes a blend of renewables and conventional energy. The government, through the Ministry of Energy should formulate a comprehensive RE measures and policies that is committed to:

- develop the country's renewable energy resources over the medium to long term (KITE, 2002);
- explore and provide appropriate financial mechanisms for the development of RET projects;
- create the enabling fiscal and regulatory environment that would stimulate the effective participation and injection of private capital into the renewable energy sector (RDREG, 2002).
- promote inter-institutional involvement in the design and implementation of government funded renewable energy projects
- provide support to institutions that are involved in RE research and dissemination.

#### **8.1 Create Regulatory framework that are RE friendly**

While RETs are generally speaking not competitive with grid-connected electricity supply (Terry and Jaccard, 2001), the contribution of wind and biomass cogeneration in the short to medium term periods could be enhanced by means of regulatory intermediation and financial incentives.

First, regulatory requirements such as Renewable Energy Portfolio Standards that specify minimum percentage for renewable energy sources in the mix of electricity generation sources from power companies can be instituted similar to what is being done in Germany (explained in chapter 3 of this dissertation). In general, renewable energy based power supply, whether from power companies or individuals, should have priority dispatch status into the national interconnected electricity grid system.

For small, decentralised RETs a system of certification and standardisation needs to be developed in order to ensure high quality installation and performance [(Karekezi & Karotki, 1989), (Karekezi & Kimani, 2002), (Ward *et. al.* 1984)]. The energy commission should establish and enforce certification and licensing of small RET dealers and also keep a register of these licensees (RDREG, 2002). The granting of licenses should be based on pre-determined requirements such as:

- Evidence of competence of technical staff
- Track record
- Evidence of certification from principals
- Evidence of capacity to provide after sale service
- Evidence of financial capacity to offer services.

It may be recommendable that for PV applications, standards developed by GHASES, ERG and GSB should be adopted as national standards (MME, 2000).

### **8.2 Promotion of innovative market delivery models to offset the high initial costs of RETs**

The high upfront cost of RETs has been the single major barrier to their widespread deployment. The key problem that any innovative market delivery models has to deal with is the high initial cost of RETs and the additional sum cost needed for operation and maintenance as well as for repairing broken down components. This can be achieved through micro-credit schemes.

Remote rural communities not connected to the grid should be supported in meeting the high installation cost associated with commissioning of RE projects. The Ministry of Energy should for instance promote marketing models that will enhance the sustenance of RE projects by directly tying the generated electricity to commercially viable activities. Emphasis should be placed on management and marketing models that employ the active participation of the benefiting community, local institutions and entrepreneurs all geared towards helping to achieve sustainable development.

Locally there is a rural private sector enterprise [Renewable Energy Service Centres (RESC)] that sell renewable energy-based services (such as solar battery charging, solar-powered telephone services and solar lighting and also products like PV modules and components). The RESC concept should be incorporated in the dissemination of government supported PV

programmes for rural households. Building rural private sector enterprises through the RESCs concept could provide the appropriate institutional arrangements that will ensure the sustainability of renewable energy programmes.

### **8.3 Establish favourable pricing policies for RETs**

The single most important policy intervention that will accelerate the development and utilization of RE for electricity generation is the establishment of a friendly tariff regime (Akuffo, 1998) where guaranteed prices for generated electricity from REs are instituted by the Public Utilities Regulatory Commission (PURC) similar to the German experience (German Renewable Energy Act, 2000).

### **8.4 Rationalise the fiscal regime for RETs**

Considerable effort has been previously made by the government of Ghana to promote the development of RETs through liberal fiscal policies. Significant to this include the Ghana Investment Promotion Centre (GIPC) Act 478 (the investment code) (RDREG, 2002). This investment code for example, makes provision for tax exemptions for RETs manufacture and installation. In addition, wind powered and solar energy generating sets, plant, machinery equipment or parts for the establishment of PV manufacturing facility are exempted from import duty, VAT and excise duties, which together could account for up to 22.5% tax on these equipment (KITE, 2002).

There are however two major drawbacks in the existing fiscal regime for renewable energy technologies; firstly, when PV systems are imported as complete systems (i.e. including modules, regulators, batteries, lamps, inverters) they are exempted from VAT of 12.5% (Akuffo, 1998). On the other hand, where they are not imported as complete systems, only panels are exempted from import duty and VAT while the Balance of System (BOS) components such as batteries, regulators and lamps attract import duty. Secondly, other RETs such as solar water heaters, solar cookers, solar ovens, biogas equipments, biomass-based generating sets, etc are not exempted from VAT. The current regime for RETs should be further expanded to include import duty and VAT exemption for the following:

- Solar water heater
- Solar cookers
- Solar ovens
- Biogas utilisation equipment, appliances and system components
- Biomass-based generating sets

Recall from chapter 3 that the BOS are not exempted from import duty and VAT due to the fact that some fraudulent businessmen abused this tax exemption by importing pumps that were for other purposes instead of for SWP BOEs (Personal Communication, 2004). Appropriate policy recommendation will be to provide a working mechanism where importers of BOS can reclaim the import duty and VAT on their BOS upon showing prove that the BOS has been utilized in a RE project. BOS used in other conventional activities forfeit their import duty and VAT. The import duty and VAT refund procedure for the BOS can be achieved via a reverse supply chain activity where the RE project implementor/investor (after commissioning his/her RE project) can claim the refund from the retail shop where the BOS was purchased and the retailer subsequently reclaiming the money from the importer who then get his BOS import duty and VAT directly from the government or port authorities (or whoever is responsible). In order to avoid unforeseen bottlenecks along the reverse supply chain it will be prudent to make it possible for any of the stakeholders along the supply chain to be able to obtain his/her refund directly from the government.

### **8.5 Create awareness on the benefits of RETs**

In order to build a viable market of RETs, there is the need to create awareness of RETs as an alternative to conventional energy technologies. In doing so the potential benefits of RETs regarding their strategic nature, environmental benefit, self-sufficiency and reliability have to be emphasized and projected. A recent survey (KITE, 2002) to determine awareness of SWH in hotels came out that most of the hoteliers interviewed were not aware of SWHs let alone to understand the immense benefits of SWHs towards energy saving retrofitting.

In the past, the MME has promoted RETs through demonstration projects in both the urban and rural communities and most of these projects collapsed with the withdrawal of external support because project sustainability issues were not incorporated at the initial stage of implementation. In the future information dissemination and awareness creation on the benefits and market potential of RETs should be the main focus. The RETScreen tool can be an extremely useful tool in the feasibility analysis and economic performance of intended or proposed RE projects.

### **8.6 Coordination in Local Research and Development in RETs**

Ghanaian universities, research institutes and local private companies have the capacity and expertise in renewable energy R&D and project implementation. The main problem however is that RETs R&D activities are mainly uncoordinated among the players leading to

duplication of research activities and waste of resources which can be avoided through sharing of information. Further more there is the need to focus R&D to priority challenges:

- The first important strategy action will be to establish national renewable energy research and development priorities. The current major renewable energy R&D challenge is how to reduce costs with the view to make them more cost competitive. The primary focus of R&D activities in the short to medium term periods will therefore be to improve the cost effectiveness of RETs especially those that have good prospects for local manufacture. Prioritization of RETs R&D should be defined and implemented in partnership with industries, private sector, universities and research institutions.
  
- The second important action is to strengthen university research. In this regard efforts should be made to strengthen individual investigator's capabilities, increase cost sharing in funding proposals, and upgrade university equipment and instrumentation.

### **8.7 Taking advantage of international financing opportunities**

Government should support all private sector initiatives that can draw on the World Bank's Prototype Carbon Fund (PCF), Global Environmental Facility (GEF) and United Nations Framework Convention on Climate Change (UNFCCC): Clean Development Mechanism/Joint Implementation [CDM/JI] financing instruments, all of which are funding sources for clean energy projects.

The Ministries of Energy, Finance, Environment and Science and the Environmental Protection Agency should provide more information and technical support to organisations that intend to seek funding support from these international financing schemes. A Carbon Project Financing (CPF) committee can be set up in this regard by the now Ministry of Energy (MOE) [former MME] to assist both public institutions and private sector operatives in securing funding from multilateral sources (RDREG, 2002).

The CPF committee should include representatives from all stakeholders who are to work closely with the EPA and other relevant Ghanaian agencies such as the Ministry of Energy, Energy Commission, Energy Foundation, VRA, ECG, private sector, NGOs and universities etc.

### **8.8 Support development of expertise in RETs**

In order to achieve a higher level of RET development and utilization in the country, there is the need to build expertise in RET development and management through enhanced training of Ghanaian professionals locally and abroad and government must endeavour to solicit funding possibilities to make this possible.

### **8.9 Establishment of a comprehensive database on RE sources**

While considerable amount of data on renewable energy resources has been collected in the past two decades, the data have not been properly collated. The Energy Commission should create a comprehensive database on RE sources and technologies in the country by building on what has already been achieved in that area and what is yet to be done or undone.

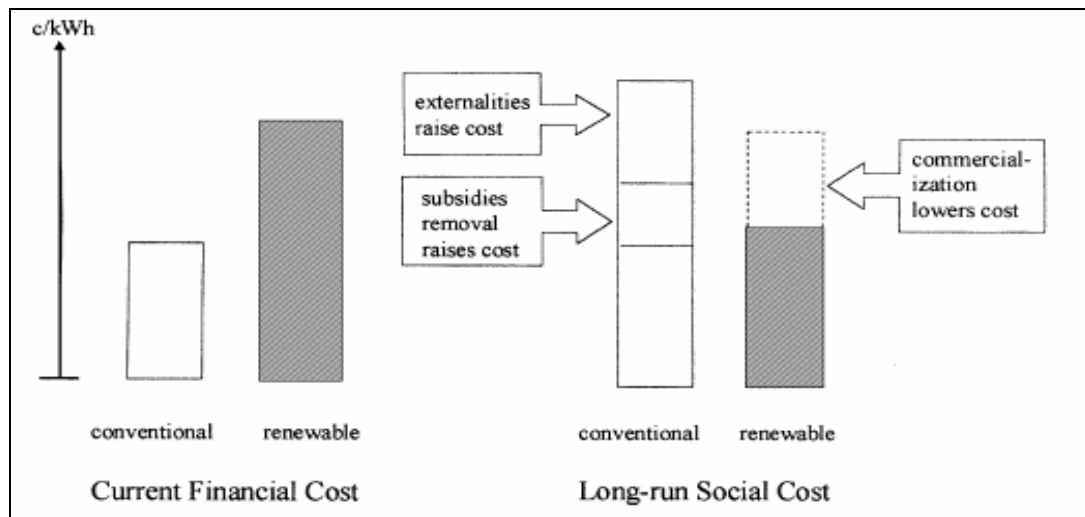
## CHAPTER 9 SUMMARY OF FINDINGS

The energy insecurity dilemma in Ghana where demand for energy services is desperately needed for survival and sustainable development, coupled with high deforestation rate (22,000 hectares or 2.1% per annum) [(Hagan, 1994)] partly due to energy utilization; threat of desertification and land degradation (soil erosion) leaves Ghana with no other option than to exploit utilization of its renewable energy resources. RETs exploitation can offset significantly the proportion of foreign exchange used in importation of electricity from neighbouring countries and oil for electricity generation. RET applications utilize locally available resources and expertise and therefore provided employment opportunities for the locals in Ghana.

However, the success of RETs in the Ghana has been limited by a combination of factors which include: poor institutional framework and infrastructure; inadequate RET planning policies; lack of co-ordination and linkage in the RET programme; pricing distortions which have placed renewable energy at a disadvantage; high initial capital costs; weak dissemination strategies; lack of skilled manpower; poor baseline information; and, weak maintenance, service and infrastructure. The RE scenario will look much better if subsidies were removed and externality costs included in conventional energy, where the costs of conventional electricity sources could rise substantially (Figure 9.1). At the same time, renewables costs could decrease as a result of advancing commercialization (Terry & Jaccard, 2001). On the left side of Figure (9.1), it is shown that, from a strict financial cost perspective, most renewables are more expensive than conventional electricity sources. On the right, it shows that the externality cost and subsidies have mainly led to the current financial unattractiveness of renewables. It can also be observed from Figure 9.1 that incorporating externalities and removal of subsidies from conventional energy systems will lead to renewables being a cheaper option.



Figure 9.1 Conventional vs. renewable electricity: financial and social cost comparison.



(Source:Terry & Jaccard, 2001)

Following a resource assessment, four main renewable options were identified having potential viability in Ghana. These are biomass, PV/solar, small hydro and wind. Case study applications of these resources were subjected to extensive and critical analysis for the identification of technically and economically viable options. Results obtained are summarized below;

### 9.1 Biomass

Biomass resource makes up 70% of the energy mix in Ghana (RDREG, 2002). Biomass energy utilization in Ghana involves the following resources; sawmill residues, agricultural wastes, animal waste, municipal wastes and energy crops. Well-tested applications in Ghana of biomass-based technologies are co-generation, biogas production from anaerobic digestion and quite recently bio-diesel production. However, utilization of sawmill residue and energy crops came out to be technically and economically, the most promising for energy purposes.

Sawmill residue of about 132 000 tonnes is wasted annually and could be exploited to generate about 15MW of power annually. It was observed from the analysis of saw dust briquetting (found in chapter 4) that in the event of a 10% increase in production costs, IRR of the project in the best-case scenario reduces to 28% with a discounted payback period of 5.2 years. In the worst case, the IRR reduces to 26% with a discounted payback period of 5.5

years. In the event of a 10% decrease in the estimated total revenue for the project and production costs remain unchanged, the IRR of the venture, in the best case, reduces to 23% with a discounted payback period of 7years. In the same situation, the IRR in worst case reduces to 21% with a discounted payback period of 7.2years. The project on the whole was adjudged to be financially viable, especially in the best-case scenario.

Jatropha is a drought resistant energy crop. Its versatility renders it of immense importance to meeting the energy demands of remote communities that are experiencing the threat of desertification due to excessive land use resulting from increasing population and development pressures. A collaborative development model for rural sustainable development in Ghana using the Jatropha (gender based) system was postulated in this dissertation. The aim of model has been to explore the conditions under which the Jatropha option can represent a valid alternative that fosters more sustainable livelihoods in remote rural communities.

## **9.2 Solar**

Ghana receives an average solar radiation of about 4-6 kWh/m<sup>2</sup>/day and a sunshine duration of 1,800-3,000 hours per annum. Generally, solar radiation levels are good enough to be exploited for electricity generation and direct thermal applications. Large numbers (>4600) of photovoltaic (PV) and solar technology applications have been tested in Ghana (KITE, 2002). Applications include; lighting (>4,200), vaccine refrigeration (210), water pumping (80), telecommunications (63), radio transceivers (34), battery charging stations (20), rural telephone systems (3), grid connected power generation (1).

Techno-economic and barrier analysis on existing projects gave the following results; even though there is capacity to locally manufacture the systems, the systems developed were mostly, robust, inefficient and unreliable. There is however the possibility of improving with increased research and development (R&D). A failed investment is the many (> 4,000) PV rural solar home systems. For many low and middle income rural households in Ghana, the purchase price of a solar home system represents more than one year income. In such impoverished rural communities main energy needs are for mainly for cooking rather than lighting. Ironically PV rural solar home systems are to provide clean energy for lighting purposes as a substitute to kerosene. Difficulty with full cost recovery of PV solar home systems in rural areas renders the application unviable techno-economically. Application of

PV/solar technology systems becomes more viable when the generated electricity end use is tied to existing economic activities in rural communities such as in water pumping for irrigating farm crops. The irrigation will serve to substitute the otherwise dependence on rainfall which is unreliable, leading to a sustainable bumper harvest, improvement in economic status of farmers and subsequently the ability to pay back the investment.

Another techno-economically viable option is in solar crop drying applications in farming communities which would reduce post harvest losses and improve quality of cash crops both for internal consumption and export. A cost benefit analysis (CBA) for a 5 ton capacity locally manufactured solar crop dryer yielded annual profits of \$ US 1, 473.38 at a discount rate of 36% with a simple payback period of 2 years. Results obtained from RETScreen analysis also came out with similar findings yielding profitability index (PI) of 3.88 at 36% discount rate and a Net Present Value (NPV) of \$ US 228 200, which is indicative of a very viable project. Viability of SCDs is even much more attractive at lower discount rates e.g. RETScreen analysis yielded PI and NPV of 13.69 and \$ US 228 200 respectively at 12% discount rate (which is the highest rate set by the World Bank for loans on such projects).

A cost benefit analysis undertaken for a locally manufactured Solar Water Heating System (SWH) resulted in the conclusion that under the current tariff regime of \$ US 0.04/kWh, SWH are not viable. The payback period for the system is about 22 years, which is too long from a purely economic standpoint.

Other PV/solar technology applications like vaccine refrigeration, powering rural health centres and telecommunications though not competitive with conventional energy sources can however be considered depending on the community's remoteness from the central grid and reliability of the supporting back up system, also if there happens to be no suitable alternative than PV/solar.

### **9.3 Small Hydro Power**

Six main sites have recently been identified for potentially viable Small Hydro Projects (SHP), however the continued high deforestation rate in the catchment areas of the 6 sites and the draining of the wetlands for agricultural, commercial and domestic purposes have led to the extremely unfavourable flow duration curves in these rivers. This coupled with a long dry season of up to about 7 months, renders SHP an unfavourable RE option in Ghana. Techno-

economic analysis undertaken on Wli Fall which is the best identified site with the highest head flow resulted in a *Net Present Value* (NPV) of about-\$ US 3 500 000, a *Simple Payback* of 23.9 years and a *Benefit-Cost (B-C)* ratio of 0.65 at a *Plant Capacity Factor* of 75% using the RETScreen software. This result implies that SHPs are not techno-economically viable to make any meaningful contribution to the national power demand when the electricity tariff remains as low as \$ US 0.04/kWh. However, in the event of an increment in electricity tariff to \$ US 0.08/kWh, a *B-C* ratio of 3.30 will be achieved which is indicative of a very techno-economically viable investment yielding a NPV of over \$ US 4 800 000 and a simple payback period of about 9.3 years. The other 5 sites were not techno-economically viable for electricity generation when analyzed with the RETScreen tool. They could be put into other income generating projects such as development of sites for tourist attractions.

#### **9.4 Wind Power**

Main land wind resource assessment undertaken in Ghana came out with very poor speeds of <2m/s for most months in the investigated sites (KITE, 2002) which are impossible to generate electricity using currently prevailing turbine technologies. A more recent wind speed feasibility assessment along the coast of Ghana resulted in wind speeds of between 4.7-5.3 m/s at 10 metres height of measurement (RDREG; 2002). These speeds are adequate for electricity generation. The coastal belt wind speeds obtained were then analyzed with the RETScreen in central grid systems in order to determine the techno-economic viability performance for setting up proposed wind farms in the investigated sites. The calculations were based a discount rate of 12% (12% discount rate is the highest limit based on the World Bank's guidelines).

Most of the projects analyzed were viable (except for Aplaku and Kpone) even at the current highly subsidized convectional electricity tariff of \$ US 0.04 /kWh. Adafoah happens to be the most viable project with a NPV of \$ US 16 482 553 and 1.81 B-C ratio. Year to positive cash flow for Adafoah was as low as 5.3 years.

Investing more money however, in the Aplaku Wind Farm project (i.e. almost doubling the initial investment cost) by purchasing more turbines from 35 to 70, Aplaku becomes viable with B-C ratio of 1.33, IRR of 15.5%, simple payback of 8.2 years and NPV of \$ US 127 637 765 (refer to Wind Farm Appendix), still at the \$ US 0.04/kWh electricity tariff. Kpone however still remains unattractive even upon doubling the initial investment cost. With

advancement in technology and improvement in turbine efficiency, Kpone might possibly be a viable venture in future. Detailed RETScreen analysis of all the projects can be seen in the appendix.

However, in order to avoid the bitter experiences encountered in other countries with the establishment of wind farms, it is recommendable for a social acceptability study to be undertaken on the investigated sites before commencement of wind farms. Such a study should seek to gather and accept the local populace opinion on the projects as that will go a long way to offset any future problems encountered elsewhere in other countries. Issues of noise, shadows, and routes of migratory birds should be properly taken care of. Possibility of setting up wind farms off-shore can also be recommended, in case opinion poll from local communities rejects the proposed projects but this too however, must be subject to meeting other demands like non-interference with navigation electromagnetic signals.

## **9.5 Strategy for Renewables in Ghana**

Based on the entire findings from this study a renewable strategy can be proposed. The strategy serves to meet the energy needs and to promote sustainable development by linking potentially viable RETs and projects to socio-economic activities while simultaneously helping to solve environmental problems. It is important to indicate clearly here that the strategy postulated here is very general and applies mainly to remote communities as urban centres in Areas I, II & III are already connected to the grid. This strategy provides answers to the where, what, why and how to implement viable renewable energy projects in Ghana.

### **Area I**

Along the coastal belt of Ghana, wind farms are the best option because wind speeds obtained here are very adequate to generate electricity using currently available technology. RETScreen analysis showed that about 70% (i.e. 4 out of 6) of the sites investigated are technically and economically viable even under the prevailing highly subsidized low conventional electricity tariff of \$0.04/kWh. Most of the big cities, academic and research institutes are found along the coast of Ghana, thus even though the country has no experience with wind farms there exist the capacity to manage such systems with possibly very little additional training.

## **Area II**

This is the forest zone in Ghana. This zone houses most of the country's carbon sink. Deforestation is occurring at an alarming rate in this region due to tree logging activities for timber, which takes place here and as mentioned in chapter 1 as timber is a main source of foreign exchange in Ghana. Cocoa, another major source of foreign exchange is also cultivated here in Area II.

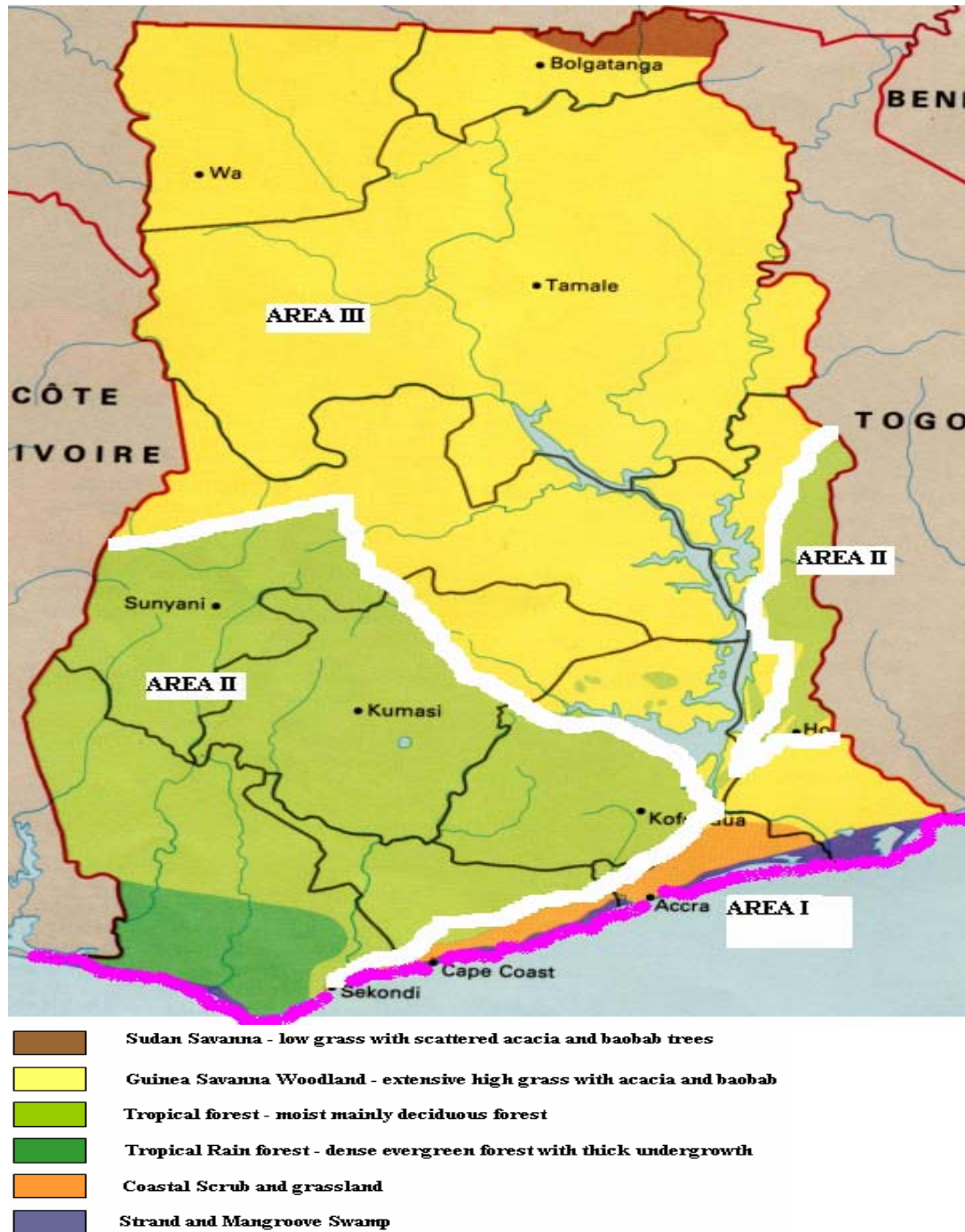
The first renewable energy to be recommended for this area will be biomass energy technologies such as dissemination of low cost but efficient sawdust stoves. Recall that sawmill residue of about 132 000 tons is wasted each year which could be exploited to generate about 15MW of power annually. Sawdust availability for communities distant from the logging activities is an immense hindrance to this strategy, thus education and awareness on tree planting and agro-forestry practices should mainly be encouraged in such localities in order to ensure sustainable utilization of wood resources at least as an immediate to near term policy. Since Area II is already a forested zone, minimum effort is need for trees to grow to maturity when planted. Ad hoc introduction of modern electricity to such remote rural communities in the immediate to near term might fail especially when such modern energy system comes with a high fee to the impoverish populace because they can get wood resources for their energy needs for free from their surroundings. This will be similar to the failed investment the government of Ghana undertook in 1997 by extending electricity to remote rural communities thinking it was going to automatically led to the 'springing up' of light enterprises. What happened however was that no light enterprises were created but instead the communities could not afford to pay even for the service the highly subsidized electricity (tariff of \$ US 0.04 kWh) provided. Access to modern electricity can be introduced however, after putting in place mechanisms that serves to improve the overall economic status of communities and hence their ability to payback the service and the investment. Since major cash crops are cultivated here in Area II; solar crop drying applications can be promoted in such remote farming communities which would serve to reduce post harvest losses and improve quality of cash crops both for internal consumption and export, and subsequently improving economic status of farmers.

## **Area III**

This is a savanna area comprising mainly of grass and with very few trees. Threat of desertification is very obvious in this locality. Large distances are covered, usually by women

and children in order to obtain fuel wood for the household. Soil erosion is quite common here due to the relatively sparse vegetation cover. Subsistence agriculture is principally the major economic activity in this region which depends solely on rainfall that is highly unreliable in recent times. During the rainy season certain communities, usually in the Northern sector of Area III are cut off from other parts of the country due to the fact that access roads are untarred and become unmotorable due to heavy erosions. Most rural communities in this region are remote from the national grid. The Jatropha System can be recommended to Area III. The plant will be utilized to satisfy energy needs and to combating desertification at the same time. The extracted oil can be used in conventional diesel generators without any modification (Henning, 1996, 1998). Since the main economic activity in Area III is agriculture and the rainfall is not very reliable, it can be recommended that the extracted oil be used in running diesel generators for water pumping to irrigate farm lands. This subsequently will lead to bumper harvest and hence improvement in the economic status of farmers and the entire community. Eventually the oil can also be used to generate modern electricity for home lighting, powering rural health facilities etc that will lead to socio-economic improvement in life style. All these attributes from the Jatropha system coupled with the environmental benefit it brings can result in sustainable development of the locality. The Jatropha system thus promotes four main aspects of development which combine to help achieve a sustainable way of life for rural Ghanaian communities in terms of provision of renewable energy, erosion control, economic empowerment through job creation and poverty reduction.

Figure 9.2 Strategy for Renewables in Ghana.



[Source: Map of Ghana from Ghana's Official website, 2005 (modification made to the map with respect to renewable energy strategy)].



## 9.6 Performance Matrix for Renewable Energy in Ghana.

Concluding, Table 9, below provides a relative ranking data on the overall technical and economic viability performance of renewables in Ghana gathered from the study. In the relative ranking exercise for Table 9.1 values of 0-4 were used for each renewable, where 0 is the least value and 4 is the highest. Recall that technical viability used in the study mainly refers to technological capacity in terms of availability of spare parts, the existence of local artisans trained to master all aspects of the technology, and the ability of local people to operate, maintain and fix the technology in case of breakdowns. It can also be recalled that for economic viability the most basic condition for success is the financial profitability of projects, represented by the Net Present Values (NPV), Profitability Index (PI), Benefit Cost (B-C) Ratio, Internal Rate of Return (IRR), etc in the study. It is worth noting that economic viability takes precedence over the technical viability as defined in the study, in that an economically viable project having a high financial profitability but with poor technical viability (defined above) can still be run successfully making use of foreign expertise in the immediate term whilst developing local capacity to take over later. However, the same can not be said vice versa, where there happen to be rich local capacity in terms of technical viability but not enough RE resources to result in financial profitability of projects.

Table 9.1 Relative ranking of RET Performance and Potential in Ghana.

PERFORMANCE				
Parameter	Biomass	PV/Solar	Small Hydro Power	Wind
Economic Viability	3	2	1	4
Technical Viability	3	2	3	3
Average (overall performance)	3	2	2	3.5

Recall also that all the calculations and analysis made in the study were all based BAU situations where renewables were analyzed against a highly subsidized electricity tariff of \$ US 0.04/kWh from conventional sources. This implies that the performance of some

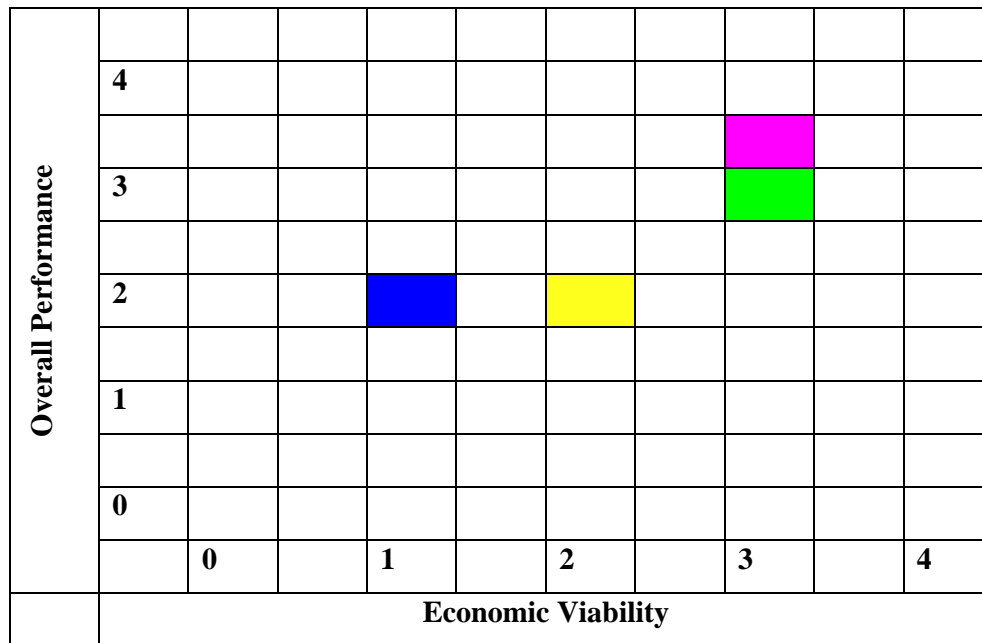
renewables might change when tariff regime, resource availability, policies etc changes. As seen in Table (9.1) wind came out as the renewable option with the best economic viability potential. Since the existing local capacity do not as yet have hands-on experience with wind systems, a bit of capacity building will be required here. Biomass is second in terms of economic viability performance, followed by PV/solar and finally Small Hydro Power. Even though no Small Hydro Power plant has been established yet, there already exist the capacity (in terms of highly qualified expertise) to man such systems due to the fact that Ghana has many years experience with large hydro plants. It is worth mentioning that though the overall financial performances of PV/solar technologies were not very encouraging, that of Solar Crop Dryer (SCD) was exceptionally high with financial performance exceeding even those of wind systems when compared on an individual technology basis.

In order to obtain a much clearer picture on the overall ranking of RETs in Ghana, a matrix was developed (Figure 9.3). Since economic viability has been identified as having precedence over technical viability, the average overall performance was plotted against economic viability in the matrix.

Wind energy offer the best prospect in the Ghanaian renewable energy mix with a high economic viability and overall performance. Biomass energy also offers high economic viability and overall performance. The economic and technical viability of PV/Solar is just average and generally not a good investment, however with the exception of solar crop drying which is quite promising in cash crop growing areas. Small hydro is the weakest renewable option in terms of their technical and economic viability.

Recalling from the research questions raised in the early chapters of this study; it is clearly observable from all the analysis that certain applications of REs such as energy crops (Jatropha), solar crop dryers (SCD) and wind installation capacities are viable technically and economically and can be effectively exploited in the Ghanaian fuel mix. The exploitation of generated energy from the above named renewables when tied to existing economic activities in a locality can serve as engines for local development. As can be seen from the entire study, such viable renewables does not rely on continual donor/external support, instead their successful applications in communities can serve as a 'ripple effect' with a potential of spreading the socio-economic development associated with it to other neighboring communities.

Figure 9.3 Matrix of Overall Performance against Economic Viability of Renewables in Ghana.



On the other hand implementation of RETs such as small hydro power (SHP), solar water heaters (SWH) and solar home systems among others might instead of development rather lead to a ‘development sink’ especially when such technologies are set up as investment projects for impoverished Ghanaian communities. In addition to the already high cost associated with renewables, SWH and Solar home systems (SHS) for an example have poor economic viability when compared to conventional systems and this is additionally compounded by the fact that impoverish rural communities in Ghana are not able to pay even for electricity services from the highly subsidized grid rate of \$ US 0.04/kWh. It is thus very obvious from the above discussions that unviable RE options depending on the locality and socio-economic status of ‘benefiting’ communities can not lead to any meaningful development but rather a development sink. Similar views on the wrong application of certain RETs (such as SHS) set up as investment projects in rural communities of developing countries were also shared by Villavicencio (2003).

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## **APPENDICE**



RETScreen® Energy Model - Solar Air Heating Project

Site Conditions		Estimate	Notes/Range
Project name	<b>Solar Crop Dryer (12% Discount Rate)</b>		
Project location	<b>Kumasi, Ghana</b>		
Nearest location for weather data	Kumasi		<a href="#">Complete SR sheet</a>
Annual solar radiation (tilted surface)	MWh/m <sup>2</sup>	1.59	
Annual average temperature	°C	26.0	
Annual average wind speed	m/s	2.0	

System Characteristics		Estimate	Notes/Range
Heating application type	-	Ventilation air	
<b>Base Case Heating System</b>			
Heating fuel type	-	<b>Diesel (#2 oil)</b>	
Heating system seasonal efficiency	%	75%	0% to 350%
<b>Building</b>			
Building type	-	Industrial	
Minimum delivered air temperature	°C	18.5	5,0 to 21,0
Maximum delivered air temperature	°C	40.0	18,5 to 60,0
Building temperature stratification	°C	2.5	0,0 to 15,0
Floor area served by solar collector	m <sup>2</sup>	1,000	
RSI-value of ceiling	m <sup>2</sup> - °C/W	1.0	0,1 to 10,0
RSI-value of building wall	m <sup>2</sup> - °C/W	2.1	0,1 to 10,0
<b>Airflow Requirements</b>			
Design airflow rate	m <sup>3</sup> /h	72,000	50 to 1.000.000
Operating days per week	d/w	7.0	1,0 to 7,0
Operating hours per day	h/d	24.0	5,0 to 24,0
<b>Solar Collector</b>			
Design objective	-	High efficiency	
Collector colour	-	Black	<a href="#">See Product Database</a>
Solar absorptivity	-	0.95	0,20 to 0,99
Suggested solar collector area	m <sup>2</sup>	500	
Solar collector area	m <sup>2</sup>	500	
Percent shading during season of use	%	0%	0% to 50%
SAH fan flow rate	m <sup>3</sup> /h/m <sup>2</sup>	144	
Average solar collector flow rate	m <sup>3</sup> /h/m <sup>2</sup>	144.0	
Average air temperature rise	°C	5.9	
Incremental fan power	W/m <sup>2</sup>	1.0	0,0 to 7,0

Annual Energy Production (12,0 months analysed)		Estimate	Notes/Range
Incremental fan energy	MWh	<b>4.4</b>	
Specific yield	kWh/m <sup>2</sup>	2,110	
Collector efficiency	%	80%	
Solar availability while operating	%	100%	
Renewable energy collected	MWh	634.5	
Building heat loss recaptured	MWh	0.0	
Destratification savings	MWh	420.5	
Renewable energy delivered	MWh	<b>1,055.0</b>	
	GJ	3798.1	<a href="#">Complete Cost Analysis sheet</a>

RETScreen® Solar Resource - Solar Air Heating Project

Site Latitude and Collector Orientation		Estimate	Notes/Range
Nearest location for weather data		Kumasi	<a href="#">See Weather Database</a>
Latitude of project location	°N	6,72	-90 to 90
Slope of solar collector	°	0.0	00 to 90
Azimuth of solar collector	°	0.0	00 to 180

Monthly Inputs					
Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m <sup>2</sup> /d)	Monthly average temperature (°C)	Monthly average wind speed (m/s)	Monthly average daily radiation in plane of solar collector (kWh/m <sup>2</sup> /d)
January	1.00	4.17	26.1	1.5	4.17
February	1.00	4.69	27.2	2.1	4.69
March	1.00	5.06	27.8	2.1	5.06
April	1.00	5.08	27.2	2.1	5.08
May	1.00	4.97	26.7	2.1	4.97
June	1.00	4.39	26.1	2.1	4.39
July	1.00	3.67	24.4	2.6	3.67
August	1.00	3.36	24.4	2.1	3.36
September	1.00	3.81	24.4	2.1	3.81
October	1.00	4.44	25.6	2.1	4.44
November	1.00	4.67	26.1	1.5	4.67
December	1.00	3.86	25.6	1.5	3.86
			<b>Annual</b>	<b>Season of use</b>	
Solar radiation (horizontal)		MWh/m <sup>2</sup>	1.59	1.59	
Solar radiation (tilted surface)		MWh/m <sup>2</sup>	1.59	1.59	
Average temperature		°C	26.0	26.0	
Average wind speed		m/s	2.0	2.0	

[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Solar Air Heating Project

Type of project:

Currency:

Cost references:

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Development</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Engineering</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Renewable Energy (RE) Equipment</b>							
Solar collector materials	m <sup>2</sup>	500	\$ 63	\$ 31,500	-	-	-
Equipment installation	m <sup>2</sup>	500	\$ 36	\$ 18,000	-	-	-
Cladding material credit	m <sup>2</sup>	-500	\$ 31	\$ (15,500)	-	-	-
Cladding labour credit	m <sup>2</sup>	-500	\$ 20	\$ (10,000)	-	-	-
Incremental transportation	project	0	\$ -	\$ -	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ 24,000	40.8%		
<b>Balance of Equipment</b>							
Fans and ducting materials	L/s	20,000	\$ 2.00	\$ 40,000	-	-	-
Fans and ducting labour	L/s	20,000	\$ 1.50	\$ 30,000	-	-	-
Fan and duct mat'l credit	L/s	-20,000	\$ 1.75	\$ (35,000)	-	-	-
Fan and duct labour credit	L/s	-20,000	\$ 0.50	\$ (10,000)	-	-	-
Incremental transportation	project	0	\$ -	\$ -	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ 25,000	42.5%		
<b>Miscellaneous</b>							
Overhead	%	10%	\$ 49,000	\$ 4,900	-	-	-
Training	p-h	0	\$ -	\$ -	-	-	-
Contingencies	%	10%	\$ 49,000	\$ 4,900	-	-	-
Sub-total :				\$ 9,800	16.7%		
<b>Initial Costs - Total</b>				\$ 58,800	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
Property taxes/Insurance	project	1	\$ 1,000	\$ 1,000	-	-	-
O&M labour	project	0	\$ -	\$ -	-	-	-
Travel and accommodation	p-trip	1	\$ 750	\$ 750	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Contingencies	%	0%	\$ 49,000	\$ -	-	-	-
Sub-total :				\$ 1,750	57.1%		
Fuel/Electricity	kWh	4,380	\$ 0.3000	\$ 1,314	42.9%	-	-
<b>Annual Costs - Total</b>				\$ 3,064	100.0%		

Periodic Costs (Credits)	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
		\$ -	\$ -	-	-
		\$ -	\$ -	-	-
		\$ -	\$ -	-	-
End of project life		\$ -	\$ -	-	-

[Go to GHG Analysis sheet](#)

RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Solar Air Heating Project

Use GHG analysis sheet?

Type of analysis

Background Information		Global Warming Potential of GHG	
<b>Project Information</b>		1 ton CH <sub>4</sub> =	21 tons CO <sub>2</sub> (IPCC 1996)
Project name	Solar Crop Dryer (12% Discount Rate)	1 ton N <sub>2</sub> O =	310 tons CO <sub>2</sub> (IPCC 1996)
Project location	Kumasi, Ghana		

Base Case Electricity System (Reference)							
Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.0%	0.975
Electricity mix	100%	268.5	0.0072	0.0072		8.0%	0.975

Base Case Heating System (Reference)							
Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)		GHG emission factor (t <sub>CO2</sub> /MWh)
Heating system							
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	75.0%		0.359

Proposed Case Heating System (Mitigation)							
Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)		GHG emission factor (t <sub>CO2</sub> /MWh)
Heating system							
Electricity	0.4%	268.5	0.0072	0.0072	100.0%		0.975
Solar	99.6%	0.0	0.0000	0.0000	100.0%		0.000
Heating energy mix	100.0%	1.1	0.0000	0.0000			0.004

GHG Emission Reduction Summary				
Heating system	Base case GHG emission factor (t <sub>CO2</sub> /MWh)	Proposed case GHG emission factor (t <sub>CO2</sub> /MWh)	End-use annual energy delivered (MWh)	Annual GHG emission reduction (t <sub>CO2</sub> )
	0.359	0.004	1055.0	374.33
			Net GHG emission reduction t <sub>CO2</sub> /yr	<b>374.33</b>

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Solar Air Heating Project

Annual Energy Balance					
Project name	Solar Crop Dryer (12% Discount Rate)		Electricity required	MWh	4.4
Project location	Kumasi, Ghana				
Renewable energy delivered	MWh	1,055.0	GHG analysis sheet used?	yes/no	Yes
			Net GHG emission reduction	t <sub>CO2</sub> /yr	374
			Net GHG emission reduction - 30 yrs	t <sub>CO2</sub>	11,230
Heating fuel displaced	-	Diesel (#2 oil)			

Financial Parameters					
Avoided cost of heating energy	\$/L	0.640	Debt ratio	%	0.0%
GHG emission reduction credit	\$/t <sub>CO2</sub>	-	Income tax analysis?	yes/no	No
Retail price of electricity	\$/kWh	0.300			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	30			

Project Costs and Savings				
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>	
Feasibility study	0.0%	\$ -	O&M	\$ 1,750
Development	0.0%	\$ -	Fuel/Electricity	\$ 1,314
Engineering	0.0%	\$ -		
RE equipment	40.8%	\$ 24,000	<b>Annual Costs - Total</b>	<b>\$ 3,064</b>
Balance of equipment	42.5%	\$ 25,000	<b>Annual Savings or Income</b>	
Miscellaneous	16.7%	\$ 9,800	Heating energy savings/income	\$ 83,825
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 58,800</b>	<b>Annual Savings - Total</b>	<b>\$ 83,825</b>
Incentives/Grants		\$ 13,000		
<b>Periodic Costs (Credits)</b>				
	\$	-		
	\$	-		
	\$	-		
End of project life -	\$	-		

Financial Feasibility					
Pre-tax IRR and ROI	%	190.3%	Calculate GHG reduction cost?	yes/no	No
After-tax IRR and ROI	%	190.3%			
Simple Payback	yr	0.6	Project equity	\$	58,800
Year-to-positive cash flow	yr	0.5			
Net Present Value - NPV	\$	995,762			
Annual Life Cycle Savings	\$	123,618			
Profitability Index - PI	-	16.93			

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(45,800)	(45,800)	(45,800)
1	84,843	84,843	39,043
2	89,130	89,130	128,172
3	93,632	93,632	221,805
4	98,361	98,361	320,165
5	103,327	103,327	423,493
6	108,543	108,543	532,036
7	114,021	114,021	646,057
8	119,774	119,774	765,831
9	125,816	125,816	891,647
10	132,161	132,161	1,023,808
11	138,826	138,826	1,162,633
12	145,824	145,824	1,308,458
13	153,174	153,174	1,461,632
14	160,893	160,893	1,622,525
15	169,000	169,000	1,791,525
16	177,513	177,513	1,969,038
17	186,454	186,454	2,155,492
18	195,843	195,843	2,351,335
19	205,703	205,703	2,557,038
20	216,058	216,058	2,773,096
21	226,933	226,933	3,000,029
22	238,353	238,353	3,238,383
23	250,346	250,346	3,488,729
24	262,941	262,941	3,751,669
25	276,167	276,167	4,027,836
26	290,056	290,056	4,317,893
27	304,642	304,642	4,622,535
28	319,960	319,960	4,942,494
29	336,045	336,045	5,278,539
30	352,937	352,937	5,631,476

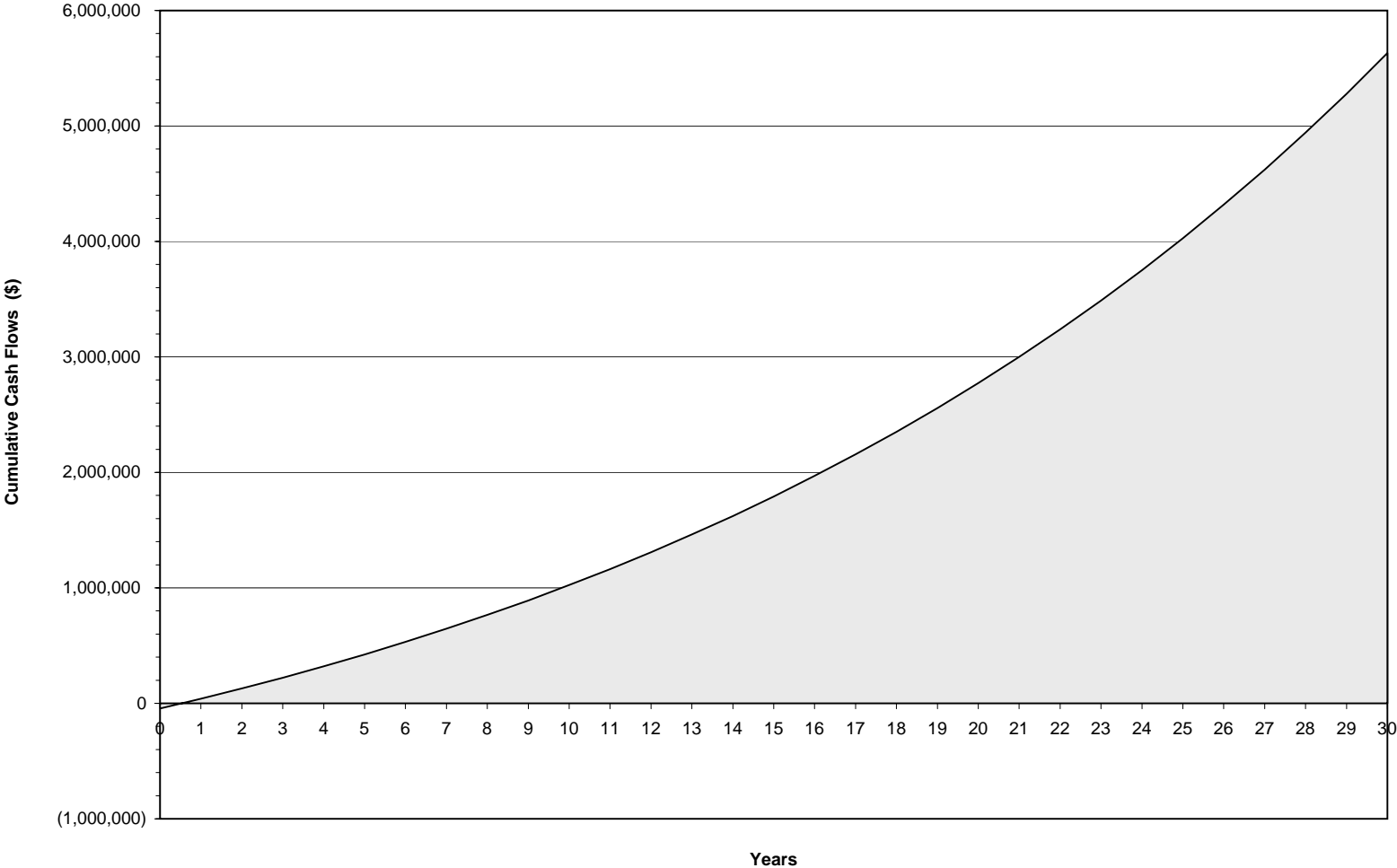
Cumulative Cash Flows Graph

### SAH Project Cumulative Cash Flows Solar Crop Dryer (12% Discount Rate), Kumasi, Ghana

Year-to-positive cash flow 0.5 yr

IRR and ROI 190.3%

Net Present Value \$ 995,762



RETScreen® Energy Model - Solar Air Heating Project

Site Conditions		Estimate	Notes/Range
Project name	Solar Crop Dryer (36% Discount Rate)		
Project location	Kumasi, Ghana		
Nearest location for weather data	Kumasi		<a href="#">Complete SR sheet</a>
Annual solar radiation (tilted surface)	MWh/m <sup>2</sup>	1.59	
Annual average temperature	°C	26.0	
Annual average wind speed	m/s	2.0	

System Characteristics		Estimate	Notes/Range
Heating application type	-	Ventilation air	
<b>Base Case Heating System</b>			
Heating fuel type	-	Diesel (#2 oil)	
Heating system seasonal efficiency	%	75%	0% to 350%
<b>Building</b>			
Building type	-	Industrial	
Minimum delivered air temperature	°C	18.5	5,0 to 21,0
Maximum delivered air temperature	°C	40.0	18,5 to 60,0
Building temperature stratification	°C	2.5	0,0 to 15,0
Floor area served by solar collector	m <sup>2</sup>	1,000	
RSI-value of ceiling	m <sup>2</sup> - °C/W	1.0	0,1 to 10,0
RSI-value of building wall	m <sup>2</sup> - °C/W	2.1	0,1 to 10,0
<b>Airflow Requirements</b>			
Design airflow rate	m <sup>3</sup> /h	72,000	50 to 1.000.000
Operating days per week	d/w	7.0	1,0 to 7,0
Operating hours per day	h/d	24.0	5,0 to 24,0
<b>Solar Collector</b>			
Design objective	-	High efficiency	
Collector colour	-	Black	<a href="#">See Product Database</a>
Solar absorptivity	-	0.95	0,20 to 0,99
Suggested solar collector area	m <sup>2</sup>	500	
Solar collector area	m <sup>2</sup>	500	
Percent shading during season of use	%	0%	0% to 50%
SAH fan flow rate	m <sup>3</sup> /h/m <sup>2</sup>	144	
Average solar collector flow rate	m <sup>3</sup> /h/m <sup>2</sup>	144.0	
Average air temperature rise	°C	5.9	
Incremental fan power	W/m <sup>2</sup>	1.0	0,0 to 7,0

Annual Energy Production (12,0 months analysed)		Estimate	Notes/Range
Incremental fan energy	MWh	4.4	
Specific yield	kWh/m <sup>2</sup>	2,110	
Collector efficiency	%	80%	
Solar availability while operating	%	100%	
Renewable energy collected	MWh	634.5	
Building heat loss recaptured	MWh	0.0	
Destratification savings	MWh	420.5	
Renewable energy delivered	MWh	1,055.0	
	GJ	3798.1	<a href="#">Complete Cost Analysis sheet</a>

RETScreen® Solar Resource - Solar Air Heating Project

Site Latitude and Collector Orientation		Estimate	Notes/Range
Nearest location for weather data		Kumasi	<a href="#">See Weather Database</a>
Latitude of project location	°N	6.72	-90 to 90
Slope of solar collector	°	0.0	00 to 90
Azimuth of solar collector	°	0.0	00 to 180

Monthly Inputs					
Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m <sup>2</sup> /d)	Monthly average temperature (°C)	Monthly average wind speed (m/s)	Monthly average daily radiation in plane of solar collector (kWh/m <sup>2</sup> /d)
January	1.00	4.17	26.1	1.5	4.17
February	1.00	4.69	27.2	2.1	4.69
March	1.00	5.06	27.8	2.1	5.06
April	1.00	5.08	27.2	2.1	5.08
May	1.00	4.97	26.7	2.1	4.97
June	1.00	4.39	26.1	2.1	4.39
July	1.00	3.67	24.4	2.6	3.67
August	1.00	3.36	24.4	2.1	3.36
September	1.00	3.81	24.4	2.1	3.81
October	1.00	4.44	25.6	2.1	4.44
November	1.00	4.67	26.1	1.5	4.67
December	1.00	3.86	25.6	1.5	3.86
			<b>Annual</b>	<b>Season of use</b>	
Solar radiation (horizontal)		MWh/m <sup>2</sup>	1.59	1.59	
Solar radiation (tilted surface)		MWh/m <sup>2</sup>	1.59	1.59	
Average temperature		°C	26.0	26.0	
Average wind speed		m/s	2.0	2.0	

[Return to Energy Model sheet](#)



RETScreen® Cost Analysis - Solar Air Heating Project

Type of project:

Currency:

Cost references:

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Development</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Engineering</b>							
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ -	0.0%		
<b>Renewable Energy (RE) Equipment</b>							
Solar collector materials	m <sup>2</sup>	500	\$ 63	\$ 31,500	-	-	-
Equipment installation	m <sup>2</sup>	500	\$ 36	\$ 18,000	-	-	-
Cladding material credit	m <sup>2</sup>	-500	\$ 31	\$ (15,500)	-	-	-
Cladding labour credit	m <sup>2</sup>	-500	\$ 20	\$ (10,000)	-	-	-
Incremental transportation	project	0	\$ -	\$ -	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ 24,000	40.8%		
<b>Balance of Equipment</b>							
Fans and ducting materials	L/s	20,000	\$ 2.00	\$ 40,000	-	-	-
Fans and ducting labour	L/s	20,000	\$ 1.50	\$ 30,000	-	-	-
Fan and duct mat'l credit	L/s	-20,000	\$ 1.75	\$ (35,000)	-	-	-
Fan and duct labour credit	L/s	-20,000	\$ 0.50	\$ (10,000)	-	-	-
Incremental transportation	project	0	\$ -	\$ -	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Sub-total :				\$ 25,000	42.5%		
<b>Miscellaneous</b>							
Overhead	%	10%	\$ 49,000	\$ 4,900	-	-	-
Training	p-h	0	\$ -	\$ -	-	-	-
Contingencies	%	10%	\$ 49,000	\$ 4,900	-	-	-
Sub-total :				\$ 9,800	16.7%		
<b>Initial Costs - Total</b>				\$ 58,800	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
Property taxes/Insurance	project	1	\$ 1,000	\$ 1,000	-	-	-
O&M labour	project	0	\$ -	\$ -	-	-	-
Travel and accommodation	p-trip	1	\$ 750	\$ 750	-	-	-
Other	Cost	0	\$ -	\$ -	-	-	-
Contingencies	%	0%	\$ 49,000	\$ -	-	-	-
Sub-total :				\$ 1,750	57.1%		
Fuel/Electricity	kWh	4,380	\$ 0.3000	\$ 1,314	42.9%	-	-
<b>Annual Costs - Total</b>				\$ 3,064	100.0%		

Periodic Costs (Credits)	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
		\$ -	\$ -	-	-
		\$ -	\$ -	-	-
		\$ -	\$ -	-	-
End of project life		\$ -	\$ -	-	-

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Solar Air Heating Project**

Use GHG analysis sheet?

Type of analysis

**Background Information**

<b>Project Information</b>		<b>Global Warming Potential of GHG</b>	
Project name	Solar Crop Dryer (36% Discount Rate)	1 ton CH <sub>4</sub> =	21 tons CO <sub>2</sub> (IPCC 1996)
Project location	Kumasi, Ghana	1 ton N <sub>2</sub> O =	310 tons CO <sub>2</sub> (IPCC 1996)

**Base Case Electricity System (Reference)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.0%	0.975
Electricity mix	100%	268.5	0.0072	0.0072		8.0%	0.975

**Base Case Heating System (Reference)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Heating system						
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	75.0%	0.359

**Proposed Case Heating System (Mitigation)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Heating system						
Electricity	0.4%	268.5	0.0072	0.0072	100.0%	0.975
Solar	99.6%	0.0	0.0000	0.0000	100.0%	0.000
Heating energy mix	100.0%	1.1	0.0000	0.0000		0.004

**GHG Emission Reduction Summary**

Heating system	Base case GHG emission factor (t <sub>CO2</sub> /MWh)	Proposed case GHG emission factor (t <sub>CO2</sub> /MWh)	End-use annual energy delivered (MWh)	Annual GHG emission reduction (t <sub>CO2</sub> )
	0.359	0.004	1055.0	374.33
			Net GHG emission reduction	t <sub>CO2</sub> /yr <b>374.33</b>

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Solar Air Heating Project

Annual Energy Balance					
Project name	Solar Crop Dryer (36% Discount Rate)		Electricity required	MWh	4.4
Project location	Kumasi, Ghana				
Renewable energy delivered	MWh	1,055.0	GHG analysis sheet used?	yes/no	Yes
			Net GHG emission reduction	t <sub>CO2</sub> /yr	374
			Net GHG emission reduction - 30 yrs	t <sub>CO2</sub>	11,230
Heating fuel displaced	-	Diesel (#2 oil)			

Financial Parameters					
Avoided cost of heating energy	\$/L	0.640	Debt ratio	%	0.0%
GHG emission reduction credit	\$/t <sub>CO2</sub>	-	Income tax analysis?	yes/no	No
Retail price of electricity	\$/kWh	0.300			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	36.0%			
Project life	yr	30			

Project Costs and Savings				
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>	
Feasibility study	0.0%	\$ -	O&M	\$ 1,750
Development	0.0%	\$ -	Fuel/Electricity	\$ 1,314
Engineering	0.0%	\$ -		
RE equipment	40.8%	\$ 24,000	<b>Annual Costs - Total</b>	<b>\$ 3,064</b>
Balance of equipment	42.5%	\$ 25,000	<b>Annual Savings or Income</b>	
Miscellaneous	16.7%	\$ 9,800	Heating energy savings/income	\$ 83,825
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 58,800</b>	<b>Annual Savings - Total</b>	<b>\$ 83,825</b>
Incentives/Grants		\$ 13,000		
<b>Periodic Costs (Credits)</b>				
	\$	-		
	\$	-		
	\$	-		
End of project life -	\$	-		

Financial Feasibility					
Pre-tax IRR and ROI	%	190.3%	Calculate GHG reduction cost?	yes/no	No
After-tax IRR and ROI	%	190.3%			
Simple Payback	yr	0.6	Project equity	\$	58,800
Year-to-positive cash flow	yr	0.5			
Net Present Value - NPV	\$	228,200			
Annual Life Cycle Savings	\$	82,160			
Profitability Index - PI	-	3.88			

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(45,800)	(45,800)	(45,800)
1	84,843	84,843	39,043
2	89,130	89,130	128,172
3	93,632	93,632	221,805
4	98,361	98,361	320,165
5	103,327	103,327	423,493
6	108,543	108,543	532,036
7	114,021	114,021	646,057
8	119,774	119,774	765,831
9	125,816	125,816	891,647
10	132,161	132,161	1,023,808
11	138,826	138,826	1,162,633
12	145,824	145,824	1,308,458
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17	186,454	186,454	2,155,492
18	195,843	195,843	2,351,335
19	205,703	205,703	2,557,038
20	216,058	216,058	2,773,096
21	226,933	226,933	3,000,029
22	238,353	238,353	3,238,383
23	250,346	250,346	3,488,729
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25	276,167	276,167	4,027,836
26	290,056	290,056	4,317,893
27	304,642	304,642	4,622,535
28	319,960	319,960	4,942,494
29	336,045	336,045	5,278,539
30	352,937	352,937	5,631,476

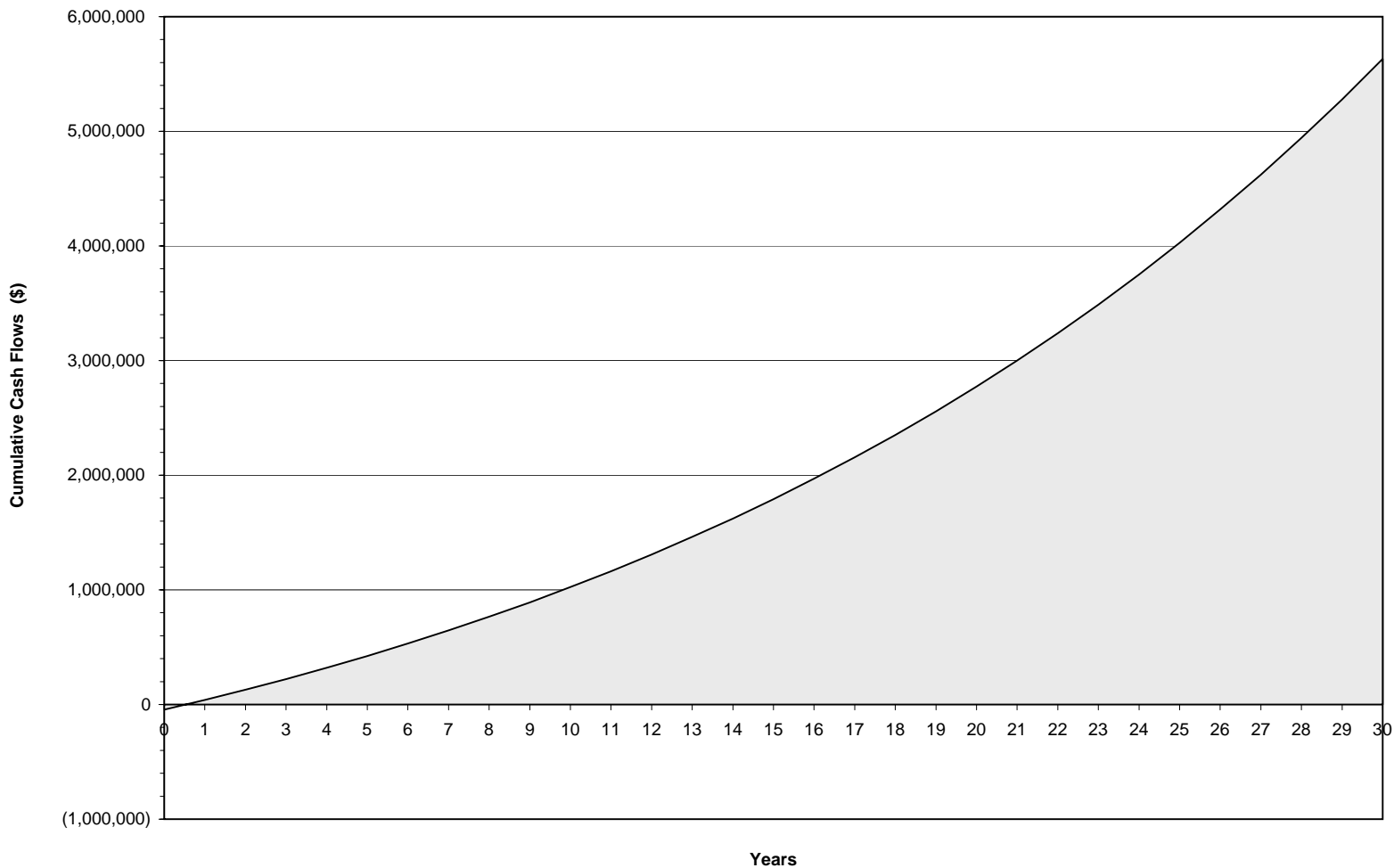
Cumulative Cash Flows Graph

### SAH Project Cumulative Cash Flows Solar Crop Dryer (36% Discount Rate), Kumasi, Ghana

Year-to-positive cash flow 0.5 yr

IRR and ROI 190.3%

Net Present Value \$ 228,200



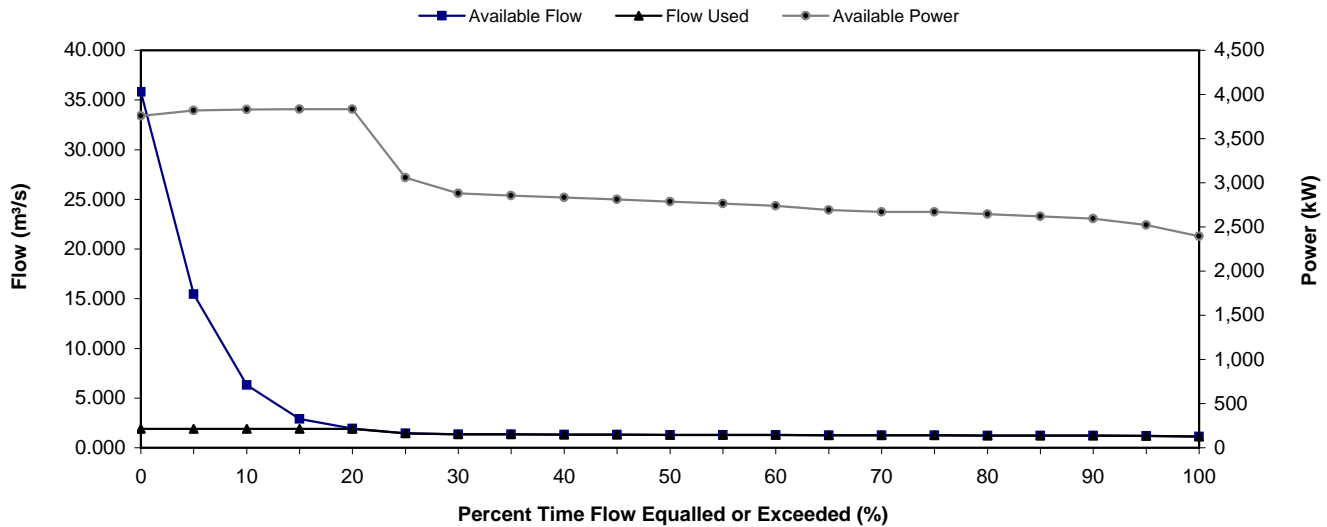
Units: Metric

Site Conditions	Estimate	Notes/Range
Project name	<b>Wli Run-of-River SHP(\$0.04/kWh avoided el</b>	<a href="#">See Online Manual</a>
Project location	<b>Wli Falls, Ghana</b>	
Latitude of project location	°N 9.50	-90.00 to 90.00
Longitude of project location	°E 0.00	-180.00 to 180.00
Gross head	m 264.00	
Maximum tailwater effect	m 5.00	
Residual flow	m³/s 0.50	➔ <a href="#">Complete Hydrology &amp; Load sheet</a>
Firm flow	m³/s 0.98	

System Characteristics	Estimate	Notes/Range
Grid type	- Central-grid	
Design flow	m³/s <b>1.900</b>	➔ <a href="#">Complete Equipment Data sheet</a>
Turbine type	- Francis	
Number of turbines	turbine 1	
Turbine peak efficiency	% 91.9%	
Turbine efficiency at design flow	% 89.0%	
Maximum hydraulic losses	% 5%	2% to 7%
Generator efficiency	% 95%	93% to 97%
Transformer losses	% 1%	1% to 2%
Parasitic electricity losses	% 2%	1% to 3%
Annual downtime losses	% 4%	2% to 7%

Annual Energy Production	Estimate	Notes/Range
Small hydro plant capacity	kW 3,833	
	<span style="border: 1px solid black; padding: 2px;">MW</span> 3,833	
Small hydro plant firm capacity	kW <b>2,028</b>	
Available flow adjustment factor	- <b>1.10</b>	
Small hydro plant capacity factor	% 75%	40% to 95%
Renewable energy delivered	MWh <b>25,039</b>	
	<span style="border: 1px solid black; padding: 2px;">GJ</span> 90,141	

**Flow-Duration and Power Curves**



[Complete Cost Analysis sheet](#)

RETScreen® Hydrology Analysis and Load Calculation - Small Hydro Project

Hydrology Analysis		Estimate	Notes/Range
Project type		Run-of-river	
Hydrology method		User-defined	
<b>Hydrology Parameters</b>			
Residual flow	m³/s	0.5	
Percent time firm flow available	%	100%	90% to 100%
Firm flow	m³/s	0.98	
<b>Flow-Duration Curve Data</b>			
<b>Time</b>	<b>Flow</b>		
<b>(%)</b>	<b>(m³/s)</b>		
0%	33.00		
5%	14.50		
10%	6.20		
15%	3.10		
20%	2.20		
25%	1.76		
30%	1.68		
35%	1.67		
40%	1.66		
45%	1.65		
50%	1.64		
55%	1.63		
60%	1.62		
65%	1.60		
70%	1.59		
75%	1.59		
80%	1.58		
85%	1.57		
90%	1.56		
95%	1.53		
100%	1.48		

**Flow-Duration Curve**

Load Characteristics	Estimate	Notes/Range
Grid type	Central-grid	

[Return to Energy Model sheet](#)

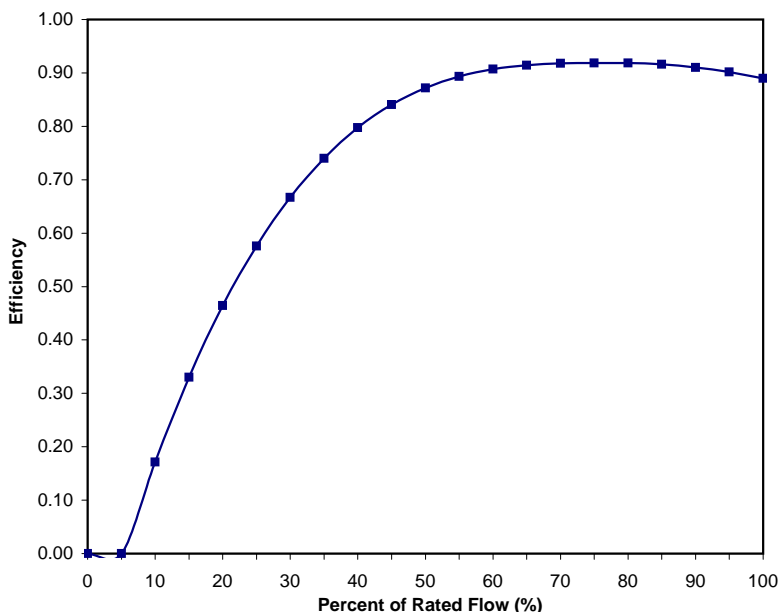
RETScreen® Equipment Data - Small Hydro Project

Small Hydro Turbine Characteristics		Estimate	Notes/Range
Gross head	m	264.00	
Design flow	m³/s	1.900	
Turbine type	-	Francis	<a href="#">See Product Database</a>
Turbine efficiency curve data source	-	Standard	
Number of turbines	turbine	1	
Small hydro turbine manufacturer	-	ABC Ltd.	
Small hydro turbine model	-	model XYZ	
Turbine manufacture/design coefficient	-	4.5	2.8 to 6.1; Default = 4.5
Efficiency adjustment	%	0%	-5% to 5%
Turbine peak efficiency	%	91.9%	
Flow at peak efficiency	m³/s	1.5	
Turbine efficiency at design flow	%	89.0%	

Turbine Efficiency Curve Data

Flow (%)	Turbine efficiency	Turbines running #	Combined turbine efficiency
0%	0.00	0	0.00
5%	0.00	1	0.00
10%	0.17	1	0.17
15%	0.33	1	0.33
20%	0.46	1	0.46
25%	0.58	1	0.58
30%	0.67	1	0.67
35%	0.74	1	0.74
40%	0.80	1	0.80
45%	0.84	1	0.84
50%	0.87	1	0.87
55%	0.89	1	0.89
60%	0.91	1	0.91
65%	0.91	1	0.91
70%	0.92	1	0.92
75%	0.92	1	0.92
80%	0.92	1	0.92
85%	0.92	1	0.92
90%	0.91	1	0.91
95%	0.90	1	0.90
100%	0.89	1	0.89

Efficiency Curve - 1 Turbine(s)



[Return to Energy Model sheet](#)

Costing method: **Detailed**

Currency: **USA**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Site investigation	p-d	60.0	USD 600	USD 36,000	0.3%	-	-
Hydrologic assessment	p-d	40.0	USD 500	USD 20,000	0.2%	-	-
Environmental assessment	p-d	120.0	USD 500	USD 60,000	0.6%	-	-
Preliminary design	p-d	50.0	USD 500	USD 25,000	0.2%	-	-
Detailed cost estimate	p-d	20.0	USD 600	USD 12,000	0.1%	-	-
GHG baseline study and MP	project	0	USD -	USD -	0.0%	-	-
Report preparation	p-d	20.0	USD 700	USD 14,000	0.1%	-	-
Project management	p-d	25.0	USD 700	USD 17,500	0.2%	-	-
Travel and accommodation	p-trip	10	USD 5,000	USD 50,000	0.5%	-	-
Other - Feasibility study	Cost	0	USD -	USD -	0.0%	-	-
Credit - Feasibility study	Credit	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 234,500</b>	<b>2.2%</b>		
<b>Development</b>							
PPA negotiation	p-d	40.0	USD 1,000	USD 40,000	0.4%	-	-
Permits and approvals	p-d	40.0	USD 700	USD 28,000	0.3%	-	-
Land rights	site	1	USD 50,000	USD 50,000	0.5%	-	-
Land survey	p-d	30.0	USD 500	USD 15,000	0.1%	-	-
GHG validation and registration	project	0	USD -	USD -	0.0%	-	-
Project financing	p-d	40.0	USD 1,500	USD 60,000	0.6%	-	-
Legal and accounting	p-d	25.0	USD 1,200	USD 30,000	0.3%	-	-
Project management	p-yr	0.50	USD 130,000	USD 65,000	0.6%	-	-
Travel and accommodation	p-trip	10	USD 2,500	USD 25,000	0.2%	-	-
Other - Development	Cost	0	USD -	USD -	0.0%	-	-
Credit - Development	Credit	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 313,000</b>	<b>3.0%</b>		
<b>Engineering</b>							
Design and tender documents	p-yr	1.00	USD 130,000	USD 130,000	1.2%	-	-
Contracting	p-d	25.0	USD 700	USD 17,500	0.2%	-	-
Construction supervision	p-yr	1.00	USD 130,000	USD 130,000	1.2%	-	-
Other - Engineering	Cost	0	USD -	USD -	0.0%	-	-
Credit - Engineering	Credit	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 277,500</b>	<b>2.6%</b>		
<b>Energy Equipment</b>							
Turbines/generators, controls	kW	3,833	USD 500	USD 1,916,373	18.2%	-	-
Equipment installation	%	10%	USD 1,916,373	USD 191,637	1.8%	-	-
Transportation	%	10%	USD 1,916,373	USD 191,637	1.8%	-	-
Other - Energy equipment	Cost	0	USD -	USD -	0.0%	-	-
Credit - Energy equipment	Credit	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 2,299,647</b>	<b>21.8%</b>		
<b>Balance of Plant</b>							
Access road	km	10.0	USD 50,000	USD 500,000	4.7%	-	-
Clearing	ha	12.0	USD 20,000	USD 240,000	2.3%	-	-
Earth excavation	m³	300.0	USD 10	USD 3,000	0.0%	-	-
Rock excavation	m³	1,000.0	USD 60	USD 60,000	0.6%	-	-
Concrete dam	m³	400	USD 1,000	USD 400,000	3.8%	-	-
Timber crib dam	m³	0	USD -	USD -	0.0%	-	-
Earthfill dam	m³	0	USD -	USD -	0.0%	-	-
Dewatering	%	10%	USD 400,000	USD 40,000	0.4%	-	-
Spillway	m³	0	USD -	USD -	0.0%	-	-
Canal	m³	1,500	USD 50	USD 75,000	0.7%	-	-
Intake	m³	500	USD 1,200	USD 600,000	5.7%	-	-
Tunnel	m³	7,000	USD 150	USD 1,050,000	10.0%	-	-
Pipeline/penstock	kg	60,000	USD 7	USD 420,000	4.0%	-	-
Powerhouse civil	m³	300	USD 1,200	USD 360,000	3.4%	-	-
Fishway	m lift	0.0	USD -	USD -	0.0%	-	-
Transmission line	km	15.0	USD 36,667	USD 550,000	5.2%	-	-
Substation	project	1.0	USD 200,000	USD 200,000	1.9%	-	-
Transportation	%	8%	USD 4,498,000	USD 359,840	3.4%	-	-
Other - Balance of plant	Cost	0	USD -	USD -	0.0%	-	-
Credit - Balance of plant	Credit	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 4,857,840</b>	<b>46.1%</b>		
<b>Miscellaneous</b>							
Special equipment	project	0	USD -	USD -	0.0%	-	-
Contractor's overhead	%	15%	USD 4,857,840	USD 728,676	6.9%	-	-
Training	p-d	20.0	USD 700	USD 14,000	0.1%	-	-
Contingencies	%	15%	USD 8,725,163	USD 1,308,775	12.4%	-	-
Interest during construction	10.0%	12 month(s)	USD 10,033,938	USD 501,697	4.8%	-	-
Other - Miscellaneous	Cost	0	USD -	USD -	0.0%	-	-
<b>Sub-total:</b>				<b>USD 2,553,147</b>	<b>24.2%</b>		
<b>Initial Costs - Total</b>				<b>USD 10,535,635</b>	<b>100.0%</b>		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
Land lease	project	1	USD -	USD -	-	-	-
Property taxes	%	0.0%	USD 10,535,635	USD -	-	-	-
Water rental	kW	3,833	USD -	USD -	-	-	-
Insurance premium	%	0.40%	USD 10,535,635	USD 42,143	-	-	-
Transmission line maintenance	%	5.0%	USD 750,000	USD 37,500	-	-	-
Spare parts	%	0.50%	USD 10,535,635	USD 52,678	-	-	-
O&M labour	p-yr	2.00	USD 35,000	USD 70,000	-	-	-
GHG monitoring and verification	project	0	USD -	USD -	-	-	-
Travel and accommodation	p-trip	6	USD 1,000	USD 6,000	-	-	-
General and administrative	%	10%	USD 208,321	USD 20,832	-	-	-
Other - O&M	Cost	0	USD -	USD -	-	-	-
Contingencies	%	10%	USD 229,153	USD 22,915	-	-	-
<b>Annual Costs - Total</b>				<b>USD 252,068</b>	<b>100.0%</b>		

Periodic Costs (Credits)	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Turbine overhaul	Cost	20 yr USD 200,000	USD 200,000	-	-
			USD -	-	-
			USD -	-	-
End of project life	Credit	- USD 1,500,000	USD (1,500,000)	-	-

[Go to GHG Analysis sheet](#)



**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Small Hydro Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>		<b>Global Warming Potential of GHG</b>	
Project name	Wli Run-of-River SHP(\$0.04/kWh) Project capacity	2.03 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub> (IPCC 1996)
Project location	Wli Falls, Ghana	Grid type Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O (IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Biomass	70.0%	0.0	0.0320	0.0040	25.0%	8.0%	0.030
Diesel (#2 oil)	20.0%	74.1	0.0020	0.0020	30.0%		0.897
Large hydro	10.0%	0.0	0.0000	0.0000	100.0%		0.000
Electricity mix	100%	49.4	0.0987	0.0135		5.6%	0.200

Does baseline change during project life?

**Proposed Case Electricity System (Small Hydro Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Electricity system							
Small hydro	100.0%	0.0	0.0000	0.0000	100.0%	8.0%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.200	0.000	23,036	4,616	0.0%

[Complete Financial Summary sheet](#)

**RETScreen® Financial Summary - Small Hydro Project**

Annual Energy Balance					
Project name Wli Run-of-River SHP(\$0.04/kWh avoided elect)					
Project location Wli Falls, Ghana					
Renewable energy delivered	MWh	25,039	Net GHG reduction	t <sub>CO2</sub> /yr	4,616
Excess RE available	MWh	-			
Firm RE capacity	kW	2,028			
Grid type		Central-grid	Net GHG emission reduction - 35 yrs	t <sub>CO2</sub>	161,557

Financial Parameters					
Avoided cost of energy	USD/kWh	0.0400	Debt ratio	%	80.0%
RE production credit	USD/kWh	-	Debt interest rate	%	9.0%
			Debt term	yr	15
GHG emission reduction credit	USD/t <sub>CO2</sub>	-	Income tax analysis?	yes/no	No
Avoided cost of capacity	USD/kW-yr	-			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	35			

Project Costs and Savings						
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>			
Feasibility study	2.2%	USD	234,500	O&M	USD	252,068
Development	3.0%	USD	313,000			
Engineering	2.6%	USD	277,500	Debt payments - 15 yrs	USD	1,045,631
Energy equipment	21.8%	USD	2,299,647	<b>Annual Costs and Debt - Total</b>	<b>USD</b>	<b>1,297,699</b>
Balance of plant	46.1%	USD	4,857,840			
Miscellaneous	24.2%	USD	2,553,147	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>USD</b>	<b>10,535,635</b>	Energy savings/income	USD	1,001,568
Incentives/Grants		USD	-	Capacity savings/income	USD	-
				<b>Annual Savings - Total</b>	<b>USD</b>	<b>1,001,568</b>
<b>Periodic Costs (Credits)</b>						
Turbine overhaul		USD	200,000	Schedule yr # 20		
		USD	-			
		USD	-			
End of project life - Credit		USD	(1,500,000)	Schedule yr # 35		

Financial Feasibility					
Pre-tax IRR and ROI	%	14.6%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	14.6%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	14.1			
Year-to-positive cash flow	yr	14.6	Project equity	USD	2,107,127
Net Present Value - NPV	USD	1,661,224	Project debt	USD	8,428,508
Annual Life Cycle Savings	USD	203,195	Debt payments	USD/yr	1,045,631
Benefit-Cost (B-C) ratio	-	1.79	Debt service coverage	-	0.76

Yearly Cash Flows			
Year #	Pre-tax USD	After-tax USD	Cumulative USD
0	(2,107,127)	(2,107,127)	(2,107,127)
1	(252,355)	(252,355)	(2,359,482)
2	(206,232)	(206,232)	(2,565,714)
3	(157,641)	(157,641)	(2,723,355)
4	(106,456)	(106,456)	(2,829,811)
5	(52,541)	(52,541)	(2,882,352)
6	4,243	4,243	(2,878,108)
7	64,045	64,045	(2,814,063)
8	127,020	127,020	(2,687,043)
9	193,330	193,330	(2,493,713)
10	263,148	263,148	(2,230,565)
11	336,654	336,654	(1,893,911)
12	414,037	414,037	(1,479,874)
13	495,495	495,495	(984,379)
14	581,238	581,238	(403,140)
15	671,486	671,486	268,346
16	1,812,100	1,812,100	2,080,446
17	1,912,060	1,912,060	3,992,506
18	2,017,252	2,017,252	6,009,757
19	2,127,943	2,127,943	8,137,700
20	1,916,691	1,916,691	10,054,391
21	2,366,961	2,366,961	12,421,352
22	2,495,893	2,495,893	14,917,245
23	2,631,537	2,631,537	17,548,782
24	2,774,234	2,774,234	20,323,015
25	2,924,343	2,924,343	23,247,359
26	3,082,243	3,082,243	26,329,602
27	3,248,331	3,248,331	29,577,933
28	3,423,022	3,423,022	33,000,955
29	3,606,754	3,606,754	36,607,709
30	3,799,988	3,799,988	40,407,696
31	4,003,205	4,003,205	44,410,902
32	4,216,914	4,216,914	48,627,816
33	4,441,647	4,441,647	53,069,463
34	4,677,964	4,677,964	57,747,428
35	8,486,261	8,486,261	66,233,688

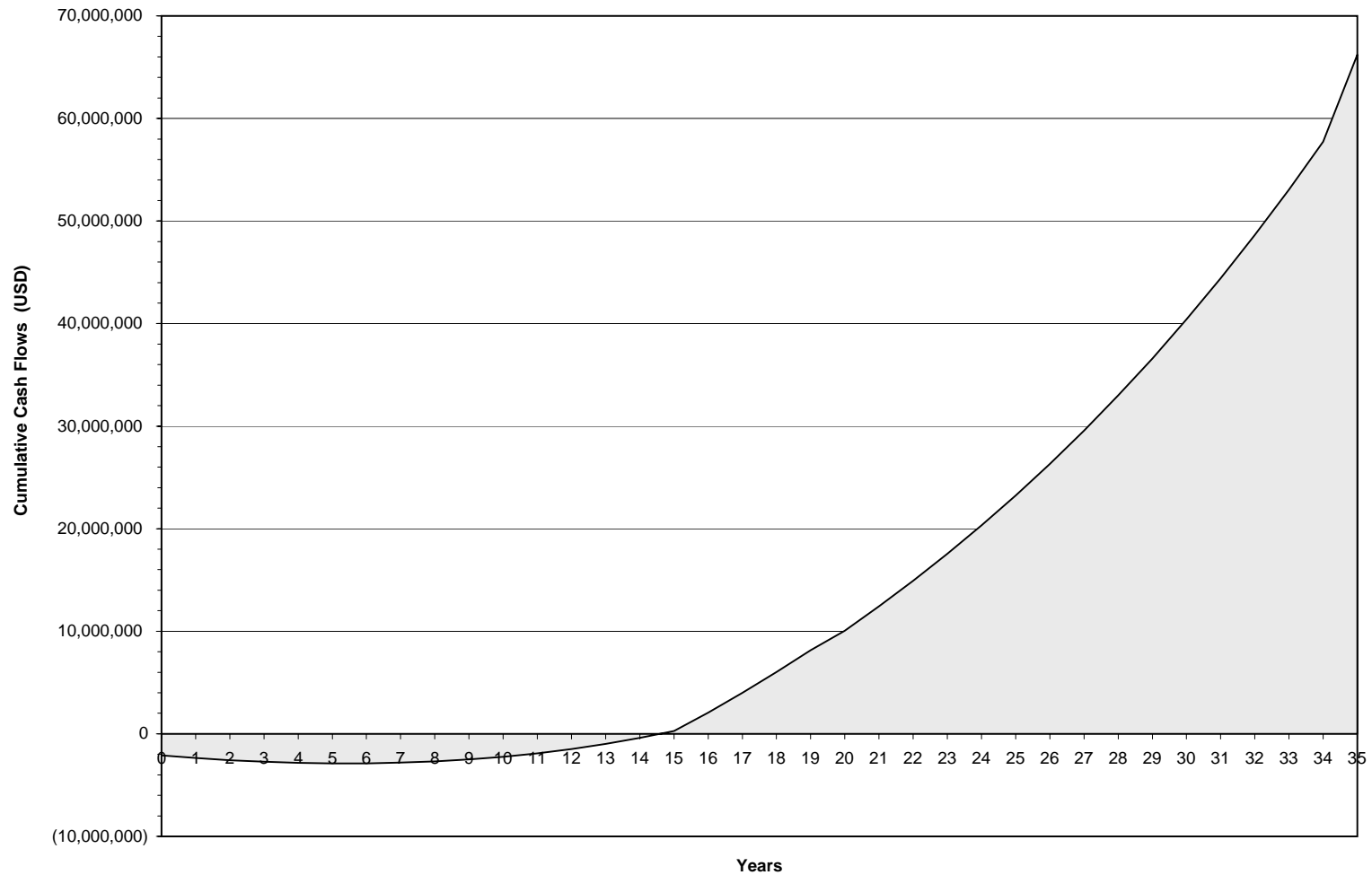
Cumulative Cash Flows Graph

### Small Hydro Project Cumulative Cash Flows Wli Run-of-River SHP(\$0.04/kWh avoided elect), Wli Falls, Ghana

Renewable energy delivered (MWh/yr): 25,039

Total Initial Costs: USD 10,535,635

Net average GHG reduction (t<sub>CO2</sub>/yr): 4,616



IRR and ROI: 14.6%

Year-to-positive cash flow: 14.6 yr

Net Present Value: USD 1,661,224

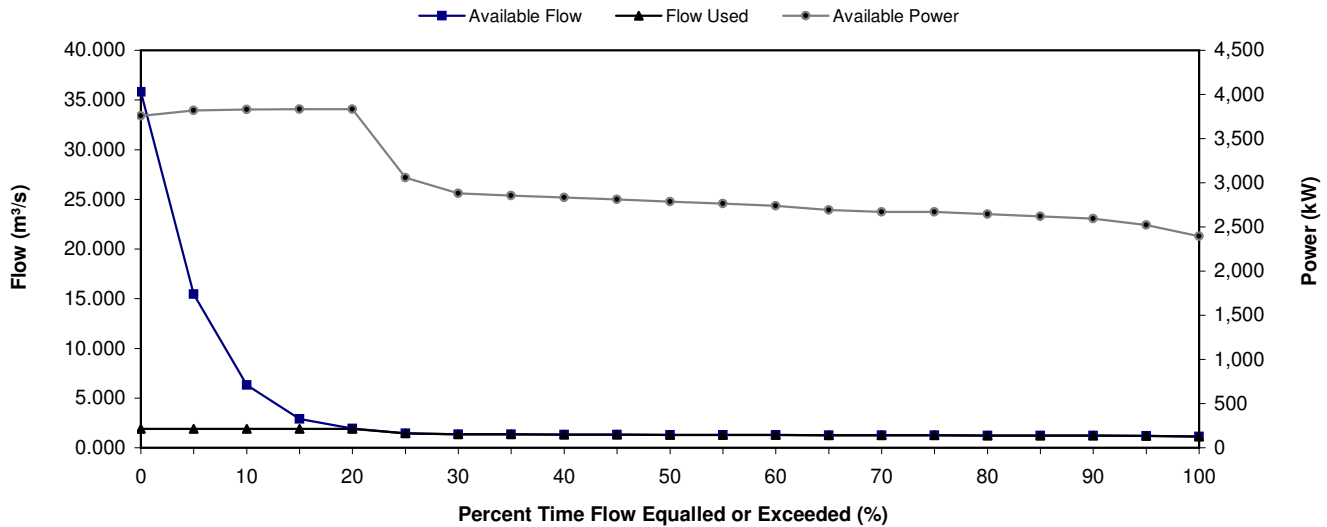
Units: Metric

Site Conditions	Estimate	Notes/Range
Project name	<b>Wli Run-of-River SHP(\$0.08/kWh avoided electrici</b>	
Project location	<b>Wli Falls, Ghana</b>	
Latitude of project location	°N 9.50	-90.00 to 90.00
Longitude of project location	°E 0.00	-180.00 to 180.00
Gross head	m 264.00	
Maximum tailwater effect	m 5.00	
Residual flow	m³/s 0.50	➔ <a href="#">Complete Hydrology &amp; Load sheet</a>
Firm flow	m³/s 0.98	

System Characteristics	Estimate	Notes/Range
Grid type	- Central-grid	
Design flow	m³/s <b>1.900</b>	➔ <a href="#">Complete Equipment Data sheet</a>
Turbine type	- Francis	
Number of turbines	turbine 1	
Turbine peak efficiency	% 91.9%	
Turbine efficiency at design flow	% 89.0%	
Maximum hydraulic losses	% 5%	2% to 7%
Generator efficiency	% 95%	93% to 97%
Transformer losses	% 1%	1% to 2%
Parasitic electricity losses	% 2%	1% to 3%
Annual downtime losses	% 4%	2% to 7%

Annual Energy Production	Estimate	Notes/Range
Small hydro plant capacity	kW 3,833	
	<span style="border: 1px solid black; padding: 2px;">MW</span> 3.833	
Small hydro plant firm capacity	kW 2,028	
Available flow adjustment factor	- 1.10	
Small hydro plant capacity factor	% 75%	40% to 95%
Renewable energy delivered	MWh 25,039	
	<span style="border: 1px solid black; padding: 2px;">GJ</span> 90,141	

**Flow-Duration and Power Curves**



[Complete Cost Analysis sheet](#)

**RETScreen® Hydrology Analysis and Load Calculation - Small Hydro Project**

Hydrology Analysis		Estimate	Notes/Range
Project type		Run-of-river	
Hydrology method		User-defined	
<b>Hydrology Parameters</b>			
Residual flow	m³/s	0.5	
Percent time firm flow available	%	100%	90% to 100%
Firm flow	m³/s	0.98	
<b>Flow-Duration Curve Data</b>			
<b>Time</b>	<b>Flow</b>		
(%)	(m³/s)		
0%	33.00		
5%	14.50		
10%	6.20		
15%	3.10		
20%	2.20		
25%	1.76		
30%	1.68		
35%	1.67		
40%	1.66		
45%	1.65		
50%	1.64		
55%	1.63		
60%	1.62		
65%	1.60		
70%	1.59		
75%	1.59		
80%	1.58		
85%	1.57		
90%	1.56		
95%	1.53		
100%	1.48		

**Flow-Duration Curve**

Percent Time Flow Equalled or Exceeded (%)	Flow (m³/s)
0	33.00
5	14.50
10	6.20
15	3.10
20	2.20
25	1.76
30	1.68
35	1.67
40	1.66
45	1.65
50	1.64
55	1.63
60	1.62
65	1.60
70	1.59
75	1.59
80	1.58
85	1.57
90	1.56
95	1.53
100	1.48

Load Characteristics	Estimate	Notes/Range
Grid type	Central-grid	
<a href="#">Return to Energy Model sheet</a>		

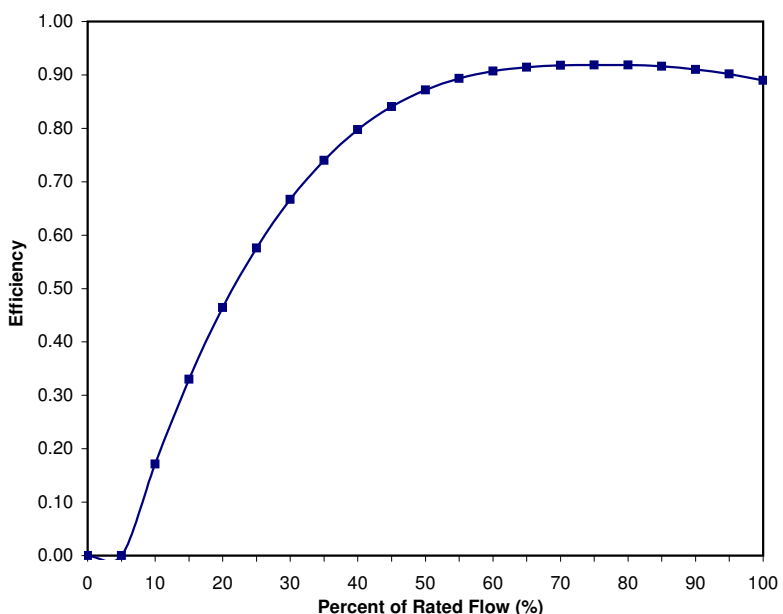
RETScreen® Equipment Data - Small Hydro Project

Small Hydro Turbine Characteristics		Estimate	Notes/Range
Gross head	m	264.00	
Design flow	m³/s	1.900	
Turbine type	-	Francis	<a href="#">See Product Database</a>
Turbine efficiency curve data source	-	Standard	
Number of turbines	turbine	1	
Small hydro turbine manufacturer	-	ABC Ltd.	
Small hydro turbine model	-	model XYZ	
Turbine manufacture/design coefficient	-	4.5	2.8 to 6.1; Default = 4.5
Efficiency adjustment	%	0%	-5% to 5%
Turbine peak efficiency	%	91.9%	
Flow at peak efficiency	m³/s	1.5	
Turbine efficiency at design flow	%	89.0%	

Turbine Efficiency Curve Data

Flow (%)	Turbine efficiency	Turbines running #	Combined turbine efficiency
0%	0.00	0	0.00
5%	0.00	1	0.00
10%	0.17	1	0.17
15%	0.33	1	0.33
20%	0.46	1	0.46
25%	0.58	1	0.58
30%	0.67	1	0.67
35%	0.74	1	0.74
40%	0.80	1	0.80
45%	0.84	1	0.84
50%	0.87	1	0.87
55%	0.89	1	0.89
60%	0.91	1	0.91
65%	0.91	1	0.91
70%	0.92	1	0.92
75%	0.92	1	0.92
80%	0.92	1	0.92
85%	0.92	1	0.92
90%	0.91	1	0.91
95%	0.90	1	0.90
100%	0.89	1	0.89

Efficiency Curve - 1 Turbine(s)



[Return to Energy Model sheet](#)

Costing method: **Detailed**

Currency: **USA**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Site investigation	p-d	60.0	USD 600	USD 36,000	0.3%	-	-
Hydrologic assessment	p-d	40.0	USD 500	USD 20,000	0.2%	-	-
Environmental assessment	p-d	120.0	USD 500	USD 60,000	0.6%	-	-
Preliminary design	p-d	50.0	USD 500	USD 25,000	0.2%	-	-
Detailed cost estimate	p-d	20.0	USD 600	USD 12,000	0.1%	-	-
GHG baseline study and MP	project	0	USD -	USD -	0.0%	-	-
Report preparation	p-d	20.0	USD 700	USD 14,000	0.1%	-	-
Project management	p-d	25.0	USD 700	USD 17,500	0.2%	-	-
Travel and accommodation	p-trip	10	USD 5,000	USD 50,000	0.5%	-	-
Other - Feasibility study	Cost	0	USD -	USD -	0.0%	-	-
Credit - Feasibility study	Credit	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 234,500</b>	<b>2.2%</b>		
<b>Development</b>							
PPA negotiation	p-d	40.0	USD 1,000	USD 40,000	0.4%	-	-
Permits and approvals	p-d	40.0	USD 700	USD 28,000	0.3%	-	-
Land rights	site	1	USD 50,000	USD 50,000	0.5%	-	-
Land survey	p-d	30.0	USD 500	USD 15,000	0.1%	-	-
GHG validation and registration	project	0	USD -	USD -	0.0%	-	-
Project financing	p-d	40.0	USD 1,500	USD 60,000	0.6%	-	-
Legal and accounting	p-d	25.0	USD 1,200	USD 30,000	0.3%	-	-
Project management	p-yr	0.50	USD 130,000	USD 65,000	0.6%	-	-
Travel and accommodation	p-trip	10	USD 2,500	USD 25,000	0.2%	-	-
Other - Development	Cost	0	USD -	USD -	0.0%	-	-
Credit - Development	Credit	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 313,000</b>	<b>3.0%</b>		
<b>Engineering</b>							
Design and tender documents	p-yr	1.00	USD 130,000	USD 130,000	1.2%	-	-
Contracting	p-d	25.0	USD 700	USD 17,500	0.2%	-	-
Construction supervision	p-yr	1.00	USD 130,000	USD 130,000	1.2%	-	-
Other - Engineering	Cost	0	USD -	USD -	0.0%	-	-
Credit - Engineering	Credit	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 277,500</b>	<b>2.6%</b>		
<b>Energy Equipment</b>							
Turbines/generators, controls	kW	3,833	USD 500	USD 1,916,373	18.2%	-	-
Equipment installation	%	10%	USD 1,916,373	USD 191,637	1.8%	-	-
Transportation	%	10%	USD 1,916,373	USD 191,637	1.8%	-	-
Other - Energy equipment	Cost	0	USD -	USD -	0.0%	-	-
Credit - Energy equipment	Credit	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 2,299,647</b>	<b>21.8%</b>		
<b>Balance of Plant</b>							
Access road	km	10.0	USD 50,000	USD 500,000	4.7%	-	-
Clearing	ha	12.0	USD 20,000	USD 240,000	2.3%	-	-
Earth excavation	m³	300.0	USD 10	USD 3,000	0.0%	-	-
Rock excavation	m³	1,000.0	USD 60	USD 60,000	0.6%	-	-
Concrete dam	m³	400	USD 1,000	USD 400,000	3.8%	-	-
Timber crib dam	m³	0	USD -	USD -	0.0%	-	-
Earthfill dam	m³	0	USD -	USD -	0.0%	-	-
Dewatering	%	10%	USD 400,000	USD 40,000	0.4%	-	-
Spillway	m³	0	USD -	USD -	0.0%	-	-
Canal	m³	1,500	USD 50	USD 75,000	0.7%	-	-
Intake	m³	500	USD 1,200	USD 600,000	5.7%	-	-
Tunnel	m³	7,000	USD 150	USD 1,050,000	10.0%	-	-
Pipeline/penstock	kg	60,000	USD 7	USD 420,000	4.0%	-	-
Powerhouse civil	m³	300	USD 1,200	USD 360,000	3.4%	-	-
Fishway	m lift	0.0	USD -	USD -	0.0%	-	-
Transmission line	km	15.0	USD 36,667	USD 550,000	5.2%	-	-
Substation	project	1.0	USD 200,000	USD 200,000	1.9%	-	-
Transportation	%	8%	USD 4,498,000	USD 359,840	3.4%	-	-
Other - Balance of plant	Cost	0	USD -	USD -	0.0%	-	-
Credit - Balance of plant	Credit	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 4,857,840</b>	<b>46.1%</b>		
<b>Miscellaneous</b>							
Special equipment	project	0	USD -	USD -	0.0%	-	-
Contractor's overhead	%	15%	USD 4,857,840	USD 728,676	6.9%	-	-
Training	p-d	20.0	USD 700	USD 14,000	0.1%	-	-
Contingencies	%	15%	USD 8,725,163	USD 1,308,775	12.4%	-	-
Interest during construction	10.0%	12 month(s)	USD 10,033,938	USD 501,697	4.8%	-	-
Other - Miscellaneous	Cost	0	USD -	USD -	0.0%	-	-
Sub-total:				<b>USD 2,553,147</b>	<b>24.2%</b>		
<b>Initial Costs - Total</b>				<b>USD 10,535,635</b>	<b>100.0%</b>		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
Land lease	project	1	USD -	USD -	-	-	-
Property taxes	%	0.0%	USD 10,535,635	USD -	-	-	-
Water rental	kW	3,833	USD -	USD -	-	-	-
Insurance premium	%	0.40%	USD 10,535,635	USD 42,143	-	-	-
Transmission line maintenance	%	5.0%	USD 750,000	USD 37,500	-	-	-
Spare parts	%	0.50%	USD 10,535,635	USD 52,678	-	-	-
O&M labour	p-yr	2.00	USD 35,000	USD 70,000	-	-	-
GHG monitoring and verification	project	0	USD -	USD -	-	-	-
Travel and accommodation	p-trip	6	USD 1,000	USD 6,000	-	-	-
General and administrative	%	10%	USD 208,321	USD 20,832	-	-	-
Other - O&M	Cost	0	USD -	USD -	-	-	-
Contingencies	%	10%	USD 229,153	USD 22,915	-	-	-
<b>Annual Costs - Total</b>				<b>USD 252,068</b>	<b>100.0%</b>		

Periodic Costs (Credits)	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Turbine overhaul	Cost	20 yr USD 200,000	USD 200,000	-	-
			USD -	-	-
			USD -	-	-
End of project life	Credit	USD 1,500,000	USD (1,500,000)	-	-

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Small Hydro Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>		<b>Global Warming Potential of GHG</b>	
Project name	Wli Run-of-River SHP(\$0.08/kWh : Project capacity	2.03 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub> (IPCC 1996)
Project location	Wli Falls, Ghana	Grid type Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O (IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Biomass	70.0%	0.0	0.0320	0.0040	25.0%	8.0%	0.030
Diesel (#2 oil)	20.0%	74.1	0.0020	0.0020	30.0%		0.897
Large hydro	10.0%	0.0	0.0000	0.0000	100.0%		0.000
Electricity mix	100%	49.4	0.0987	0.0135		5.6%	0.200

Does baseline change during project life?

**Proposed Case Electricity System (Small Hydro Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t <sub>CO2</sub> /MWh)
Electricity system							
Small hydro	100.0%	0.0	0.0000	0.0000	100.0%	8.0%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.200	0.000	23,036	4,616	0.0%

[Complete Financial Summary sheet](#)



**RETScreen® Financial Summary - Small Hydro Project**

Annual Energy Balance					
Project Name - Wli Falls-of-River SHP (\$0.08/kWh avoided electricity cost)					
Project location Wli Falls, Ghana					
Renewable energy delivered	MWh	25,039	Net GHG reduction	t <sub>CO2</sub> /yr	4,616
Excess RE available	MWh	-			
Firm RE capacity	kW	2,028			
Grid type		Central-grid	Net GHG emission reduction - 35 yrs	t <sub>CO2</sub>	161,557

Financial Parameters					
Avoided cost of energy	USD/kWh	0.0800	Debt ratio	%	80.0%
RE production credit	USD/kWh	-	Debt interest rate	%	9.0%
			Debt term	yr	15
GHG emission reduction credit	USD/t <sub>CO2</sub>	-	Income tax analysis?	yes/no	No
Avoided cost of capacity	USD/kW-y	-			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	35			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	2.2%	USD	234,500	O&M	USD 252,068
Development	3.0%	USD	313,000		
Engineering	2.6%	USD	277,500	Debt payments - 15 yrs	USD 1,045,631
Energy equipment	21.8%	USD	2,299,647	<b>Annual Costs and Debt - Total</b>	<b>USD 1,297,699</b>
Balance of plant	46.1%	USD	4,857,840		
Miscellaneous	24.2%	USD	2,553,147	<b>Annual Savings or Income</b>	
<b>Initial Costs - Total</b>	100.0%	<b>USD</b>	<b>10,535,635</b>	Energy savings/income	USD 2,003,135
Incentives/Grants		USD	-	Capacity savings/income	USD -
				<b>Annual Savings - Total</b>	<b>USD 2,003,135</b>
<b>Periodic Costs (Credits)</b>					
Turbine overhaul		USD	200,000	Schedule yr # 20	
		USD	-		
		USD	-		
End of project life - Credit		USD	(1,500,000)	Schedule yr # 35	

Financial Feasibility					
Pre-tax IRR and ROI	%	48.8%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	48.8%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	6.0			
Year-to-positive cash flow	yr	2.4	Project equity	USD	2,107,127
Net Present Value - NPV	USD	15,115,221	Project debt	USD	8,428,508
Annual Life Cycle Savings	USD	1,848,843	Debt payments	USD/yr	1,045,631
Benefit-Cost (B-C) ratio	-	8.17	Debt service coverage	-	1.76

Yearly Cash Flows			
Year #	Pre-tax USD	After-tax USD	Cumulative USD
0	(2,107,127)	(2,107,127)	(2,107,127)
1	799,291	799,291	(1,307,836)
2	897,996	897,996	(409,840)
3	1,001,798	1,001,798	591,959
4	1,110,956	1,110,956	1,702,915
5	1,225,741	1,225,741	2,928,656
6	1,346,440	1,346,440	4,275,096
7	1,473,351	1,473,351	5,748,447
8	1,606,791	1,606,791	7,355,238
9	1,747,090	1,747,090	9,102,329
10	1,894,596	1,894,596	10,996,925
11	2,049,675	2,049,675	13,046,600
12	2,212,708	2,212,708	15,259,308
13	2,384,100	2,384,100	17,643,408
14	2,564,274	2,564,274	20,207,682
15	2,753,673	2,753,673	22,961,355
16	3,998,396	3,998,396	26,959,752
17	4,207,671	4,207,671	31,167,423
18	4,427,644	4,427,644	35,595,067
19	4,658,854	4,658,854	40,253,921
20	4,574,148	4,574,148	44,828,069
21	5,157,291	5,157,291	49,985,360
22	5,425,740	5,425,740	55,411,099
23	5,707,875	5,707,875	61,118,974
24	6,004,389	6,004,389	67,123,364
25	6,316,007	6,316,007	73,439,370
26	6,643,490	6,643,490	80,082,860
27	6,987,640	6,987,640	87,070,500
28	7,349,296	7,349,296	94,419,796
29	7,729,342	7,729,342	102,149,138
30	8,128,705	8,128,705	110,277,843
31	8,548,359	8,548,359	118,826,202
32	8,989,325	8,989,325	127,815,527
33	9,452,679	9,452,679	137,268,206
34	9,939,547	9,939,547	147,207,753
35	14,010,923	14,010,923	161,218,676

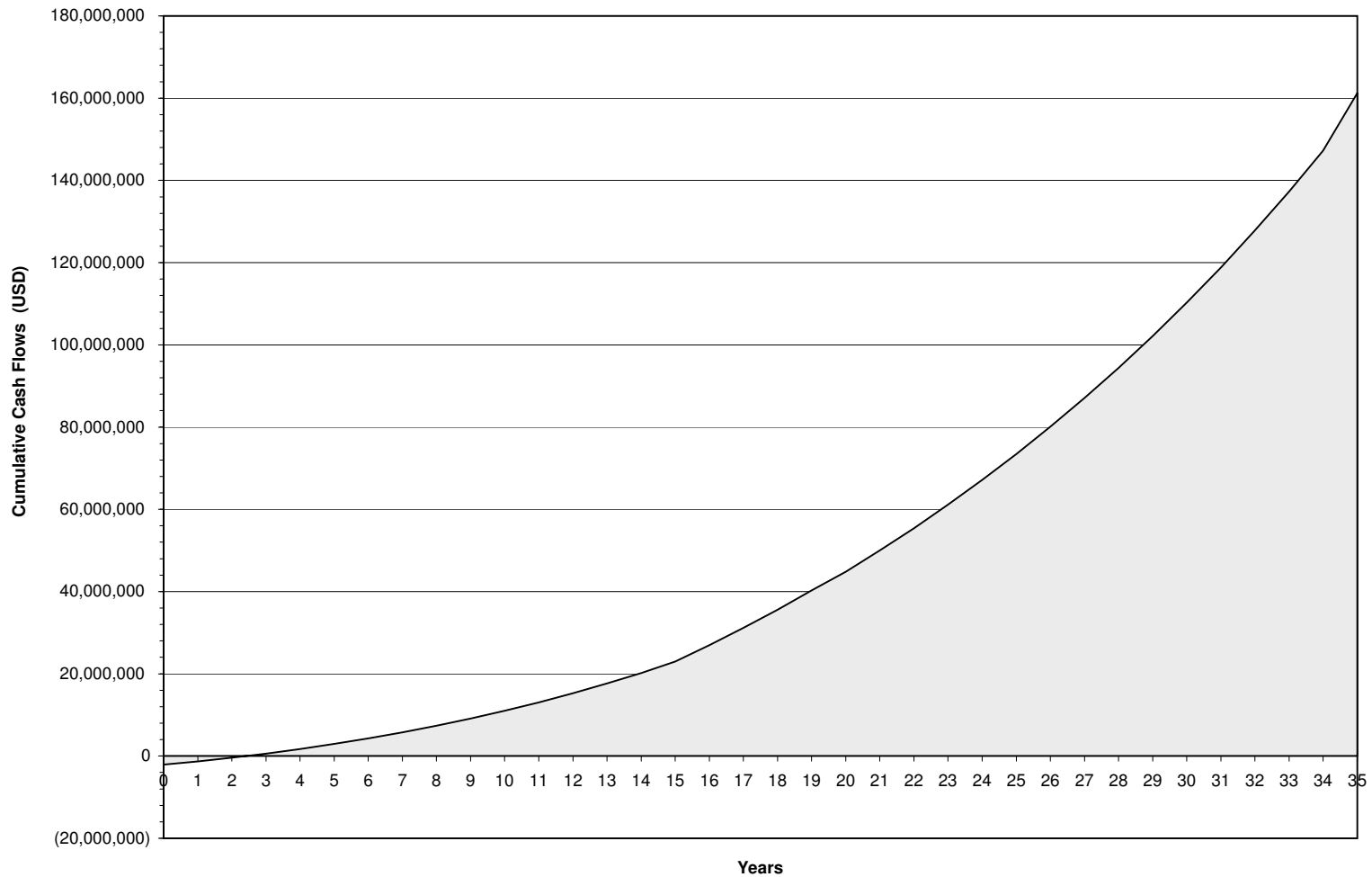
Cumulative Cash Flows Graph

### Small Hydro Project Cumulative Cash Flows Wli Run-of-River SHP(\$0.08/kWh avoided electricity cost), Wli Falls, Ghana

Renewable energy delivered (MWh/yr): 25,039

Total Initial Costs: USD 10,535,635

Net average GHG reduction (tCO<sub>2</sub>/yr): 4,616



IRR and ROI: 48.8%

Year-to-positive cash flow: 2.4 yr

Net Present Value: USD 15,115,221

Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		<b>Adafoah Wind Farm</b>	<a href="#">See Online Manual</a>
Project location		<b>Adafoah, Ghana</b>	
Wind data source		Wind speed	
Nearest location for weather data		Coastal Belt Ghana	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	5.5	
Height of wind measurement	m	12.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	5.3	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	Central-grid	
Wind turbine rated power	kW	1,500	<a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	35	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	7.5	
Wind power density at hub height	W/m <sup>2</sup>	485	
Array losses	%	3%	0% to 20%
Airfoil soiling and/or icing losses	%	2%	1% to 10%
Other downtime losses	%	2%	2% to 7%
Miscellaneous losses	%	3%	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<span style="border: 1px solid black; padding: 2px;">MW</span>	1,500	52,500	
Unadjusted energy production	MWh	4,812	168,421	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	4,668	163,369	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	1,036	1,036	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	32%	32%	20% to 40%
Renewable energy delivered	MWh	4,218	<b>147,626</b>	
	<span style="border: 1px solid black; padding: 2px;">GJ</span>	15,184	531,455	

[Complete Cost Analysis sheet](#)

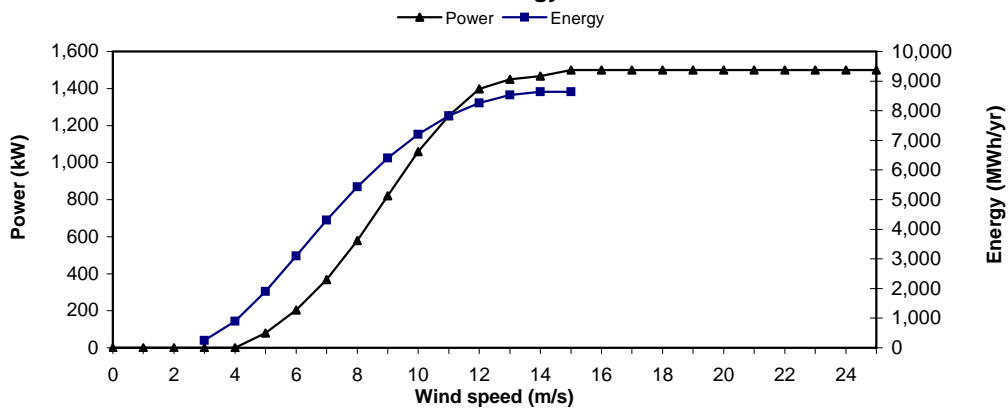
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project: **Standard**

Currency: **\$**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
			\$ -	\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Adafoah Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Adafoah, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.7%	0.983
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	270.5	0.0073	0.0073		8.7%	0.983

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.983	0.000	134,783	132,442	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

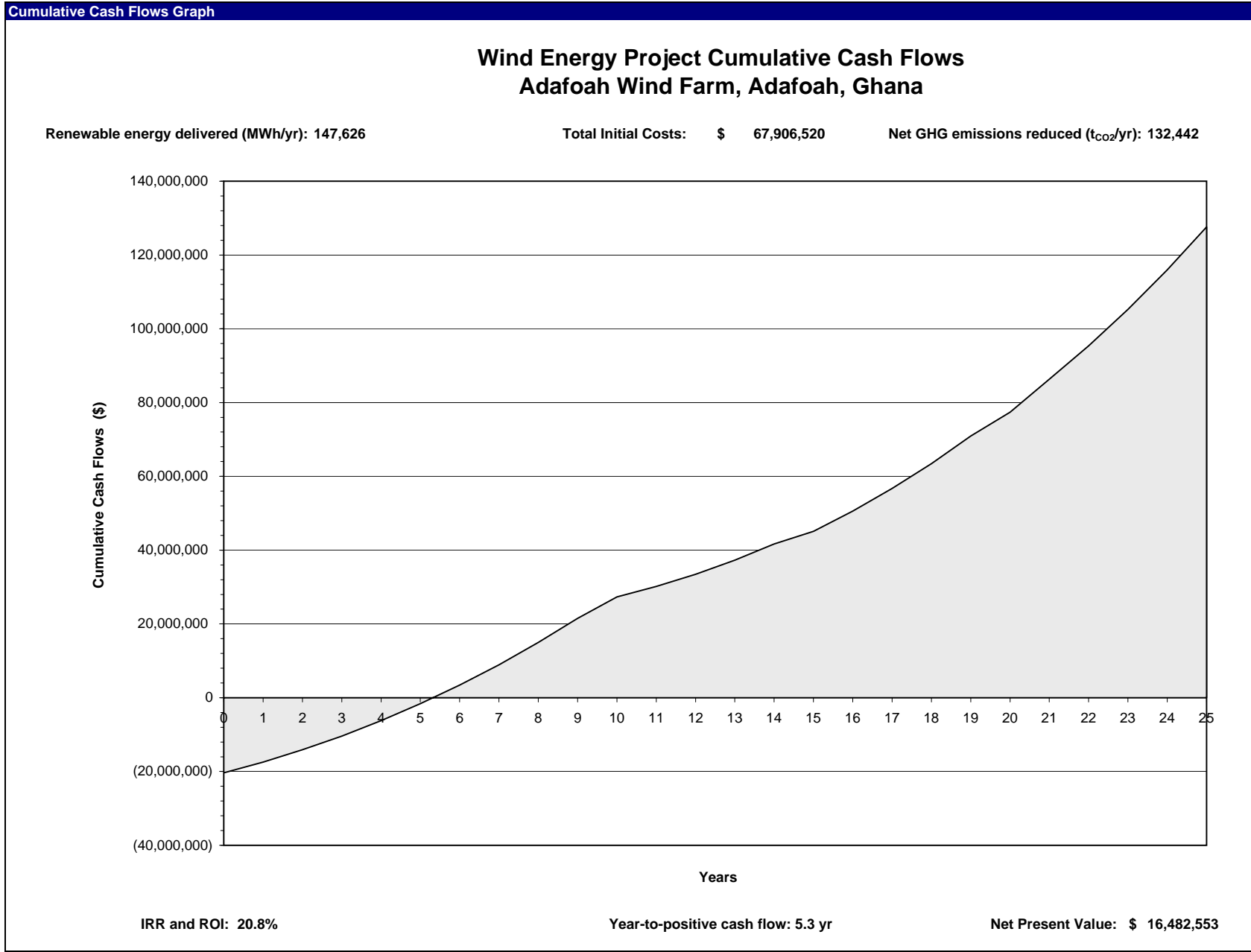
Annual Energy Balance					
Project name	Adafoah Wind Farm				
Project location	Adafoah, Ghana				
Renewable energy delivered	MWh	147,626	Net GHG reduction	t <sub>CO2</sub> /yr	132,442
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	2,781,286
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	3,311,055

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	100.0%	<b>\$ 67,906,520</b>	Energy savings/income	\$	5,905,059
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	3,690,662
			GHG reduction income - 21 yrs	\$	662,211
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>10,257,931</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	20.8%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	20.8%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	7.2			
Year-to-positive cash flow	yr	5.3	Project equity	\$	20,371,956
Net Present Value - NPV	\$	16,482,553	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	2,101,525	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	1.81	Debt service coverage	-	1.43

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	2,939,997	2,939,997	(17,431,958)
2	3,324,855	3,324,855	(14,107,103)
3	3,727,084	3,727,084	(10,380,019)
4	4,147,507	4,147,507	(6,232,512)
5	4,586,986	4,586,986	(1,645,526)
6	5,046,423	5,046,423	3,400,897
7	5,526,767	5,526,767	8,927,664
8	6,029,011	6,029,011	14,956,676
9	6,554,198	6,554,198	21,510,874
10	5,823,335	5,823,335	27,334,209
11	2,835,355	2,835,355	30,169,564
12	3,315,080	3,315,080	33,484,644
13	3,819,423	3,819,423	37,304,067
14	4,349,630	4,349,630	41,653,697
15	3,458,713	3,458,713	45,112,410
16	5,492,941	5,492,941	50,605,351
17	6,108,864	6,108,864	56,714,215
18	6,756,298	6,756,298	63,470,513
19	7,436,836	7,436,836	70,907,349
20	6,513,535	6,513,535	77,420,885
21	8,904,002	8,904,002	86,324,887
22	9,032,023	9,032,023	95,356,910
23	9,862,574	9,862,574	105,219,484
24	10,735,482	10,735,482	115,954,966
25	11,652,884	11,652,884	127,607,850





Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		<b>Aplaku Wind Farm</b>	<a href="#">See Online Manual</a>
Project location		<b>Aplaku, Ghana</b>	
Wind data source		Wind speed	
Nearest location for weather data		Coastal Belt Ghana	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	4.9	
Height of wind measurement	m	10.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	4.9	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	Central-grid	
Wind turbine rated power	kW	1,500	<a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	35	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	6.8	
Wind power density at hub height	W/m <sup>2</sup>	374	
Array losses	%	3%	0% to 20%
Airfoil soiling and/or icing losses	%	2%	1% to 10%
Other downtime losses	%	2%	2% to 7%
Miscellaneous losses	%	3%	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<span style="border: 1px solid black; padding: 2px;">MW</span>	1,500	52,500	
Unadjusted energy production	MWh	4,107	143,730	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	3,983	139,418	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	884	884	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	27%	27%	20% to 40%
Renewable energy delivered	MWh	3,600	<b>125,984</b>	
	<span style="border: 1px solid black; padding: 2px;">GJ</span>	12,958	453,543	

[Complete Cost Analysis sheet](#)

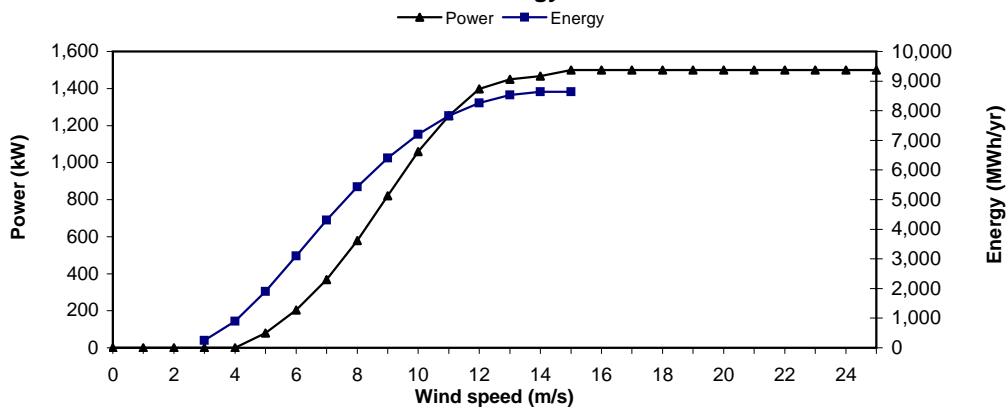
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project: **Standard**

Currency: **\$**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
			\$ -	\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Aplaku Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Aplaku, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Large hydro	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	0.0	0.0000	0.0000		8.7%	0.000

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tco <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tco <sub>2</sub> )
		0.000	0.000	115,023	0	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance					
Project name	Aplaku Wind Farm				
Project location	Aplaku, Ghana				
Renewable energy delivered	MWh	125,984	Net GHG reduction	t <sub>CO2</sub> /yr	0
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	0
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	0

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 67,906,520</b>	Energy savings/income	\$	5,039,361
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	3,149,601
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>8,188,962</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	10.7%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	10.7%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	9.2			
Year-to-positive cash flow	yr	9.0	Project equity	\$	20,371,956
Net Present Value - NPV	\$	(2,355,598)	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	(300,339)	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	0.88	Debt service coverage	-	1.12

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	814,217	814,217	(19,557,739)
2	1,139,761	1,139,761	(18,417,978)
3	1,480,057	1,480,057	(16,937,920)
4	1,835,806	1,835,806	(15,102,114)
5	2,207,741	2,207,741	(12,894,373)
6	2,596,631	2,596,631	(10,297,743)
7	3,003,282	3,003,282	(7,294,461)
8	3,428,541	3,428,541	(3,865,919)
9	3,873,296	3,873,296	7,376
10	3,058,391	3,058,391	3,065,768
11	692,508	692,508	3,758,276
12	1,098,201	1,098,201	4,856,477
13	1,524,811	1,524,811	6,381,288
14	1,973,398	1,973,398	8,354,686
15	996,779	996,779	9,351,465
16	2,941,021	2,941,021	12,292,487
17	3,462,459	3,462,459	15,754,946
18	4,010,684	4,010,684	19,765,630
19	4,587,051	4,587,051	24,352,681
20	3,554,372	3,554,372	27,907,053
21	5,829,991	5,829,991	33,737,045
22	6,499,633	6,499,633	40,236,677
23	7,203,565	7,203,565	47,440,242
24	7,943,522	7,943,522	55,383,764
25	8,721,326	8,721,326	64,105,091

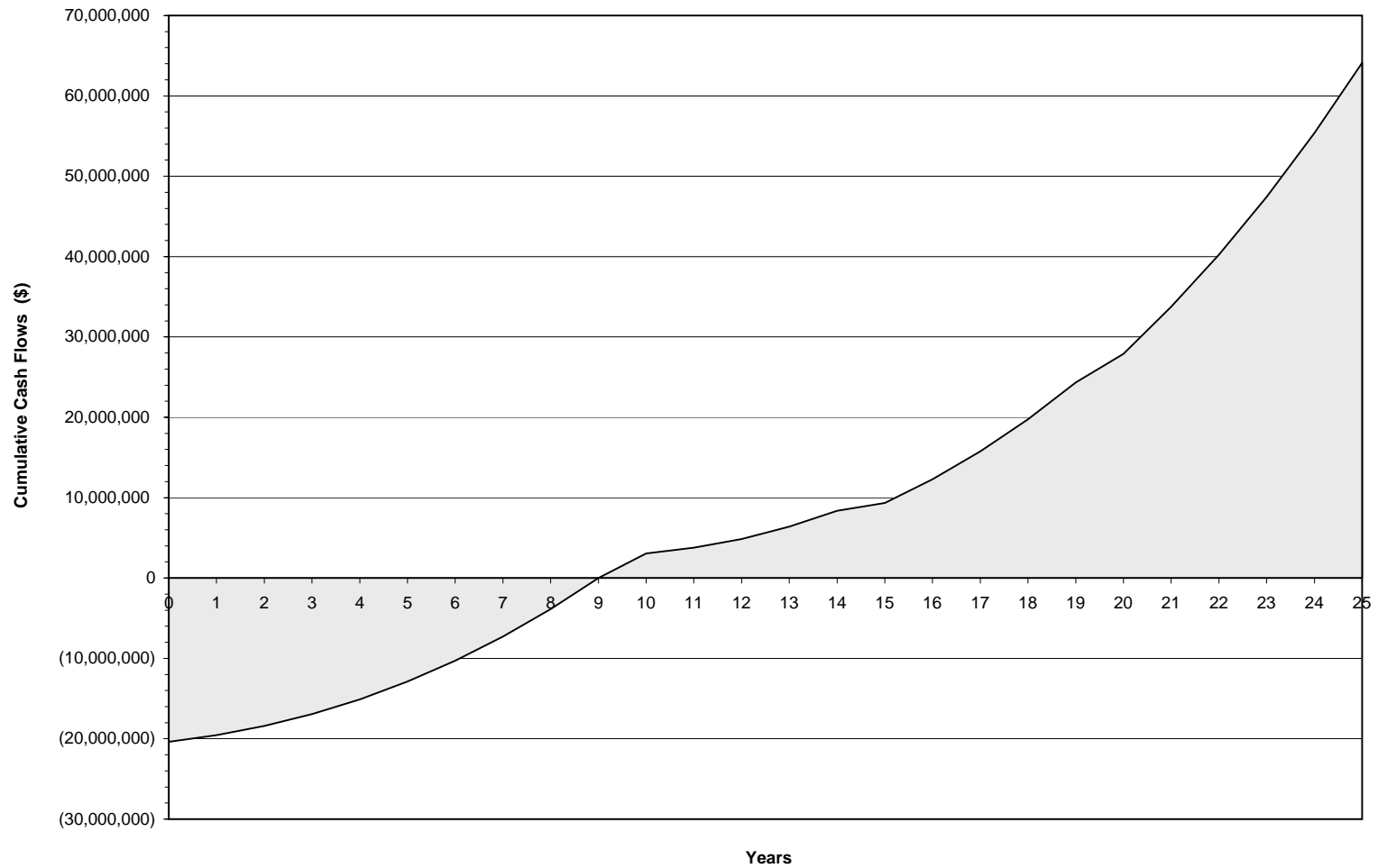
Cumulative Cash Flows Graph

### Wind Energy Project Cumulative Cash Flows Aplaku Wind Farm, Aplaku, Ghana

Renewable energy delivered (MWh/yr): 125,984

Total Initial Costs: \$ 67,906,520

Net GHG emissions reduced (tCO<sub>2</sub>/yr): 0



IRR and ROI: 10.7%

Year-to-positive cash flow: 9 yr

Net Present Value: \$ -2,355,598

Units: Metric

Site Conditions		Estimate		Notes/Range
Project name		<b>Aplaku Wind Farm, 70 Turbines</b>		<a href="#">See Online Manual</a>
Project location		<b>Aplaku, Ghana</b>		
Wind data source		Wind speed		
Nearest location for weather data		Coastal Belt Ghana		<a href="#">See Weather Database</a>
Annual average wind speed	m/s	4.9		
Height of wind measurement	m	10.0		3.0 to 100.0 m
Wind shear exponent	-	0.16		0.10 to 0.40
Wind speed at 10 m	m/s	4.9		
Average atmospheric pressure	kPa	100.9		60.0 to 103.0 kPa
Annual average temperature	°C	25		-20 to 30 °C

System Characteristics		Estimate		Notes/Range
Grid type	-	Central-grid		
Wind turbine rated power	kW	1,500		<a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	70		
Wind plant capacity	kW	105,000		
Hub height	m	80.0		6.0 to 100.0 m
Wind speed at hub height	m/s	6.8		
Wind power density at hub height	W/m <sup>2</sup>	374		
Array losses	%	3%		0% to 20%
Airfoil soiling and/or icing losses	%	2%		1% to 10%
Other downtime losses	%	2%		2% to 7%
Miscellaneous losses	%	3%		2% to 6%

Annual Energy Production		Estimate	Estimate	Notes/Range
		Per Turbine	Total	
Wind plant capacity	kW	1,500	105,000	
	<span style="border: 1px solid black; padding: 2px;">MW</span>	1,500	105,000	
Unadjusted energy production	MWh	4,107	287,460	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	3,983	278,837	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	884	884	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	27%	27%	20% to 40%
Renewable energy delivered	MWh	3,600	<b>251,968</b>	
	<span style="border: 1px solid black; padding: 2px;">GJ</span>	12,958	907,085	

[Complete Cost Analysis sheet](#)

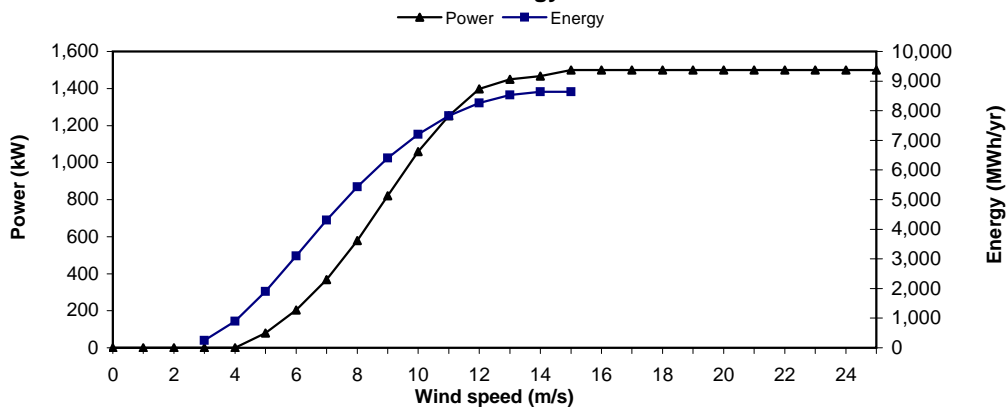
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)



RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project:

Currency:

Cost references:

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.2%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	0.7%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.5%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	105,000	\$ 1,000	\$ 105,000,000		-	-
Spare parts	%	3.0%	\$ 105,000,000	\$ 3,150,000		-	-
Transportation	turbine	70	\$ 33,000	\$ 2,310,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 110,460,000	86.5%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	4.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 118,019,200	\$ 5,900,960		-	-
Interest during construction	6.0%	12 month(s)	\$ 123,920,160	\$ 3,717,605		-	-
Sub-total:				\$ 9,618,565	7.5%		
<b>Initial Costs - Total</b>				\$ 127,637,765	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
				\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Aplaku Wind Farm, 70 Turbines	Project capacity	105.0 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Aplaku, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Large hydro	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	0.0	0.0000	0.0000		8.7%	0.000

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.000	0.000	230,047	0	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance					
Project name	Aplaku Wind Farm, 70 Turbines				
Project location	Aplaku, Ghana				
Renewable energy delivered	MWh	251,968	Net GHG reduction	t <sub>CO2</sub> /yr	0
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	0
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	0

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.2%	\$ 245,200	O&M	\$	770,000
Development	0.7%	\$ 835,500			
Engineering	0.5%	\$ 610,500	Debt payments - 25 yrs	\$	12,999,764
Energy equipment	86.5%	\$ 110,460,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>13,769,764</b>
Balance of plant	4.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 9,618,565	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 127,637,765</b>	Energy savings/income	\$	10,078,723
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	6,299,202
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>16,377,925</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	15.5%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	15.5%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	8.2			
Year-to-positive cash flow	yr	7.0	Project equity	\$	38,291,329
Net Present Value - NPV	\$	12,520,416	Project debt	\$	89,346,435
Annual Life Cycle Savings	\$	1,596,353	Debt payments	\$/yr	12,999,764
Benefit-Cost (B-C) ratio	-	1.33	Debt service coverage	-	1.25

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(38,291,329)	(38,291,329)	(38,291,329)
1	3,250,327	3,250,327	(35,041,003)
2	3,921,146	3,921,146	(31,119,857)
3	4,621,963	4,621,963	(26,497,894)
4	5,354,191	5,354,191	(21,143,703)
5	6,119,309	6,119,309	(15,024,394)
6	6,918,868	6,918,868	(8,105,526)
7	7,754,495	7,754,495	(351,032)
8	8,627,896	8,627,896	8,276,864
9	9,540,859	9,540,859	17,817,723
10	9,215,175	9,215,175	27,032,898
11	3,227,966	3,227,966	30,260,863
12	4,064,610	4,064,610	34,325,473
13	4,943,718	4,943,718	39,269,191
14	5,867,428	5,867,428	45,136,619
15	5,389,689	5,389,689	50,526,309
16	7,857,755	7,857,755	58,384,063
17	8,929,208	8,929,208	67,313,271
18	10,054,947	10,054,947	77,368,218
19	11,237,706	11,237,706	88,605,924
20	10,841,737	10,841,737	99,447,662
21	13,785,903	13,785,903	113,233,565
22	15,157,518	15,157,518	128,391,083
23	16,598,523	16,598,523	144,989,606
24	18,112,406	18,112,406	163,102,012
25	19,702,832	19,702,832	182,804,844

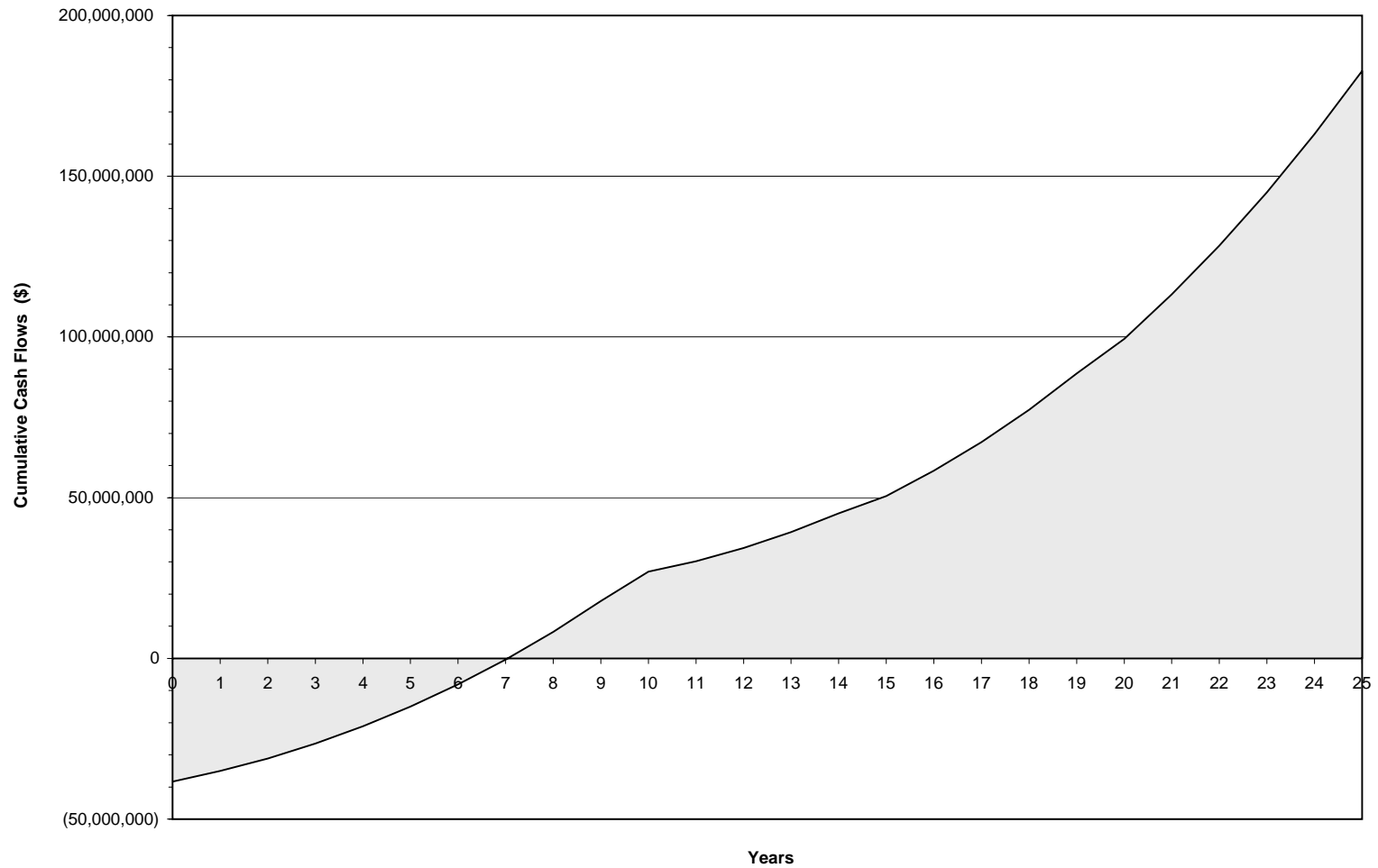
Cumulative Cash Flows Graph

### Wind Energy Project Cumulative Cash Flows Aplaku Wind Farm, 70 Turbines, Aplaku, Ghana

Renewable energy delivered (MWh/yr): 251,968

Total Initial Costs: \$ 127,637,765

Net GHG emissions reduced (tCO<sub>2</sub>/yr): 0



IRR and ROI: 15.5%

Year-to-positive cash flow: 7 yr

Net Present Value: \$ 12,520,416

Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		<b>Kpone Wind Farm</b>	<a href="#">See Online Manual</a>
Project location		<b>Kpone, Ghana</b>	
Wind data source		<b>Wind speed</b>	
Nearest location for weather data		<b>Coastal Belt Ghana</b>	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	4.8	
Height of wind measurement	m	12.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	4.7	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	<b>Central-grid</b>	
Wind turbine rated power	kW	1,500	→ <a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	<b>35</b>	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	6.5	
Wind power density at hub height	W/m <sup>2</sup>	323	
Array losses	%	<b>3%</b>	0% to 20%
Airfoil soiling and/or icing losses	%	<b>2%</b>	1% to 10%
Other downtime losses	%	<b>2%</b>	2% to 7%
Miscellaneous losses	%	<b>3%</b>	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<b>MW</b>	1,500	52,500	
Unadjusted energy production	MWh	3,705	129,675	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	3,594	125,785	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	798	798	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	25%	25%	20% to 40%
Renewable energy delivered	MWh	3,248	<b>113,664</b>	
	<b>GJ</b>	11,691	409,192	

[Complete Cost Analysis sheet](#)

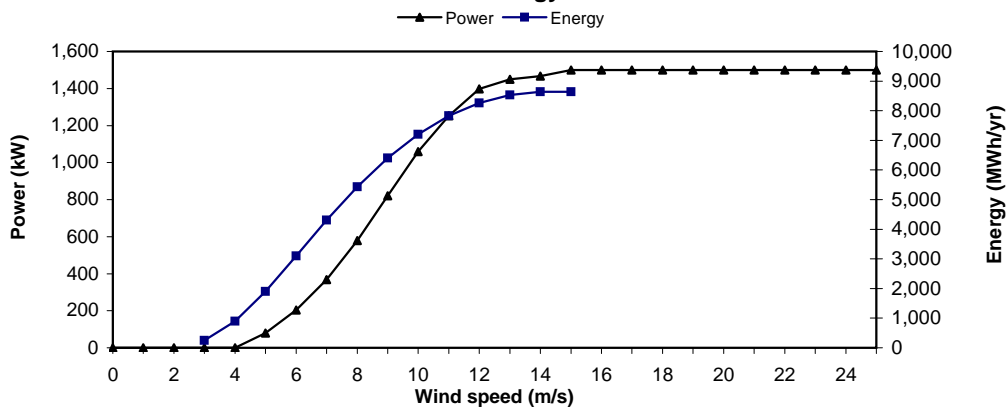
# RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

## Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project: **Standard**

Currency: **\$**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
			\$ -	\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Kpone Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Kpone, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Large hydro	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	0.0	0.0000	0.0000		8.7%	0.000

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.000	0.000	103,776	0	0.0%

[Complete Financial Summary sheet](#)



RETScreen® Financial Summary - Wind Energy Project

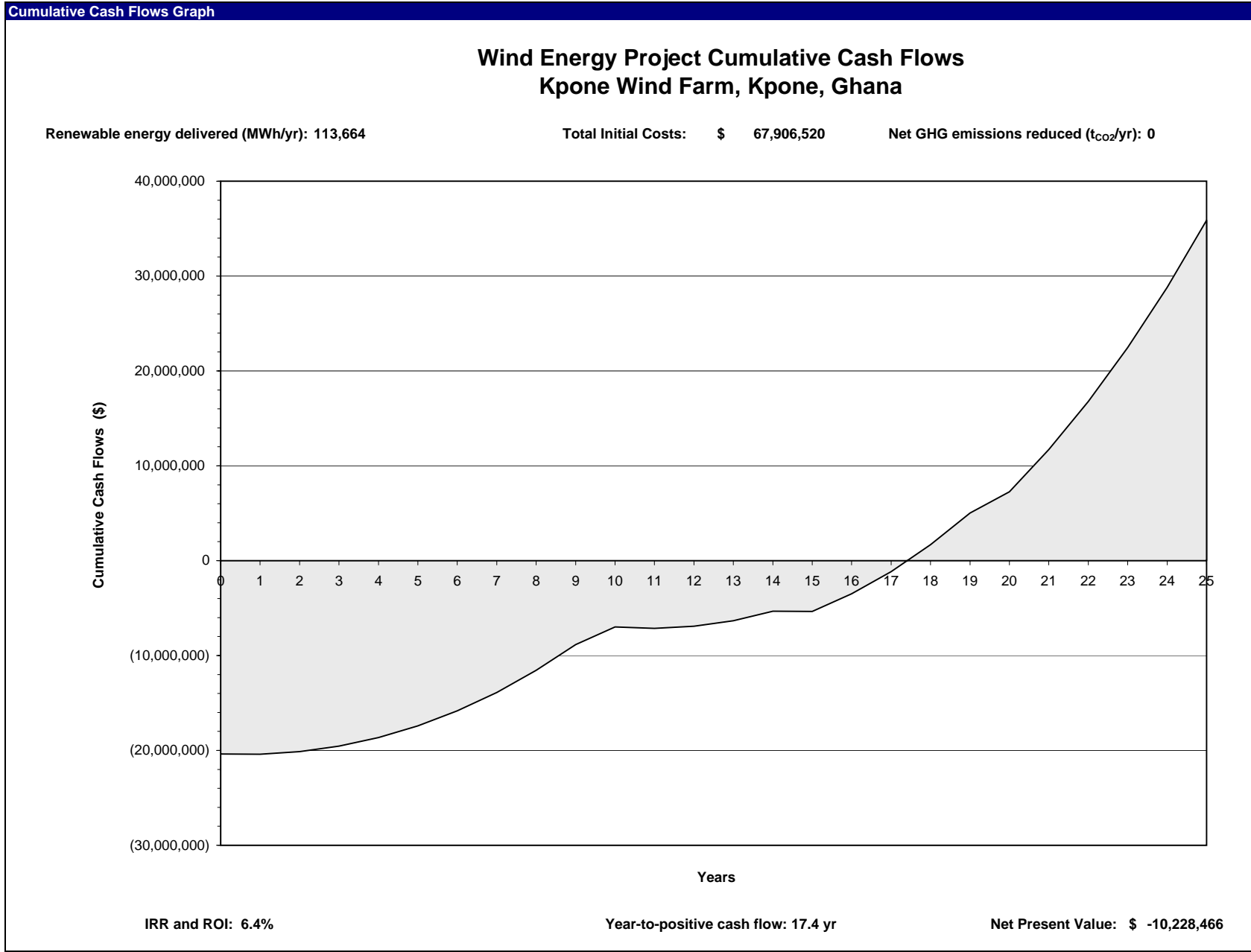
Annual Energy Balance					
Project name	Kpone Wind Farm				
Project location	Kpone, Ghana				
Renewable energy delivered	MWh	113,664	Net GHG reduction	t <sub>CO2</sub> /yr	0
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	0
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	0

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 67,906,520</b>	Energy savings/income	\$	4,546,573
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	2,841,608
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>7,388,181</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	6.4%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	6.4%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	10.3			
Year-to-positive cash flow	yr	17.4	Project equity	\$	20,371,956
Net Present Value - NPV	\$	(10,228,466)	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	(1,304,129)	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	0.50	Debt service coverage	-	1.00

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	(18,904)	(18,904)	(20,390,860)
2	272,876	272,876	(20,117,984)
3	577,918	577,918	(19,540,066)
4	896,852	896,852	(18,643,214)
5	1,230,338	1,230,338	(17,412,876)
6	1,579,069	1,579,069	(15,833,807)
7	1,943,772	1,943,772	(13,890,035)
8	2,325,208	2,325,208	(11,564,827)
9	2,724,178	2,724,178	(8,840,649)
10	1,861,433	1,861,433	(6,979,216)
11	(150,328)	(150,328)	(7,129,543)
12	213,224	213,224	(6,916,320)
13	595,584	595,584	(6,320,736)
14	997,710	997,710	(5,323,026)
15	(27,693)	(27,693)	(5,350,719)
16	1,865,325	1,865,325	(3,485,393)
17	2,332,979	2,332,979	(1,152,415)
18	2,824,729	2,824,729	1,672,314
19	3,341,799	3,341,799	5,014,113
20	2,246,857	2,246,857	7,260,969
21	4,457,100	4,457,100	11,718,069
22	5,058,097	5,058,097	16,776,167
23	5,689,953	5,689,953	22,466,119
24	6,354,229	6,354,229	28,820,348
25	7,052,569	7,052,569	35,872,917



Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		Lolonaya Wind Farm	<a href="#">See Online Manual</a>
Project location		Lolonaya, Ghana	
Wind data source		Wind speed	
Nearest location for weather data		Coastal Belt Ghana	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	5.4	
Height of wind measurement	m	12.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	5.2	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	Central-grid	
Wind turbine rated power	kW	1,500	<a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	35	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	7.3	
Wind power density at hub height	W/m <sup>2</sup>	459	
Array losses	%	3%	0% to 20%
Airfoil soiling and/or icing losses	%	2%	1% to 10%
Other downtime losses	%	2%	2% to 7%
Miscellaneous losses	%	3%	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<span style="border: 1px solid black; padding: 2px;">MW</span>	1,500	52,500	
Unadjusted energy production	MWh	4,660	163,108	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	4,520	158,214	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	1,003	1,003	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	31%	31%	20% to 40%
Renewable energy delivered	MWh	4,085	<b>142,969</b>	
	<span style="border: 1px solid black; padding: 2px;">GJ</span>	14,705	514,688	

[Complete Cost Analysis sheet](#)

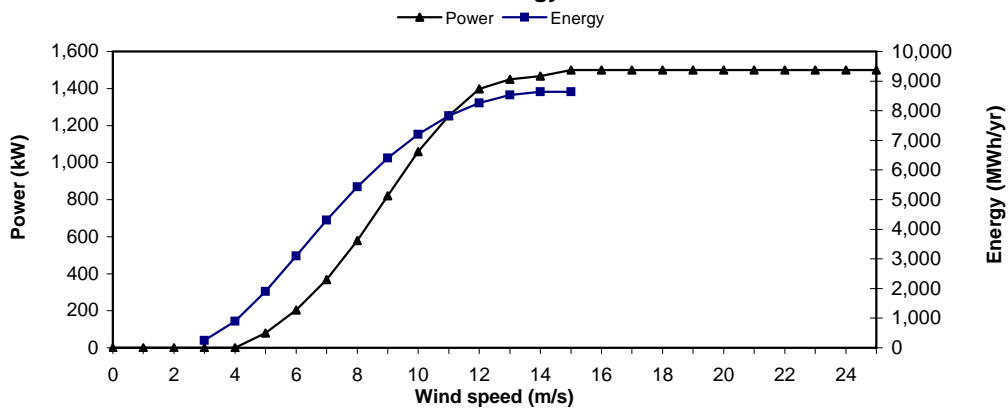
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project: **Standard**

Currency: **\$**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
			\$ -	\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Lolonaya Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Lolonaya, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.7%	0.983
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	270.5	0.0073	0.0073		8.7%	0.983

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tco <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tco <sub>2</sub> )
		0.983	0.000	130,531	128,264	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance					
Project name	Lolonaya Wind Farm				
Project location	Lolonaya, Ghana				
Renewable energy delivered	MWh	142,969	Net GHG reduction	t <sub>CO2</sub> /yr	128,264
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	2,693,538
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	3,206,593

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	100.0%	<b>\$ 67,906,520</b>	Energy savings/income	\$	5,718,757
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	3,574,223
			GHG reduction income - 21 yrs	\$	641,319
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>9,934,298</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	19.1%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	19.1%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	7.4			
Year-to-positive cash flow	yr	5.7	Project equity	\$	20,371,956
Net Present Value - NPV	\$	13,348,178	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	1,701,892	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	1.66	Debt service coverage	-	1.38

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	2,604,138	2,604,138	(17,767,817)
2	2,976,231	2,976,231	(14,791,586)
3	3,365,133	3,365,133	(11,426,453)
4	3,771,637	3,771,637	(7,654,816)
5	4,196,580	4,196,580	(3,458,236)
6	4,640,835	4,640,835	1,182,599
7	5,105,320	5,105,320	6,287,920
8	5,590,997	5,590,997	11,878,917
9	6,098,874	6,098,874	17,977,791
10	5,349,925	5,349,925	23,327,717
11	2,495,823	2,495,823	25,823,540
12	2,959,616	2,959,616	28,783,156
13	3,447,231	3,447,231	32,230,387
14	3,959,873	3,959,873	36,190,260
15	3,050,512	3,050,512	39,240,772
16	5,065,375	5,065,375	44,306,147
17	5,660,965	5,660,965	49,967,111
18	6,287,048	6,287,048	56,254,159
19	6,945,168	6,945,168	63,199,328
20	5,998,328	5,998,328	69,197,656
21	8,364,080	8,364,080	77,561,736
22	8,487,041	8,487,041	86,048,777
23	9,290,344	9,290,344	95,339,121
24	10,134,640	10,134,640	105,473,761
25	11,022,000	11,022,000	116,495,762

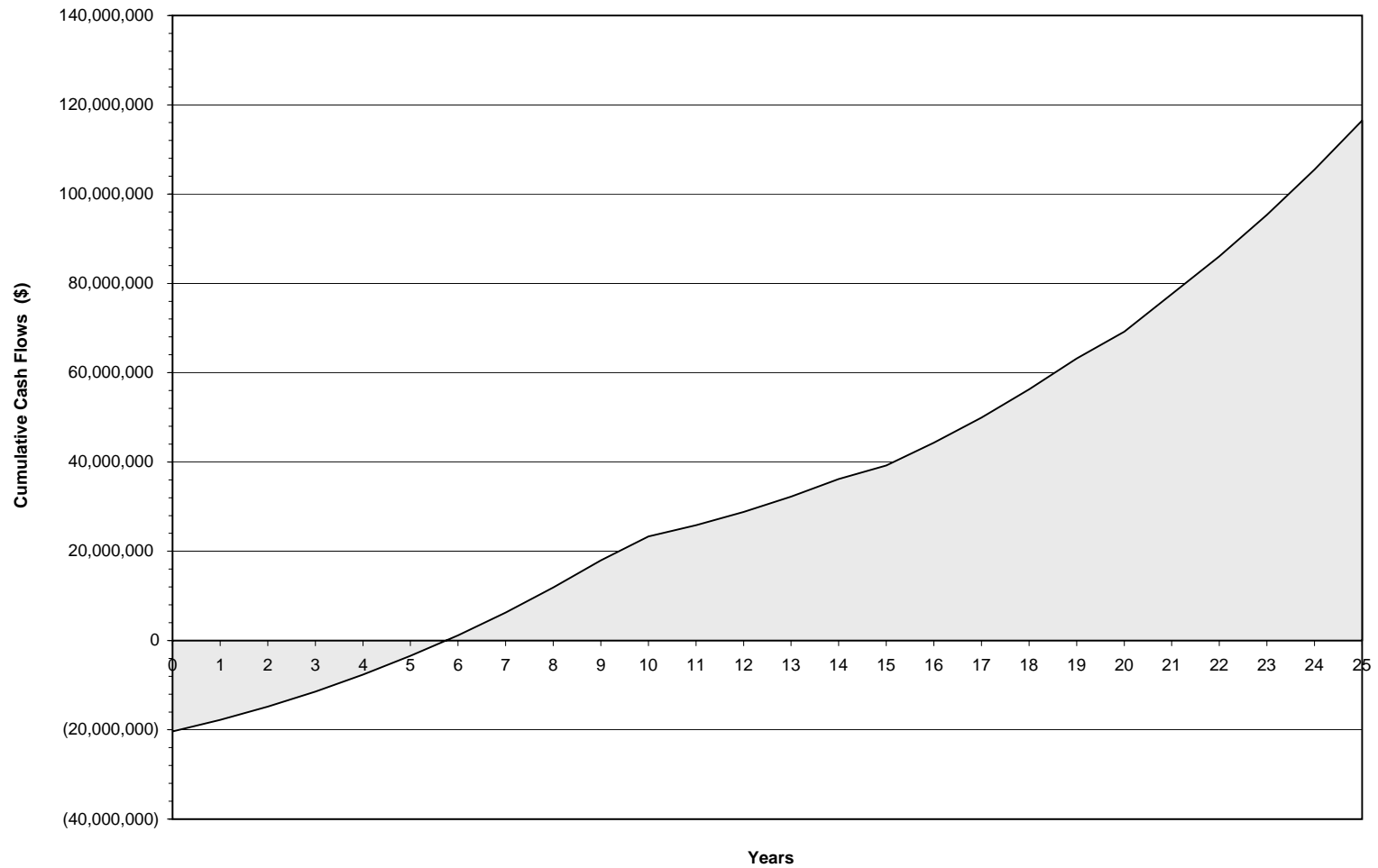
Cumulative Cash Flows Graph

### Wind Energy Project Cumulative Cash Flows Lolonaya Wind Farm, Lolonaya, Ghana

Renewable energy delivered (MWh/yr): 142,969

Total Initial Costs: \$ 67,906,520

Net GHG emissions reduced (tCO<sub>2</sub>/yr): 128,264



IRR and ROI: 19.1%

Year-to-positive cash flow: 5.7 yr

Net Present Value: \$ 13,348,178



Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		<b>Pute Wind Farm</b>	<a href="#">See Online Manual</a>
Project location		<b>Pute, Ghana</b>	
Wind data source		<b>Wind speed</b>	
Nearest location for weather data		<b>Coastal Belt Ghana</b>	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	5.0	
Height of wind measurement	m	10.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	5.0	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	<b>Central-grid</b>	
Wind turbine rated power	kW	1,500	→ <a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	<b>35</b>	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	7.0	
Wind power density at hub height	W/m <sup>2</sup>	398	
Array losses	%	<b>3%</b>	0% to 20%
Airfoil soiling and/or icing losses	%	<b>2%</b>	1% to 10%
Other downtime losses	%	<b>2%</b>	2% to 7%
Miscellaneous losses	%	<b>3%</b>	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<b>MW</b>	1,500	52,500	
Unadjusted energy production	MWh	4,275	149,636	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	4,147	145,147	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	920	920	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	29%	29%	20% to 40%
Renewable energy delivered	MWh	3,747	<b>131,160</b>	
	<b>GJ</b>	13,491	472,177	

[Complete Cost Analysis sheet](#)

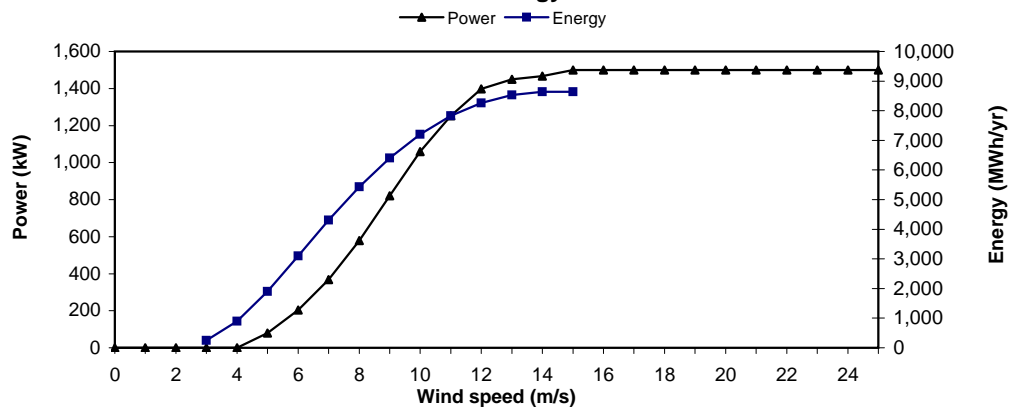
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)

RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project: **Standard**

Currency: **\$**

Cost references: **None**

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
			\$ -	\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Pute Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Pute, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.7%	0.983
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	270.5	0.0073	0.0073		8.7%	0.983

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tco <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tco <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tco <sub>2</sub> )
		0.983	0.000	119,749	117,670	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance					
Project name	Pute Wind Farm				
Project location	Pute, Ghana				
Renewable energy delivered	MWh	131,160	Net GHG reduction	t <sub>CO2</sub> /yr	117,670
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	2,471,065
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	2,941,744

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	100.0%	<b>\$ 67,906,520</b>	Energy savings/income	\$	5,246,415
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	3,279,010
			GHG reduction income - 21 yrs	\$	588,349
<b>Periodic Costs (Credits)</b>			<b>Annual Savings - Total</b>	<b>\$</b>	<b>9,113,774</b>
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	14.9%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	14.9%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	8.1			
Year-to-positive cash flow	yr	7.1	Project equity	\$	20,371,956
Net Present Value - NPV	\$	5,401,420	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	688,681	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	1.27	Debt service coverage	-	1.25

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	1,752,616	1,752,616	(18,619,340)
2	2,092,346	2,092,346	(16,526,993)
3	2,447,456	2,447,456	(14,079,537)
4	2,818,673	2,818,673	(11,260,864)
5	3,206,763	3,206,763	(8,054,102)
6	3,612,526	3,612,526	(4,441,576)
7	4,036,802	4,036,802	(404,774)
8	4,480,475	4,480,475	4,075,701
9	4,944,467	4,944,467	9,020,168
10	4,149,663	4,149,663	13,169,830
11	1,634,989	1,634,989	14,804,820
12	2,058,389	2,058,389	16,863,209
13	2,503,590	2,503,590	19,366,799
14	2,971,699	2,971,699	22,338,498
15	2,015,578	2,015,578	24,354,076
16	3,981,343	3,981,343	28,335,419
17	4,525,379	4,525,379	32,860,798
18	5,097,332	5,097,332	37,958,130
19	5,698,615	5,698,615	43,656,745
20	4,692,096	4,692,096	48,348,841
21	6,995,184	6,995,184	55,344,025
22	7,105,319	7,105,319	62,449,345
23	7,839,536	7,839,536	70,288,880
24	8,611,291	8,611,291	78,900,172
25	9,422,484	9,422,484	88,322,656

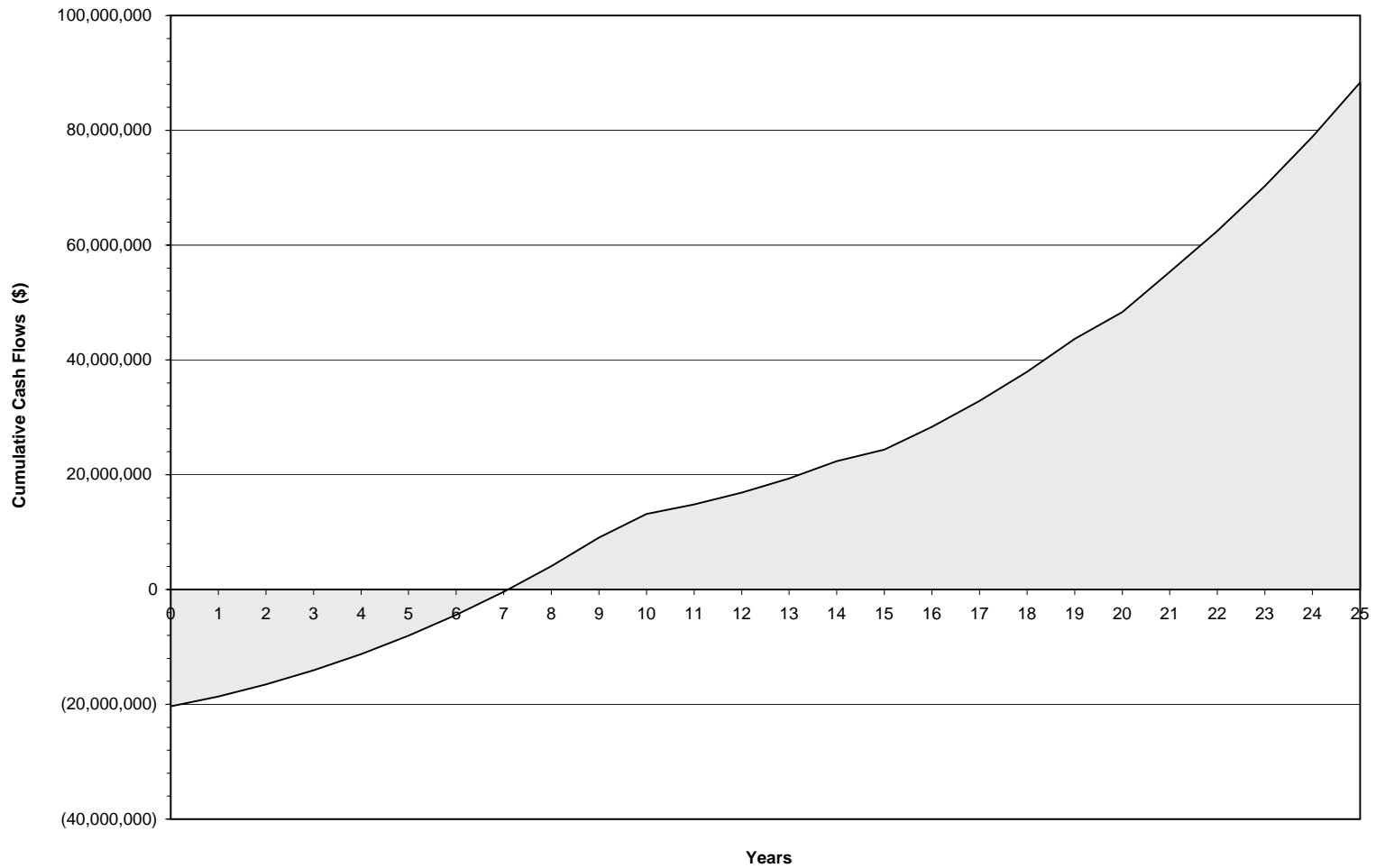
Cumulative Cash Flows Graph

### Wind Energy Project Cumulative Cash Flows Pute Wind Farm, Pute, Ghana

Renewable energy delivered (MWh/yr): 131,160

Total Initial Costs: \$ 67,906,520

Net GHG emissions reduced (t<sub>CO2</sub>/yr): 117,670



IRR and ROI: 14.9%

Year-to-positive cash flow: 7.1 yr

Net Present Value: \$ 5,401,420

Units: Metric

Site Conditions		Estimate	Notes/Range
Project name		<b>Tema Wind Farm</b>	<a href="#">See Online Manual</a>
Project location		<b>Tema, Ghana</b>	
Wind data source		<b>Wind speed</b>	
Nearest location for weather data		<b>Coastal Belt Ghana</b>	<a href="#">See Weather Database</a>
Annual average wind speed	m/s	5.0	
Height of wind measurement	m	12.0	3.0 to 100.0 m
Wind shear exponent	-	0.16	0.10 to 0.40
Wind speed at 10 m	m/s	4.9	
Average atmospheric pressure	kPa	100.9	60.0 to 103.0 kPa
Annual average temperature	°C	25	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	<b>Central-grid</b>	
Wind turbine rated power	kW	1,500	<a href="#">Complete Equipment Data sheet</a>
Number of turbines	-	<b>35</b>	
Wind plant capacity	kW	52,500	
Hub height	m	80.0	6.0 to 100.0 m
Wind speed at hub height	m/s	6.8	
Wind power density at hub height	W/m <sup>2</sup>	365	
Array losses	%	<b>3%</b>	0% to 20%
Airfoil soiling and/or icing losses	%	<b>2%</b>	1% to 10%
Other downtime losses	%	<b>2%</b>	2% to 7%
Miscellaneous losses	%	<b>3%</b>	2% to 6%

Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	1,500	52,500	
	<b>MW</b>	1,500	52,500	
Unadjusted energy production	MWh	4,033	141,147	
Pressure adjustment coefficient	-	1.00	1.00	0.59 to 1.02
Temperature adjustment coefficient	-	0.97	0.97	0.98 to 1.15
Gross energy production	MWh	3,912	136,912	
Losses coefficient	-	0.90	0.90	0.75 to 1.00
Specific yield	kWh/m <sup>2</sup>	868	868	150 to 1,500 kWh/m <sup>2</sup>
Wind plant capacity factor	%	27%	27%	20% to 40%
Renewable energy delivered	MWh	3,535	<b>123,719</b>	
	<b>GJ</b>	12,725	445,390	

[Complete Cost Analysis sheet](#)

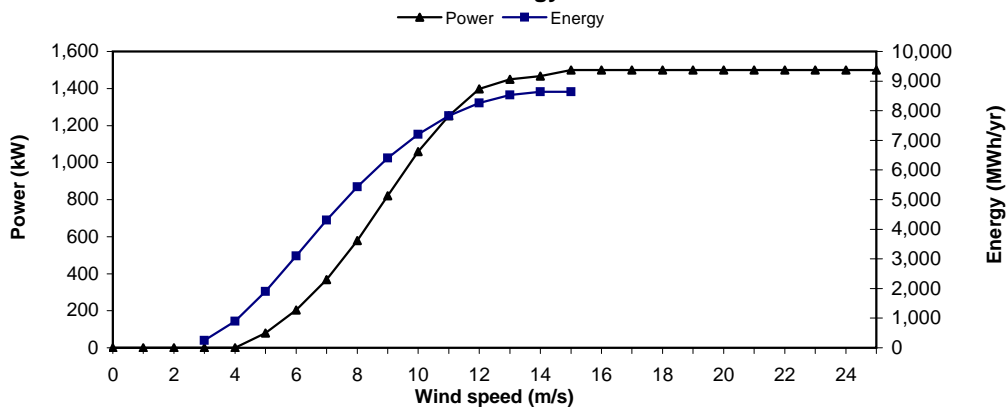
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	1,500	<a href="#">See Product Database</a>
Hub height	m	80.0	6.0 to 100.0 m
Rotor diameter	m	72	7 to 80 m
Swept area	m <sup>2</sup>	4,072	35 to 5,027 m <sup>2</sup>
Wind turbine manufacturer		NEG Micon	
Wind turbine model		NM72C	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	250.9
4	0.0	897.1
5	79.3	1,904.5
6	204.0	3,097.4
7	367.2	4,307.1
8	578.7	5,427.8
9	821.2	6,404.4
10	1,058.7	7,208.4
11	1,252.0	7,827.2
12	1,397.0	8,262.3
13	1,449.0	8,527.1
14	1,467.0	8,643.3
15	1,500.0	8,636.6
16	1,500.0	-
17	1,500.0	-
18	1,500.0	-
19	1,500.0	-
20	1,500.0	-
21	1,500.0	-
22	1,500.0	-
23	1,500.0	-
24	1,500.0	-
25	1,500.0	-

Power and Energy Curves



[Return to Energy Model sheet](#)



RETScreen® Cost Analysis - Wind Energy Project

[Search Marketplace](#)

Type of project:

Currency:

Cost references:

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>Feasibility Study</b>							
Feasibility study	Cost	1	\$ 245,200	\$ 245,200		-	-
Sub-total:				\$ 245,200	0.4%		
<b>Development</b>							
Development	Cost	1	\$ 835,500	\$ 835,500		-	-
Sub-total:				\$ 835,500	1.2%		
<b>Engineering</b>							
Engineering	Cost	1	\$ 610,500	\$ 610,500		-	-
Sub-total:				\$ 610,500	0.9%		
<b>Energy Equipment</b>							
Wind turbine(s)	kW	52,500	\$ 1,000	\$ 52,500,000		-	-
Spare parts	%	3.0%	\$ 52,500,000	\$ 1,575,000		-	-
Transportation	turbine	35	\$ 33,000	\$ 1,155,000		-	-
Other - Energy equipment	Cost	0	\$ -	\$ -		-	-
Sub-total:				\$ 55,230,000	81.3%		
<b>Balance of Plant</b>							
Balance of plant	Cost	1	\$ 5,868,000	\$ 5,868,000		-	-
Sub-total:				\$ 5,868,000	8.6%		
<b>Miscellaneous</b>							
Contingencies	%	5%	\$ 62,789,200	\$ 3,139,460		-	-
Interest during construction	6.0%	12 month(s)	\$ 65,928,660	\$ 1,977,860		-	-
Sub-total:				\$ 5,117,320	7.5%		
<b>Initial Costs - Total</b>				\$ 67,906,520	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
<b>O&amp;M</b>							
O&M	Cost	1	\$ 700,000	\$ 700,000		-	-
Contingencies	%	10%	\$ 700,000	\$ 70,000		-	-
<b>Annual Costs - Total</b>				\$ 770,000	100.0%		

Periodic Costs (Credits)	Unit	Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Drive train	Cost	10 yr	\$ 1,000,000	\$ 1,000,000	-	-
Blades	Cost	15 yr	\$ 1,000,000	\$ 1,000,000	-	-
				\$ -	-	-
End of project life	Credit	-	\$ -	\$ -		

[Go to GHG Analysis sheet](#)

**RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Wind Energy Project**

Use GHG analysis sheet?   
 Potential CDM project?

Type of analysis:

**Background Information**

<b>Project Information</b>				<b>Global Warming Potential of GHG</b>	
Project name	Tema Wind Farm	Project capacity	52.5 MW	21 tonnes CO <sub>2</sub> = 1 tonne CH <sub>4</sub>	(IPCC 1996)
Project location	Tema, Ghana	Grid type	Central-grid	310 tonnes CO <sub>2</sub> = 1 tonne N <sub>2</sub> O	(IPCC 1996)

**Base Case Electricity System (Baseline)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	30.0%	8.7%	0.983
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Natural gas	0.0%	56.1	0.0030	0.0010	45.0%	0.0%	0.000
Nuclear	0.0%	0.0	0.0000	0.0000	30.0%	0.0%	0.000
Wind	0.0%	0.0	0.0000	0.0000	100.0%	0.0%	0.000
Electricity mix	100%	270.5	0.0073	0.0073		8.7%	0.983

Does baseline change during project life?

**Proposed Case Electricity System (Wind Energy Project)**

Fuel type	Fuel mix (%)	CO <sub>2</sub> emission factor (kg/GJ)	CH <sub>4</sub> emission factor (kg/GJ)	N <sub>2</sub> O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (tCO <sub>2</sub> /MWh)
Electricity system							
Wind	100.0%	0.0	0.0000	0.0000	100.0%	8.7%	0.000

**GHG Emission Reduction Summary**

Electricity system	Base case GHG emission factor (tCO <sub>2</sub> /MWh)	Proposed case GHG emission factor (tCO <sub>2</sub> /MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (tCO <sub>2</sub> )	GHG credits transaction fee (%)	Net annual GHG emission reduction (tCO <sub>2</sub> )
		0.983	0.000	112,956	110,994	0.0%

[Complete Financial Summary sheet](#)

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance					
Project name	Tema Wind Farm				
Project location	Tema, Ghana				
Renewable energy delivered	MWh	123,719	Net GHG reduction	t <sub>CO2</sub> /yr	110,994
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t <sub>CO2</sub>	2,330,876
Grid type	Central-grid		Net GHG emission reduction - 25 yrs	t <sub>CO2</sub>	2,774,852

Financial Parameters					
Avoided cost of energy	\$/kWh	0.0400	Debt ratio	%	70.0%
RE production credit	\$/kWh	0.025	Debt interest rate	%	14.0%
RE production credit duration	yr	10	Debt term	yr	25
RE credit escalation rate	%	2.5%			
GHG emission reduction credit	\$/t <sub>CO2</sub>	5.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	12.0%			
Project life	yr	25			

Project Costs and Savings					
<b>Initial Costs</b>			<b>Annual Costs and Debt</b>		
Feasibility study	0.4%	\$ 245,200	O&M	\$	770,000
Development	1.2%	\$ 835,500			
Engineering	0.9%	\$ 610,500	Debt payments - 25 yrs	\$	6,916,203
Energy equipment	81.3%	\$ 55,230,000	<b>Annual Costs and Debt - Total</b>	<b>\$</b>	<b>7,686,203</b>
Balance of plant	8.6%	\$ 5,868,000			
Miscellaneous	7.5%	\$ 5,117,320	<b>Annual Savings or Income</b>		
<b>Initial Costs - Total</b>	<b>100.0%</b>	<b>\$ 67,906,520</b>	Energy savings/income	\$	4,948,775
Incentives/Grants		\$ -	Capacity savings/income	\$	-
			RE production credit income - 10 yrs	\$	3,092,984
			GHG reduction income - 21 yrs	\$	554,970
			<b>Annual Savings - Total</b>	<b>\$</b>	<b>8,596,729</b>
<b>Periodic Costs (Credits)</b>					
Drive train	\$	1,000,000	Schedule yr # 10,20		
Blades	\$	1,000,000	Schedule yr # 15		
	\$	-			
End of project life - Credit	\$	-			

Financial Feasibility					
Pre-tax IRR and ROI	%	12.2%	Calculate energy production cost?	yes/no	No
After-tax IRR and ROI	%	12.2%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	8.7			
Year-to-positive cash flow	yr	8.2	Project equity	\$	20,371,956
Net Present Value - NPV	\$	393,862	Project debt	\$	47,534,564
Annual Life Cycle Savings	\$	50,217	Debt payments	\$/yr	6,916,203
Benefit-Cost (B-C) ratio	-	1.02	Debt service coverage	-	1.18

Yearly Cash Flows			
Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	(20,371,956)	(20,371,956)	(20,371,956)
1	1,216,039	1,216,039	(19,155,917)
2	1,535,376	1,535,376	(17,620,540)
3	1,869,192	1,869,192	(15,751,348)
4	2,218,174	2,218,174	(13,533,174)
5	2,583,040	2,583,040	(10,950,134)
6	2,964,548	2,964,548	(7,985,586)
7	3,363,488	3,363,488	(4,622,097)
8	3,780,692	3,780,692	(841,405)
9	4,217,030	4,217,030	3,375,624
10	3,393,331	3,393,331	6,768,956
11	1,092,545	1,092,545	7,861,500
12	1,490,491	1,490,491	9,351,991
13	1,908,966	1,908,966	11,260,958
14	2,349,013	2,349,013	13,609,970
15	1,363,427	1,363,427	14,973,397
16	3,298,252	3,298,252	18,271,649
17	3,809,803	3,809,803	22,081,453
18	4,347,646	4,347,646	26,429,099
19	4,913,114	4,913,114	31,342,213
20	3,868,989	3,868,989	35,211,201
21	6,132,590	6,132,590	41,343,792
22	6,234,643	6,234,643	47,578,435
23	6,925,326	6,925,326	54,503,760
24	7,651,371	7,651,371	62,155,131
25	8,414,567	8,414,567	70,569,698

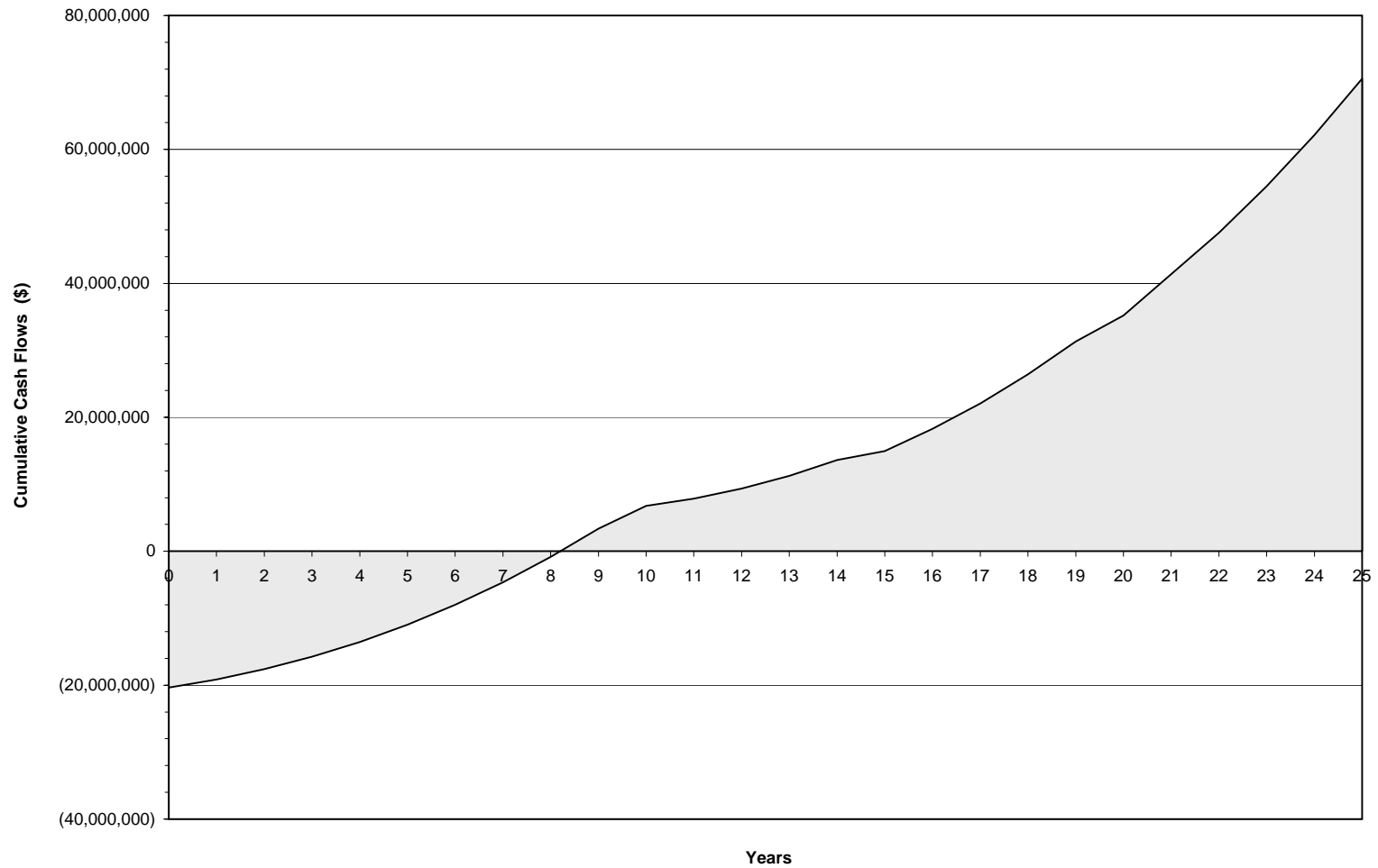
Cumulative Cash Flows Graph

### Wind Energy Project Cumulative Cash Flows Tema Wind Farm, Tema, Ghana

Renewable energy delivered (MWh/yr): 123,719

Total Initial Costs: \$ 67,906,520

Net GHG emissions reduced (tCO<sub>2</sub>/yr): 110,994



IRR and ROI: 12.2%

Year-to-positive cash flow: 8.2 yr

Net Present Value: \$ 393,862