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**TECHNO-ECONOMIC VIABILITY OF HUSK POWERED
SYSTEMS APPLICATION IN UGANDA**

By

Yonah Turinayo Karibwije. BSc. (Ind. Chem) (Mak)

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DECLARATION

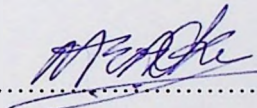
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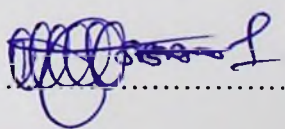
APPROVAL

This dissertation has been submitted for examination with the approval of the following supervisors:

Dr. Mackay Okure,
BSc. Eng, MSc, PhD

Signature  Date 31.12.2013

Dr. Samuel Baker Kucel
BSc. Eng, MSc, PhD

Signature  Date 31/12/2013

DEDICATION

To GOD Almighty, my parents Mr. and Mrs. George Karibwije, relatives and friends; who believed in me and gave me courage in all difficult times.

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LIST OF ABBREVIATIONS

B-C ratio	Benefit – Cost ratio
CBOs	Community Based Organizations
ERA	Electricity Regulatory Authority
FEWS-NET	Famine Early Warning Systems Network
GIS	Geographical Information System
GOU	Government of Uganda
HPS	Husk Powered System
IRR	Internal Rate of Return
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MFPED	Ministry of Finance, Planning and Economic Development
NGOs	Non Governmental Organizations
NPA	National Planning Authority
NPV	Net Present Value
PBP	Pay-Back Period
PWC	Price Waterhouse Coopers
REA	Rural Electrification Agency
RETSscreen	Renewable Energy Technology Screen
SPSS	Statistical Package for Social Scientists
UCE	Unit Cost of Electricity
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture

ABSTRACT

Approximately 90% of Uganda's population lives without access to electricity. The rural households with no access to electricity incur high prices for imported kerosene and diesel. They are vulnerable to indoor air pollution due to use of inefficient traditional energy technologies. Thus, there is an important role for adopting a cost-competitive and a less polluting alternative for electricity generation in Uganda.

A Husk Powered System (HPS) is an attractive option for rural electrification but has not been widely adopted due to various techno-economic constraints. The purpose of the study was therefore to provide a technical and economic evaluation of the viability of HPSs application in coffee and rice processing centers in Uganda. A 34kW_e pilot HPS, rice processing centers in Pallisa and Butaleja, and coffee processing centers in Masaka, Lwengo, Ssembabule, Bukomansimbi, Mubende and Mityana Districts were investigated. Technical evaluation of a pilot HPS and estimation of the sustainability of husks for its operation were done using models developed in Microsoft Excel. Investigation of local interest to adopt HPSs using Logistic Regression Model (developed in SPSS), economic analysis using RETScreen and mapping of potential sites using GIS, were also done.

The research revealed that overall energy conversion efficiency of HPS was 23.5% and 28.3% when using rice husks and coffee husks as fuel source, respectively. Sustainability of husks for HPS was high in coffee processing centers (104 – 1047kW_e) than rice processing centers (10 – 249kW_e), and the local interest to adopt HPS was high in all studied areas (odds ratio > 1). Investing in HPS using rice husks and coffee husks as fuel would be economically viable with a positive NPV (US\$ 4,039 and US\$ 15,275, respectively), B-C ratio > 1 (1.05 and 1.18, respectively), an attractive PBP of 5.2 years and 4.6 years with a 10 year IRR of 13.20% and 16.4%, respectively. The cost of HPS-derived electricity using rice husks and coffee husks (0.38214 and 0.38625 US\$.kWh_e⁻¹, respectively) was lower than that of solar and diesel but more expensive than national grid electricity for households.

CHAPTER ONE: INTRODUCTION

1.1. Background

As a country whose economy is mostly dependant on agriculture, Uganda has an abundant biomass resource which contributes over 90% of total energy consumption (MEMD, 2007). The use of biomass for energy production reduces greenhouse gas (GHG) emissions and promotes sustainable energy supply especially for remote rural communities (Gan and Smith, 2006; Kumar *et al.*, 2008). Uganda's biomass standing stock is about 460 million tons with a sustainable annual yield of 50 million tons (GOU, 2013), including 2.625million tones from agricultural residues (Dasappa, 2011). Coffee and paddy (un-milled rice) production are estimated at 154,700 tons/year (MAAIF, 2010) and 180,000 tons/year (Savitri, 2009), respectively. The residues produced after processing these crops are known as coffee husks and rice husks, and have an estimated power potential of 95MW_e and 16MW_e, respectively (MEMD, 2007). Nevertheless, this energy is not being fully utilized (Norplan, 2003; Bingh, 2004).

The renewable energy policy for Uganda is aimed at increasing the use of modern renewable energy from 4 to 61% of the total energy consumed by 2017 (MEMD, 2007). However, one of the major challenges is that there is limited progress especially in rural electrification. Unreliable grid electricity and high costs (about 0.455US\$.kWh⁻¹) of diesel (Szab'o, *et al.*, 2011) are some of the major obstacles of Uganda's economic development. 24.5% of the population is extremely poor (below the poverty line) and rural people are mostly vulnerable (MFPED, 2012). About 61% of rural households rely primarily on agriculture (54% subsistence and 5% commercial) as a source of income (MFPED, 2012). Nevertheless, Uganda has the lowest rural electrification of about 3% compared to 39% in urban areas (REA, 2011). The low access to electricity, about 11% nationwide, is due to low connectivity and remoteness. Limited access to electricity has led to low development and high cost of production in rural areas.

Most of rice growing districts don't have electrical power in the main rice growing areas (Odogola, 2006). Consequently, some crop processing machines in rural areas use diesel engines to run the mills. This has led to much higher operation costs and thus contributing to higher milling charges. Therefore, the installation of Husk Powered Systems (HPSs) seems to be a promising solution for this energy crisis.

Technologies for conversion of husks into electricity at relatively higher efficiencies are now available (Mahajan and Mishra, 1992; Bhattacharya, 1993). Among many competing bioenergy technologies, an HPS (a biomass gasification power project (BGPP)) has emerged as a role model in the renewable energy sector. HPS has proved to be an attractive option for rural electrification but has not been widely adopted due to various techno-economic and logistics constraints (McKendry 2002a; Caputo *et al.*, 2005; Klimantos *et al.*, 2009). The accelerated use of gasification technologies ultimately depends upon their ability to compete with fossil fuels.

The technology of HPS is based on the conversion of biomass such as rice husks into combustible gases that can run generators to produce electricity. Running on an environmentally friendly model, HPS ensures sustainable electricity to even the most remote parts of the country. The system consists of biomass preparation unit, biomass gasifier, gas cooling and cleaning system, internal combustion engine coupled with a generator and electricity distribution system. Because of the dispersed distribution and massive volume, biomass residues are difficult to utilize and have therefore been usually treated as waste. Small-and medium-scale biomass gasification systems can fully utilize these biomass residues in a small district, avoiding collection and long distance transportation problems. This enhances the competitiveness of biomass gasification with other energy technologies in the market. (Leung *et al.*, 2004)

An economic analysis of the use of biomass for the production of electricity must consider, among other factors:

- The characteristics of the biomass residue (as for example, moisture content and lower heating value)
- Biomass geographical distribution
- The technology for the transformation into electricity (which, in turn, depends on the residue properties)
- The economies of scale of the transformation plant and
- The income accrued as feed-in tariffs for the electricity generated (Antonio *et al.*, 2010).

Having this in mind, in the present work a system analysis is presented in order to investigate the feasibility of coffee husk and rice husk utilization for direct production of electric energy in Uganda through gasification processes. Considering the technical, organizational and logistical issues related to the value chain of HPSs, these systems have been chosen for analysis because

they are quite mature technologically but have not yet reached their full diffusion potential. This study is aimed at carrying out a technical and economic evaluation of the viability of Husk Powered Systems application in coffee and rice processing centers in Uganda.

1.2. Problem Statement

There is no commercial production of electricity using rice and coffee husks in Uganda. This could be due to limited information regarding technical and economic viability of biomass based renewable energy technologies including use of coffee and rice husks to generate power. Inadequate information on exploitation of rice husks and coffee husks for electricity generation in Uganda has led to their inefficient utilization. Such husks are directly combusted in brick firing kilns, tobacco smoking, crop drying among others, and the rest dumped near mills resulting into environmental pollution. Conversion of the unutilized husks to electricity using HPS is a viable alternative use.

1.3. Research Objectives

1.3.1. Main Objective

The main objective of the study was to carry out a technical and economic evaluation of the viability of Husk Powered Systems (HPSs) application in coffee and rice processing centers in Uganda.

1.3.2. Specific Objectives

The specific objectives were:-

- To determine the sustainability of husks for HPSs application in coffee and rice processing centers.
- To evaluate the technical viability of a HPS.
- To investigate the local interest to adopt and operate HPSs in coffee and rice processing centers.
- To evaluate the economic viability of adopting HPSs in coffee and rice processing centers.

- To develop a map as a guide showing electric power potential from sites of coffee and rice processing centers.

1.4. Research Questions

The study was guided by the following research questions:

- 1) What is the sustainability of husks to generate electricity using HPSs adopted in coffee and rice processing centers?
- 2) What operating parameters can make HPS technically viable in coffee and rice processing centers?
- 3) To what extent are the local people interested in adoption and operation of HPSs?
- 4) What is the cost of electricity generated by a HPS using coffee and rice husks in Uganda?
- 5) How economically viable is it to adopt HPSs in coffee and rice processing centers?
- 6) How does HPSs compare to other alternative power systems in terms of cost of electricity generated?
- 7) What are the possible sites for viable operation of HPSs?

1.5. Justification

Uganda, whose electrification is low at about 11%, is rich with biomass and can to a large extent, increase access to electricity by the use of renewable energy resources. However, investing in renewable energy technologies such as biomass gasification power projects is a major challenge in Uganda. This is due to lack of sufficient information regarding technical and economic viability of these projects. Such information is useful for the design and adoption of biomass gasification power project businesses, as a way of promoting use of renewable energy technologies.

Coffee (of which Uganda is Africa's leading producer) contributes the largest percentage (19%) of the country's exports (PWC, 2012) and generates large quantities of husks. The estimated total power potential of coffee husks is about 95MWe (MEMD, 2007) with unutilized fuel of about 56.2GWh based on 2004 estimates (Olwa, 2011). On the other hand, rice husks generate a total power potential of about 16MWe (MEMD, 2007) with unutilized fuel of about 9.88 GWh (Bingh, 2004). If these husks are used to generate electricity, they may improve on

Environmental conservation and economic development, hence contributing to Millennium Development Goals (MDGs).

Use of renewable energy technologies is a cross-cutting contributor in achieving the MDGs through combating climate change, promoting environmental sustainability, poverty eradication, health, gender and development, universal primary education and global partnerships for development. This data provides vital information concerning the initial feasibility of biomass gasification power projects and is utilized to quantify the economic parameters that determine the considered projects' viability/profitability.

1.6. Scope

Technical and economic feasibility of adoption of HPS in coffee and rice processing centers was done basing on an investigative study of a pilot HPS installed in Mpigi District, central part of Uganda. The study sites for adoption of HPS were selected from districts including Pallisa, Butaleja, Masaka Lwengo, Ssembabule, Bukomansimbi, Mubende and Mityana (appendix 2). Coffee husks and rice husks were considered as the feedstock for HPS in this study.

A pilot HPS was technically evaluated for its viability in coffee processing centers and the following parameters were determined: Required Fuel Input (RFI), plant electric power output, power consumed by the auxiliaries, overall energy conversion efficiency and equipment availability (Capacity Utilization Factor, CUF). Whereas economic viability of HPS was evaluated using its capital costs, total operating costs under consideration of personnel (labour) cost, Operation and Maintenance (O&M) costs, fuel cost, estimated Levelized Unit Cost of Electricity (LUCE), and financial parameters such as Net Present Value (NPV), Benefit – Cost (B-C) ratio, payback period (PBP) and Internal Rate of Return (IRR). Consumers' response towards electricity derived by a pilot HPS was also determined.

1.7. Conceptual Framework

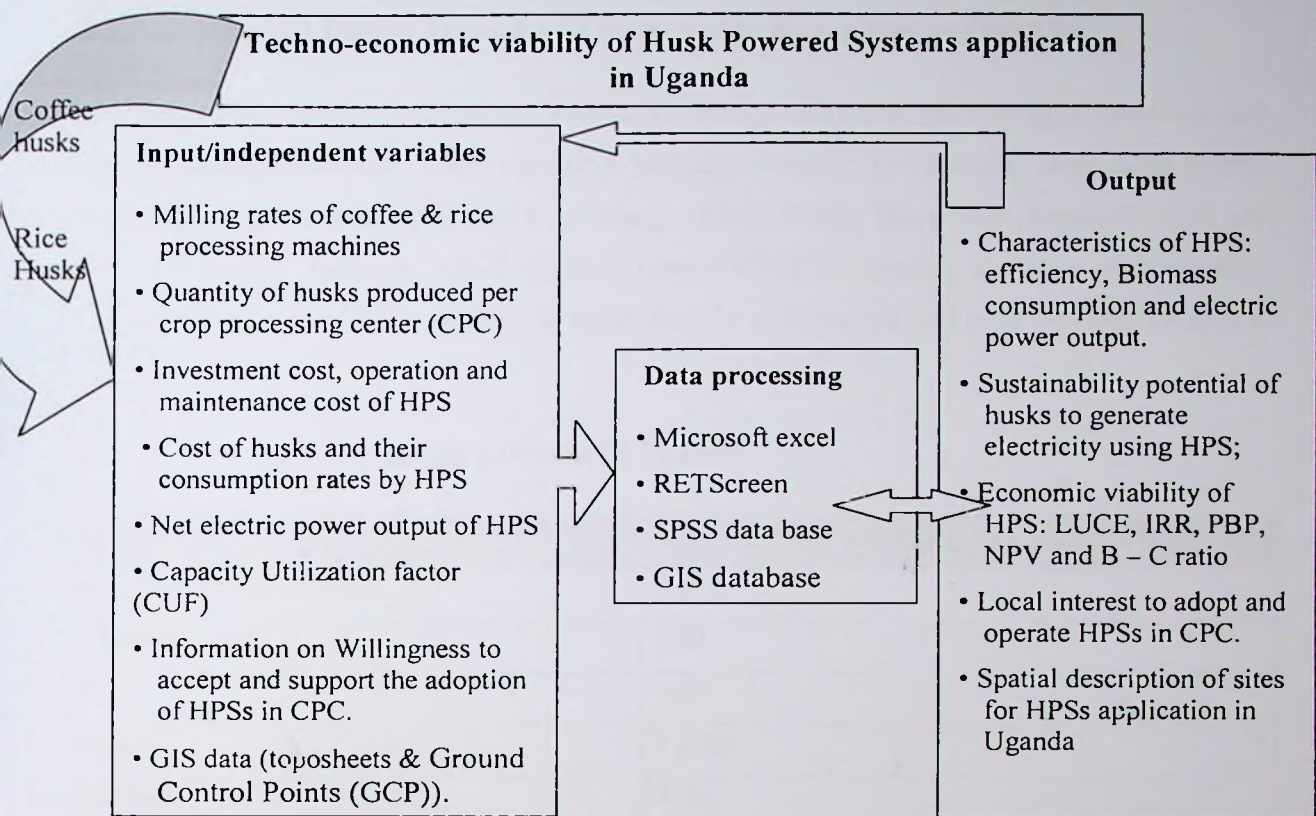


Figure 1.1: Conceptual framework

Figure 1.1 represents the conceptual framework of the study. The input variables used in the evaluation include: milling rates and amount of husks generated by coffee and rice processing machines, investment, operation and maintenance costs of HPS, cost of husks and their consumption rates using HPS, net electric power output of HPS, Capacity Utilization Factor (CUF), willingness to accept and support the adoption of HPSs, and Ground Control Points (GCP) of the study areas. When these variables were processed in Microsoft excel, RETScreen, SPSS and GIS data bases, the output results including the efficiency, Biomass consumption and electric power output of HPS, sustainability of husks for HPSs application in coffee and rice processing centers, economic viability of HPS, Local interest to adopt and operate HPSs and spatial description of sites for HPSs application, were generated. Such output results indicated the technical and economic viability of HPSs application in coffee and rice processing centers.

CHAPTER TWO: LITERATURE REVIEW

2.1. Electrical Power Potential of Renewable Resources in Uganda

Uganda has considerable underutilized renewable energy resources for energy production and provision of energy services. These resources include: biomass, geothermal, large scale hydro, mini/micro/pico hydro, wind, peat and solar energy (ERA, 2009). The power potential values are shown in Table 2.1. Biomass, which supplies over 90% of the country's energy requirements, has continued to be used in its traditional form, largely as firewood and crop residues (MEMD, 2007).

Table 2.1: The renewable energy potential of Uganda

Energy source	Estimated Electrical Potential (MW)
Hydro (Mainly on the Nile)	2,000
Mini-hydro	200
Solar	200
Biomass	1,650
Geothermal	450
Peat	800
Wind	-
Total	5,300

Source: ERA (2009)

On a large, agro-industrial scale, biomass residues (particularly bagasse, coffee husks, rice husks and sawdust) are underutilized for heat and electricity production in Uganda (Buchholz and Da Silva, 2010). In 2004, only an estimated 27.7GWh of electricity, vis-à-vis 150.7GWh (at a conversion of three kilograms of bagasse to one kWh of electricity (Bhattacharyya 2004)) was produced from 452,200 tons of bagasse (Bingh, 2004). According to Bingh (2004), the theoretically produced coffee husks in the year 2002 was 172,000 tons and out of this, only 7% was used for energy purposes. Approximately 160,000 tons of coffee husks were therefore available for utilization, which was equivalent to 738 GWh by applying the gross calorific value of 4.61kWh/kg (Werther *et al.*, 1998). Assuming an efficiency of 25 % heat to electricity

conversion, the electricity generation was found to be 15,033 kW, equivalent to 131.7 GWh (basing on maximum capacity of 24 hours a year). Norplan (2003) also found that the theoretical amount of rice husks produced in 2003 was 29,430 tons of which only 9,760 tons, was potentially utilized for energy. This was equivalent to 29.8 GWh and 9.88 GWh respectively of energy output, based on the gross calorific value of rice husks of 4.44 kWh/kg and 25 % efficiency of generating electricity from the heat (Bingh, 2004). Given this energy potential, the technology of making it available to Ugandan consumers has been a challenge. This could be due to various techno-economic and logistic constraints (McKendry 2002a; Caputo *et al.*, 2005; Klimantos *et al.*, 2009). Such constraints entail; ability to compete (in terms of cost and resource availability) with fossil fuels, solar, hydro and other energy technologies.

2.2. Availability and Sustainability of Rice and Coffee Husks for Energy in Uganda

Uganda is a predominantly agricultural country, growing crops such as coffee and rice (MAAIF, 2010). The processing of such crops generates large volumes of residues. Factories such as rice mills and coffee mills, mostly in the South West and East of Uganda, produce biomass residues.

Hima cement factory in Uganda burns coffee husks as an alternative fuel, saving about \$3.1 million in foreign exchange per annum, with a reduction of 30% fossil fuel consumption (UNEP, 2009). According to Balasankari and Arul (2008), and Buljit *et al.*, (2010), conversion of these husks to producer gas can be used as an engine fuel for electricity generation. Depending on good reliability and availability of gasification technology, this can be an ideal system for rural electrification (Balasankari and Arul, 2008). Nevertheless, there must be a sustainable supply of the biomass feedstock for gasification to be a reliable technology for rural electrification (la *et al.*, 2012).

Okure, Ndemere and Kucel (2006) performed a study on sustainability of agricultural residues as feedstock for fixed bed gasifier, and found a great potential in reduction of unsustainable exploitation of woody biomass in Uganda. Forests have been cleared for energy needs, settlement and for farming due to the increasing demand. This led to increase in prices for biomass fuels and to further environmental degradation. Large amounts of agricultural residues are burnt in the fields as a means of disposal leaving only little for improving or maintaining soil

fertility. This leaves a great deal of energy potential unutilized and being wasted (Okure *et al.*, 2006). A technology that can efficiently convert these agricultural residues into heat and power would lessen the pressure being put on the forests and also reduce on the over dependency on wood and forests residues (Okure *et al.*, 2006).

Studies on availability of agricultural residues have been done in sub-Saharan Africa, Uganda inclusive (Dasappa, 2011). Uganda has about 2.625 million tones/year of cereal production and 2.625 million tones of agricultural residues¹ (Dasappa, 2011). The ratio of crop to residues (CR) that are generated during cereal production and processing, can be in the range of 0.2 and 3.0 for the husk and for the stalk, respectively (Dasappa, 2011). In his calculations for estimation of agricultural residues, Dasappa (2011) assumed CR for both stalks and husk to be 1.0. However different values of CR have been used by different authors. Tripathi *et al.* (1998) used 0.25 for rice husks and Dasappa (2011) used 0.2 for rice husks. In line with Saenger *et al.* (2001), coffee husks have a CR of about 0.28 (at 12% moisture content dry basis).

A study conducted for MEMD by Patience and Drichi (2001) on Plan for Development of Uganda's Biomass Energy Strategy also generated data on agricultural residues from both food crops and cash crops in Uganda. The study revealed that rice generated 108,445 tones of residues of which 32,534 tones were available for energy and coffee generated 145,172 tones of which 43,552 tones were for energy. According to MEMD (2007), there is a greater potential of energy generation from agro-residues in Uganda.

2.2.1. Rice and Coffee Production in Uganda

Uganda is a developing country whose economy is dominated by agriculture. Agriculture contributes approximately 37% of the Gross Domestic Product (GDP), with coffee (of which Uganda is Africa's leading producer) contributing the largest percentage of 19% of the exports (PWC, 2012).

Statistics show that between 1999/2000 and 2005/06, there was a significant increase in production of the major crops including rice (from 41,896 tons to 880,000 tons, equivalent to 2000% increase) among others. However, coffee depicted a significant decrease in production,

¹ The agricultural residues are estimated at crop to residue ratio, 1.

from 154,700 tons to 120,139 tons, corresponding to -22% (MAAIF, 2010). According to the Ministry of Trade, rice production in Uganda has increased 2.5 times since 2004 (MAAIF, 2009). In 2008, the country's paddy (un-milled rice) production was estimated to be 180,000 tons, 11% more than in 2007 (Savitri, 2009). However, these crops produce substantial amount of husks which can be used in gasification to generate electricity, but may cause environmental havoc if not properly managed.

Rice in Uganda is grown mainly by small-scale farmers almost throughout the country, as well as large-scale farmers in few places. The Eastern and Northern regions of the country are key producers of rice (Sangeetha *et al.*, 2010). However, Western Uganda also produces substantial amount due to the presence of lowland with high moisture content throughout the growing season (GOU, 2009; NPA, 2010).

Other than rice, Uganda is ranked 19th among the world's coffee exporting nations (MAAIF, 2005). Coffee, a perennial crop, is the leading export commodity and cash crop for Uganda. Arabica and Robusta are the two varieties of coffee grown in Uganda, and both are important to the country's export earnings. According to MAAIF (2010), coffee as the main export crop, earned USD 388 million in Uganda's financial year 2007/08. Arabica coffee is primarily grown in high altitude areas of the eastern, western, and southern regions and has marginally higher yields than Robusta (Sangeetha *et al.*, 2010).

2.2.2. Potential of Husks for Energy in Uganda

In order to evaluate the sustainability of present consumption patterns and the feasibility of introducing modern biomass fuel-based applications, an assessment of the resources and its availability for energy has to be made (Auke and Jaap, 1997). According to Srinath and Reddy (2011), biomass materials with high energy potential include agricultural residues such as straw, bagasse, groundnut shells, coffee husks and rice husks. Several studies have been done on estimation of energy potential from agricultural residues in Uganda (Bingh, 2004; Buchholz, and Da Silva, 2010; MEMD, 2007). From these studies, MEMD (2007) estimated a total of about 407MW_e from agricultural residues, of which 16MW_e was attributed to rice husks and 95MW_e was attributed to coffee husks in the year 2007. However, Dasappa (2011) reported a 98MW power potential from agricultural residues in Uganda. The large discrepancy in the two values

could be due to the varying assumptions used in the estimation of the power potentials. Dasappa (2011) assumed 30% availability of residues, while MEMD (2007) assumed 100%.

As stated by Shin-ya *et al.* (2000), the energy content of biomass residue is estimated from the data of crop-to-residue ratio, moisture content, and heating value of residue of selected agricultural products. According to Abe *et al.* (2007), about 2 kg of rice husk is needed to generate 1kWh electricity. In Uganda, a study by Okure *et al.* (2006) found that coffee husks and rice husks with a moisture content of 14.073% and 10.038% on wet basis (%wt.b), generated low heating values of 17.08 MJ/kg $\pm 2\%$ and 13.37MJ/kg $\pm 2\%$, respectively. This implies that coffee husks have high lower heating value than rice husks even at higher moisture content. It was concluded that agricultural residues such as coffee husks, bagasse, maize cobs and rice husks may possibly present Uganda with a sustainable energy source, given reliable rainfall seasons. This could contribute to solving the country's current energy problems.

2.3. Technically Available Agricultural Residues for Power Generation

Large quantities of agricultural plant residues are produced annually worldwide and are vastly underutilized. The most common agricultural residue is the rice husk, which makes 25% of rice by mass (Demirbas, 2001). The technical availability refers to the initial (or exploitable) biomass fuel types, resource accessibility and competitive uses (Boukis *et al.*, 2009). Technical availability may be connected to organic matter losses during the various stages of feedstock logistics (Boukis *et al.*, 2009). These logistics can be identified as: collection, communitation, transport, storage and drying, prior to their final energetic utilization in the power plant.

Despite the widely agreed potential of bioenergy utilization, key problems regarding the use of biomass remain. These include: the limited availability in terms of time, owing to biomass seasonality, and the scattered geographical distribution over the territory that make the collection, transport and storage operations complex and expensive. These critical logistic aspects strongly affect the economic and energy performances of bio-energy conversion systems, introducing limitation on their suitability (Caputo *et al.*, 2005).

According to Tripathi *et al.* (1998), agricultural residues are not available throughout the year, and the amounts available depend upon harvesting time, their storage related characteristics and

the storage facility. Residues also differ from crop to crop and are affected by seasons, soil type, irrigation conditions, etc. The production of agricultural residues is directly related to the corresponding crop production, and the ratio between the main crop produce and its residues varies from crop to crop and, at times, with the variety of seeds in one crop itself (Nelson *et al.*, 2004; Tripathi *et al.*, 1998). Tripathi *et al.* (1998) in their study expressed the time variation of the total crop produced (*see* Equation 2.1).

$$C_p = a + bt \quad 2.1$$

Where;

C_p represents the amount of crop production in million tones/year, t the time in years (=1 for the year 1980-81), and a and b the regression coefficients.

The total availability of agricultural residue for the same crop was therefore estimated as shown in Equation 2.2 (Tripathi *et al.* 1998).

$$R_p = C_p \times CR \quad 2.2$$

Where;

CR is the crop to produce residue ratio.

It was found that, the production of crops increased consistently in the past three decades. Correspondingly, the availability of agricultural residues fluctuated with time. Since the crop production depends upon the agro-climatic conditions, all residues were not available in all parts of the country.

2.4. Gasification Technology for Power Generation

Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuels or chemical feedstock (Basu, 2010). The use of biomass gasification for power generation has been demonstrated in countries such as India and China (Wu *et al.*, 1998; Buragohain *et al.*, 2010). The most suitable technology for small-scale electricity generation (lower than 1MW_e) through gasification processes is a downdraft fixed bed gasifier coupled to an internal combustion engine (Hasler and Nussbaumer, 1999) because the gas

produced in the reactor is forced to pass through a high temperature throat, which produces a low tar content gas.

A biomass gasifier based power project consists of biomass preparation unit, biomass gasifier, gas cooling and cleaning system, internal combustion engine suitable for operation either in Dual Fuel (DF) mode with diesel as pilot fuel and producer gas as main fuel or 100% produce gas (HPG) mode, electric generator and electricity distribution system (see Figure 2.1).

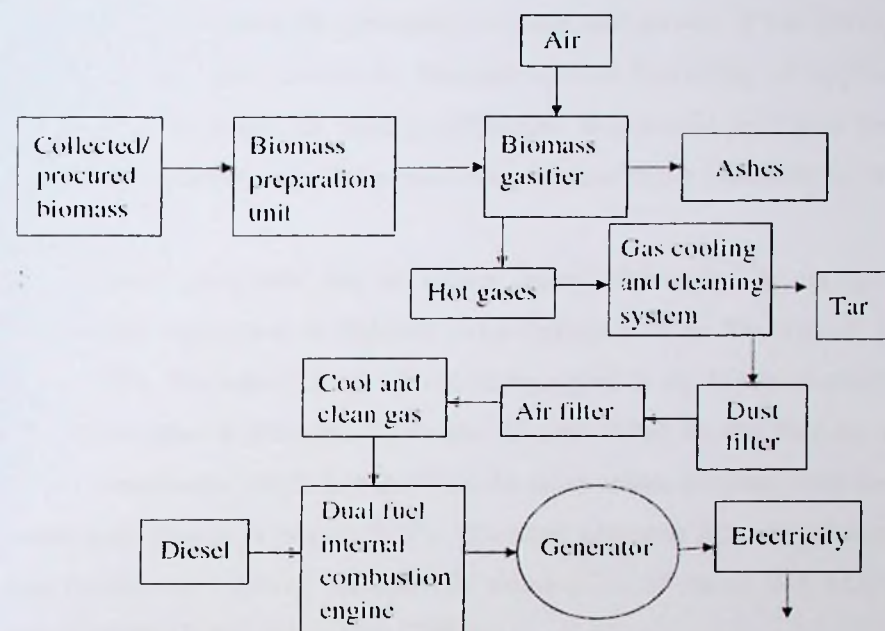


Figure 2.1: Schematic of a typical biomass gasifier based power project (Nouni et al., 2007).

Technologies of power generation through biomass gasification are established in developed countries (Yong, 2003; Larson, 1998; Kumar *et al.* 2008; Reed and Das, 1988; Mamphweli and Meyer 2009). However, there has been little experience of implementing small electricity-generating biomass plants in off-grid areas of developing countries (Dimpl, 2011).

2.4.1. Gasification Process

Commercial gasification was started as early as 1812, when coal was converted to gas for illumination (known as manufactured gas or town gas) in England (Kayhanian *et al.* 2007). The high volatile content of biomass (70–90 wt %) compared with coal (typically 30–40 wt %) and high reactivity of its char make biomass an ideal gasification fuel (Kayhanian *et al.* 2007).

However, high volatile matter in biomass generally increases tar content in the product gas and a substantial quantity of this tar should be removed before it is fed to an internal combustion engine (Reed and Das, 1988; Dasappa *et al.*, 1985). According to Reed and Das (1988), gasification can convert 60% to 90% of the energy in the biomass into energy in the gas, which ideally contains all the energy originally present in the biomass. The gas generated, synthesis (syn) gas or producer gas, has varying calorific values depending on the gasifying agents (air, steam, oxygen, hydrogen) being used in gasification process (McKendry, 2002). Not only can producer gas be used for generation of heat and power, it can serve as feedstock for production of liquid fuels and chemicals. Because of this flexibility of application, gasification has been proposed as the basis for “energy refineries” that would provide a variety of energy and chemical products, including electricity and transportation fuels (Kayhanian *et al.*, 2007).

Gasification processes can be either direct (using air or oxygen to generate heat through exothermic reactions) or indirect (transferring heat to the reactor from the outside) (Reed and Das, 1988). The use of air as an oxidizing agent in the biomass gasification process leads to high concentrations of nitrogen (between 40 and 50%) in the fuel/air mixture. Nitrogen acts as a knock suppressor which is beneficial in cases when engines with the high compression ratio are employed (Martínez *et al.*, 2012). However nitrogen introduced with the air dilutes the product gas, producing a gas of net calorific value (CV) of about 4–6 MJ/Nm³ (compared with natural gas at 36 MJ/ Nm³) (Mckendy, 2002a).

Gas composition of product from the biomass gasification depends heavily on the gasification process, the gasifying agent, and the feedstock composition (Balat, 2008). Three product gas qualities can be produced from gasification by varying the gasifying agent, the method of operation and the process operating conditions. In line with Mckendy (2002a), the three types of product gas have different calorific values (CV): shown in Table 2.2.

Table 2.2: Types of product gas have different calorific values

Product gas	Typical calorific value (MJ/Nm ³)	Gasification agent
Low CV	4–6	Using air and steam/air
Medium CV	12–18	Using oxygen and steam

High CV	40	Using hydrogen and hydrogenation
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Low CV gas is used directly in combustion or as an engine fuel, while medium/high CV gases can be utilized as feedstock for subsequent conversion into basic chemicals, principally methane and methanol (McKendry, 2002b).

According to Balat *et al.* (2009), the gasification process is carried out at high temperatures in order to optimize the gas production. This temperature is usually greater than 800 °C (McKendry, 2002b). The resulting gas is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen (Ramadhas *et al.*, 2006). The producer gas typically contains 18–20 per cent each of H₂ and CO, 2 per cent of CH₄, and the rest inert gases such as CO₂ and N₂ (Sridhar *et al.*, 2005). Gasification of biomass is generally observed to follow the reaction Equation 2.3 in accordance with Balat *et al.*, (2009):



The gas can be burned to produce industrial or residential heat, to run engines for mechanical or electrical power, or to make synthetic fuels (Reed and Das, 1988). The operation of diesel and spark-ignition engines using a variety of low heating value gases is an established practice (Bridgwater *et al.*, 2002).

2.4.2. Gasifires

Gasifiers are of mainly two types, fixed bed and fluidized bed, with variations within each type (McKendry, 2002a). A third type, the entrained suspension gasifier has been developed for coal gasification. However the need for a finely divided feed material (<0.1–0.4 mm) presents problems for fibrous materials' entrained suspension gasification. This makes entrained suspension gasification largely unsuitable for most biomass materials and therefore the process is not considered further (McKendry, 2002a).

Vertical fixed bed reactors (VFB) are the most competitive fixed bed gasifiers. As shown in figure 2.2, they are subdivided into updraft and downdraft gasifiers (Belgiorno *et al.*, 2003). In

combustion zone of the fixed bed, the highest temperature of the reactor is greater than 1200 (Belgiorno *et al.*, 2003).

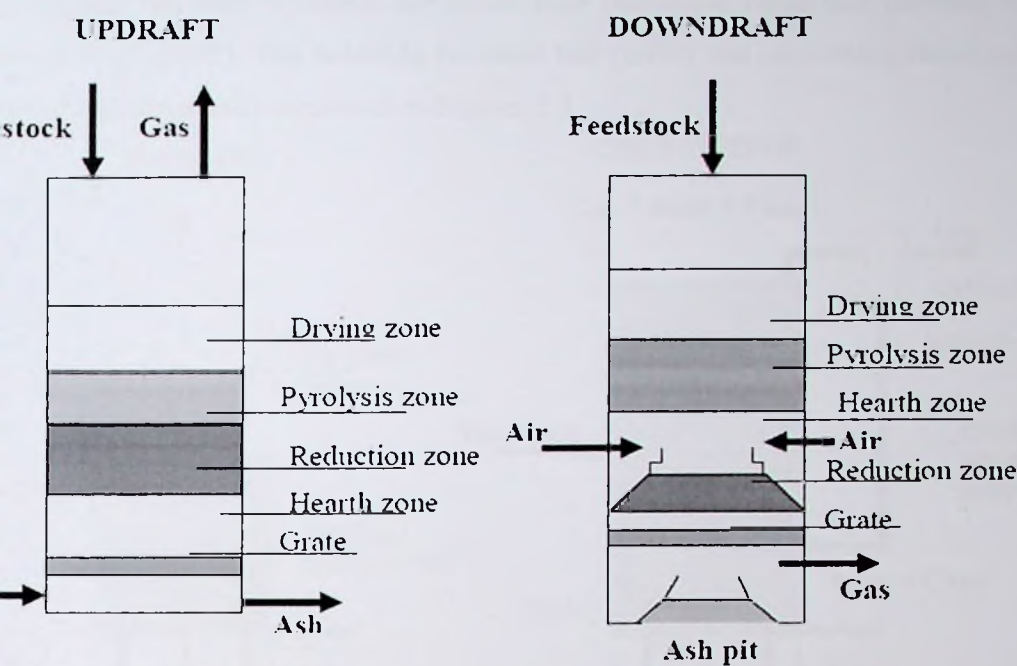


Figure 2.2: Fixed bed gasifiers (Belgiorno *et al.*, 2003)

According to McKendry (2002b), the downdraft configuration reduces the amount of high molecular weight hydrocarbons and particles as compared to the updraft configuration. In the downdraft configuration, pyrolysis vapours allow for effective tar thermal cracking (Belgiorno *et al.*, 2003). However, the internal heat exchange is not as efficient as in the updraft gasifier (Gwater, 1994). For these reasons the downdraft layout is the most satisfactory when the gasifier must be coupled with a reciprocating internal combustion engine compared with the updraft gasifier. Downdraft moving-bed gasifiers coupled with reciprocating internal combustion engines are a good choice for moderate quantities of available biomass, generating about 500 kW electric power (Tinaut *et al.*, 2006).

Fixed bed (FB) gasification has also been used extensively for coal gasification for many years. Its advantage is the uniform temperature distribution achieved in the gasification zone. The uniformity of temperature is achieved using a bed of finegrained material into which air is introduced, fluidizing the bed material and ensuring intimate mixing of the hot bed material, the

hot combustion gas and the biomass feed (McKendry, 2002a). Fluidised bed reactors are gasifier types without different reaction zones. They have an isothermal bed operating at temperatures usually around 700–900 °C which are lower than maximum fixed bed gasifiers temperatures (Belgiorno *et al.*, 2003). The bubbling fluidised bed (BFB) and circulating fluidized bed (CFB) gasifiers are schematically presented in Figure. 2.3.

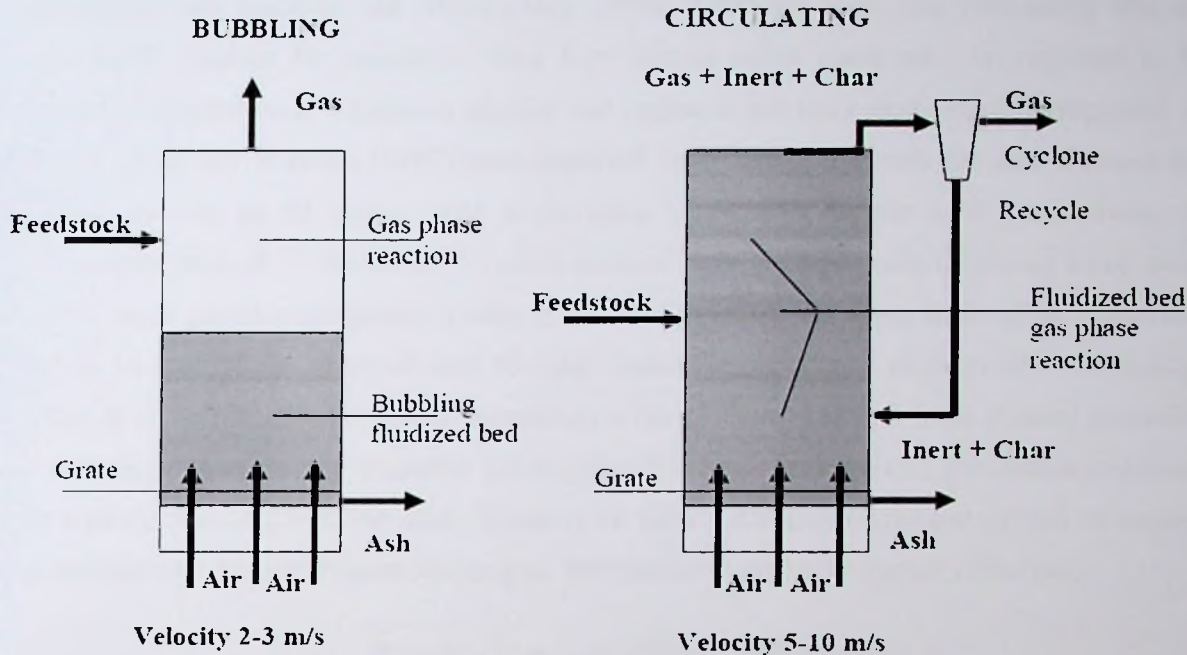


Figure 2.3: Fluidised bed gasifiers (Belgiorno *et al.*, 2003).

2.4.3. Engines and Electricity Generation

Producer gas can partially replace engine oil in compression ignition (diesel) engines, or be used on its own in spark ignition (gasoline) engines, where a generator coupled to the engine produces electricity (Brown *et al.*, 2009). The producer gas is first cleaned and cooled before being used as fuel in an Internal Combustion (IC) engine. Therefore wet gas scrubbers are generally used to clean producer gas for this type of prime mover (Bridgwater *et al.*, 1995). The disposal of tar contaminated effluents must be taken into account (Brown *et al.*, 2009).

Biomass gasifier engine sets are typically available in capacities ranging from 10 kW_e to 500kW_e (Faithel, 2009). Two types of engines are used. Diesel engines are modified and can be run on a mixture of diesel and producer gas. These are called dual-fuel engines. Typically 60 - 85% diesel

Tinaut *et al.* (2006) used an Engine Fuel Quality (EFQ) parameter to predict the performance of an internal combustion engine fuelled by producer gas and other low heating value gases. They concluded that the characteristics of the product gas that affect most quantitatively the engine power are the heating value, the stoichiometric air–fuel ratio and the volume correction factor of the mixture. The estimation of engine power made by using the EFQ parameter indicates that power at full load is reduced to about two-thirds of the maximum obtained with a conventional liquid fuel.

2.4.4. Gas Cooling and Cleaning

The quality of producer gas as a fuel is considerably poorer compared to gasoline and natural gas. Hence, engines require certain design modifications to be carried out in order to run on producer gas (Martínez *et al.*, 2012). The addition of a scrubber or a filtration system to biomass gasification significantly increases the overall plant costs (Basu, 2010). This limitation makes biomass-based distributed power-generation projects highly sensitive to the cost of tar cleanup (Basu, 2010).

Internal-combustion (IC) engines, such as diesel or Otto engines, are favorite applications of gasified biomass, especially for distributed power generation. In such applications, the gas must be cooled, but there is a good chance of condensation of the tar in the engine or in fuel-injection systems. Furthermore, the piston-cylinder system of an internal-combustion engine is not designed to handle solids, which imposes tighter limits on the tar as well as on the particulate level in the gas. Particulate and tar concentrations in the product gas should therefore be below the tolerable limits, which are 30 mg/Nm³ for particulates and 100 mg/Nm³ for tar (Milne *et al.*, 1998, p. 41).

2.5. Economic Viability of Biomass Gasification Power Projects

The economic feasibility of a biomass gasification power project (BGPP) is dependent on several factors. These include the capital costs of the equipments (i.e. gasifier, engine-generator set, civil works and local distribution network), the specific fuel consumption, the capacity utilization factor (CUF), the useful lifetime of the equipments and fuel prices (Fracaro *et al.*, 2011). According to Angevine *et al.* (2012), a capacity utilization factor indicates the portion of time

(usually measured on an annual basis) that an electric generation facility can generally be relied upon to produce electricity.

Analysis of the economics and commercialization of biomass gasification technologies for rural electrification has been done by several authors (Ghosh *et al.*, 2004; Kishore *et al.*, 2005; Nouni *et al.*, 2007). The “measures” of the economic feasibility of the biomass gasifier for decentralized power generation include the levelized unit cost of electricity (LUCE) produced by the gasifier (Nouni *et al.*, 2007). From an economic point of view, profit can only be obtained by biomass gasification when it is much cheaper than other kinds of energy (Leung *et al.*, 2004). Studies by some authors have been undertaken for economic evaluation of biomass gasification power plants (BGPP) (Kapur *et al.*, 1996; Tripathi *et al.*, 1997; Kandpal and Garg, 2003). Kandpal and Garg (2003) stated that LUCE is one of the commonly used indicators for financial performance evaluation of renewable energy based decentralized power supply systems such as BGPP. Kishore *et al.* (2005) have also emphasized the view that high LUCE from BGPP in rural areas is due to low capacity utilization factor, which in turn is influenced by purchasing power of the rural people.

Brown *et al.* (2011) state that customers’ willingness to pay for renewable power is important when assessing the economic feasibility of such projects. Measuring willingness to pay for electricity relies critically on a reliable estimate of the demand for electricity function (Choynowski, 2002). However, this poses a challenge; many developing countries lack the quality and quantity of measured data, hence survey is frequently used (Choynowski, 2002). Kapur *et al.* (1996) found the unit cost of electricity provided by a dual fuel (DF) biomass gasifier using rice husks, as feedstock to be financially unattractive compared to grid supplied electricity. However, they concluded that the unit cost of electricity generated compared favorably with diesel-generated electricity for higher capacity systems operating at higher capacity utilization factors.

Ghosh *et al.* (2004) have analyzed the impacts of a 500kW (5 x 100kW) wood-based gasifier power plant in Gosaba Island of Sundarbans, West Bengal which was installed in July 1997 for supplying electricity to five villages. They found an increase in the number of commercial units in the region and improvement in the standard of living of the people. They also found that the

cost of production of a unit of electricity was \$0.2 when capital costs were included in the analysis and \$0.09 when capital costs were not included in the analysis. Nouni *et al.* (2007), during their study on financial evaluation of biomass gasifier projects for decentralized power supply in India, found that LUCE was 13.72 Rs. kWh⁻¹ (0.31083 US\$.kWh⁻¹) for a 30kW power plant. Similarly, Mukhopadhyay (2004) has found that the establishment of a gasification power plant (4 x 125kW) at Chottomollakhali Island in West Bengal has led to an increase of economic activities and more profitable turnover for the commercial consumers.

According to Palit and Chaurey (2011), choosing an electrification method and the associated generating equipment can never be done without careful regard to local conditions, with regard to resource availability, technical skills, socioeconomics and governance setting. Boukis *et al.* (2009) pointed out that any project is feasible provided the basic economic figures such as Internal Rate of Return (IRR), Cost-Benefit (CB) ratio and Net Present Value (NPV) are satisfactory. From an economic point of view, the keys to make biomass gasification economically feasible are to cut down the investment cost and to extend its application areas (Leung *et al.*, 2004). In the case of a biomass-fuelled power plant, the major goal is to deliver energy (electricity) at a reasonable cost (Boukis *et al.*, 2009). However, these generic remarks have to be quantified and specific figures that will help decide whether the conceived project is feasible or not, have to be referenced upon. Some of these figures include: the Specific Investment Cost (SIC), i.e. an estimation of the capital cost of the plant, expressed as €/installed kW_e; the Cost of Electricity (COE), i.e. how much it costs to generate a unit of electricity, expressed in ¢€/kWh_e, the project IRR and NPV (Boukis *et al.*, 2009). When the calculated NPV is positive, the investment results in a rate of return greater than the minimum rate, and in the absence of alternatives this would be a profitable investment. However, when the NPV is negative, the investment would not give a return at the minimum rate, and indicates a non-profitable investment (Wood and Rowley, 2011).

2.6. Technical Viability of Biomass Gasification Power Projects

The technical feasibility of biomass gasifier was proven long ago as gasifiers existed even during World War II. It is estimated that over 7 million vehicles (with spark ignition engines) in Europe, Australia, South America and Pacific Islands were converted to run on producer gas during

World War II (Ramadhas *et al.*, 2006). In line with power production, the only viable technologies for commercialization of electricity generation from biomass are: biomass gasification coupled with an IC engine operating on producer gas, and boiler-steam turbine route (or cogeneration) (Buragohain *et al.*, 2010).

From a system perspective, the techno-economic performance of biomass energy production plants are characterized by the overall energy conversion efficiency, required biomass amount for a given power output and the plant size (Caputo *et al.*, 2005). There are several ways of producing electricity by thermal conversion of biomass: pressurized gasification with a gas turbine in a combined cycle mode, atmospheric gasification with a turbine or an engine, and orthodox combustion with a Rankine cycle. Compared to gas turbines, IC engines have been said to be more efficient and can be economically more attractive for small scale electricity production. This goes up to a break-even point of about 5–6 MW_e above which the specific costs of gas turbine combined cycle (GT-CC) are said to be lower (Bridgwater *et al.* 1995; Bridgwater, 2003).

A single biomass gasification unit (with either updraft or downdraft design) can generate up to 500 kW power, while a gasification station (with fluidized bed design) could have capacity of about 5 MW (Buragohain *et al.*, 2010). According to Mansaray *et al.* (1999), fluidized bed technology offers great advantages when used for gasifying low calorific value fuels such as rice husks, producing gas that can be used to operate spark and diesel engines or gas turbines to generate power. However, information on technical lifetimes of the various system components is not available; estimates are used in designing (Siemons, 2001). Krishna and Kumar (1994) used coffee husk as biomass for gasification and analyzed the performance of a diesel engine on dual fuel mode. They could achieve the maximum diesel replacement of 31% only. It is because of formation of clinkers and a low density of biomass.

Sandro *et al.* (2001) compared an externally fired gas turbine using biomass fuel and natural gas. It has been estimated that around 11.5% reduction in efficiency is achieved by using biomass fuel. Sonaton *et al.* (2004) focused on technical performance of the largest biomass gasifier-based power plant (500 kW) in India. Sustainability of such a power plant has been reviewed with respect to diesel replacement, fuel wood supply, cost of electricity generation and

environmental pollution. The overall efficiency of that plant was about 19%. It has been reported that the maximum diesel replacement of 64% (at optimum load conditions) was achieved while using wood chips. Efforts have been made to utilize different types of biomasses as fuel in engines by Uma *et al.* (2004), Singh (2004), Gouli *et al.* (2001) and Dorgu *et al.* (2002). According to Brown *et al.* (2009), liquid fuel replacements of up to 85% are attainable in so called dual fuel (or gas diesel) engines which are said to have higher efficiencies than spark engines. But it is possible to increase the efficiency of producer gas fuelled spark engines by operating them at high compression ratios (Sridhar, Paul, and Mukunda, 2001).

Though efforts at scaling up gasifier unit sizes (up to 500kW) have been successful, there remain barriers in developing gasifier-based systems for low load applications (in the range of 10kW or less) that may be useful for power supply in remote, rural areas. One of the problems associated with decentralized power projects in remote villages is their low capacity utilization due to absence of energy consuming productive activities (Ghosh, Sagar and Kishore, 2005). In accordance with Ghosh *et al.* (2005), gasifiers that can utilize woody biomass are well developed, but there remain further developmental needs for utilizing a variety of powdery, loose biomass such as rice husk (along with other agricultural residues) and industrial wastes like sawdust. Jain (2006) reported that a rice husk fired gasifier performed well and showed the gasification efficiency as around 65% in the capacity range of 3 to 30 kW.

2.7. Summary of the Literature Review

A literature review on electrical power potential of renewable resources in Uganda, technical and economic viability of biomass gasification power plants has been done. It has been found that estimated total power potential from the renewable resources in Uganda is 5,300MW; biomass generating about 1,650MW (ERA, 2009). For effective exploitation of energy from biomass resource within a geographical location, the amount of biomass must be available and sustainable for a given energy conversion technology. The most suitable technology for small-scale electricity generation (lower than 1MW_e) through gasification processes is a downdraft fixed bed gasifier coupled to an internal combustion engine (Hasler and Nussbaumer, 1999). This is because the gas produced in the reactor is forced to pass through a high temperature throat, which produces a low tar content gas (Hasler and Nussbaumer, 1999).

In this study, coffee husks and rice husks have been considered as the energy source for rural electrification using a Husk Powered System. However, their availability for power generation in different geographical locations of Uganda must be documented. Availability of agricultural residues for energy potential in Uganda has been reported by Dasappa (2011) at 2.625 million tonnes, generating about 98MW_e at about 30% availability. MEMD (2007) also estimated a total power potential of about 407MW_e from agricultural residues, of which 16MW_e was from rice husks and 95MW_e was from coffee husks in the year 2007. Okure *et al.* (2006) found that coffee husks and rice husks generated low heating values of 17.08 MJ/kg $\pm$ 2% and 13.37MJ/kg $\pm$ 2%, respectively. This may possibly present Uganda with a sustainable energy source, given reliable rainfall seasons for crop production (Okure *et al.*, 2006).

The use of biomass gasification for power generation is a reality (Wu *et al.*, 1998; Buragohain *et al.*, 2010). However, there has been little experience of implementing small electricity-generating biomass plants in off-grid areas of developing countries (Dimpl, 2011) due to various techno-economic and logistic constraints (McKendry 2002a; Caputo *et al.*, 2005; Klimantos *et al.*, 2009). Constraints are mainly biomass resource availability in various geographical locations, economic factors such as; capital costs of the equipments (i.e. gasifier, engine-generator set, civil works and local distribution network), the specific fuel consumption, the capacity utilization factor (CUF), the useful lifetime of the equipments and fuel prices (Fracaro *et al.*, 2011). This calls for a study on technical and economic evaluation of adopting electricity-generating biomass plants in off-grid areas of Uganda.

CHAPTER THREE: METHODOLOGY

3.1. Research Design

The study used both quantitative and qualitative methods. A pilot HPS was technically evaluated for its viability in coffee processing centers basing on the estimated parameters which include: required Fuel Input (RFI), plant electric power output, power consumed by the auxiliaries, overall energy conversion efficiency and equipment availability (Capacity Utilization Factor, CUF). Consumers' response towards electricity generated and local interest to adopt and operate HPSs were critically analyzed. Investment cost, fuel cost and operation and maintenance cost of HPS were determined for economic evaluation. Measurements were done to determine electric power potentials of husks generated from coffee and rice processing centers.

3.2. Study Area

Selection of study districts was guided by the Uganda-livelihood zones map (Appendix 1) showing areas where coffee and rice are grown. Site location of paddy rice and coffee processing centers in respective districts, including Butaleja, Pallisa, Masaka, Lwengo, Ssembabule, Bukomansimbi, Mubende and Mityana was done in collaboration with the District Production and Agricultural Officers. The maps in Figure 3.1 shows the geographical location of the study areas of both rice and coffee growing regions of Uganda, and the location of a pilot HPS.

3.3. Sampling Strategy and Data Collection

Sampling of study areas was based on the number and location of processing machines in sub-counties/district, seasonal crop production per year and area coverage for crop production. Sampling and data collection was done in selected villages of respective districts as shown in Figure 3.1 and Appendix 2. The data that was collected is discussed in subsections 3.3.1, 3.3.2, 3.3.3, and 3.3.4. Data was collected using a questionnaire (Appendix 6), focus group discussions, interviews, observations and measurements.

ratio, CR), damping site of husks and amount of crop processed in a given time. Data on lower heating values (LHVs) of husks was got from existing literature in published journals.

3.3.2. Technical Evaluation of HPS and Consumers' Response to Electricity Generated

Figure 3.2 shows a pilot HPS where an investigative study was done. Specifications of the generator and auxiliary equipments including power rating of pump and drive motors, lighting bulbs, were recorded basing on manufacturers information. Recordings of the net electrical power output using a top view power analyser (*see* Figure 3.3), in conjunction with information on Required Fuel Input (RFI) and equipment availability (Capacity Utilization Factor, CUF), was done. Through interviews of power consumer (using checklist, Appendix 7), plant operators, plant manager (Pamoja Cleantech) and equipment supplier (Husk Power Systems Pvt Ltd.), data was obtained. This included; response to HPS derived electricity, total operating costs, Operation and Maintenance (O&M) costs, fuel cost and plant investment costs.



Figure 3.2: A pilot HPS installed at Tiribogo village, Muduma sub-county, Mpigi District (1st HPS in Uganda)

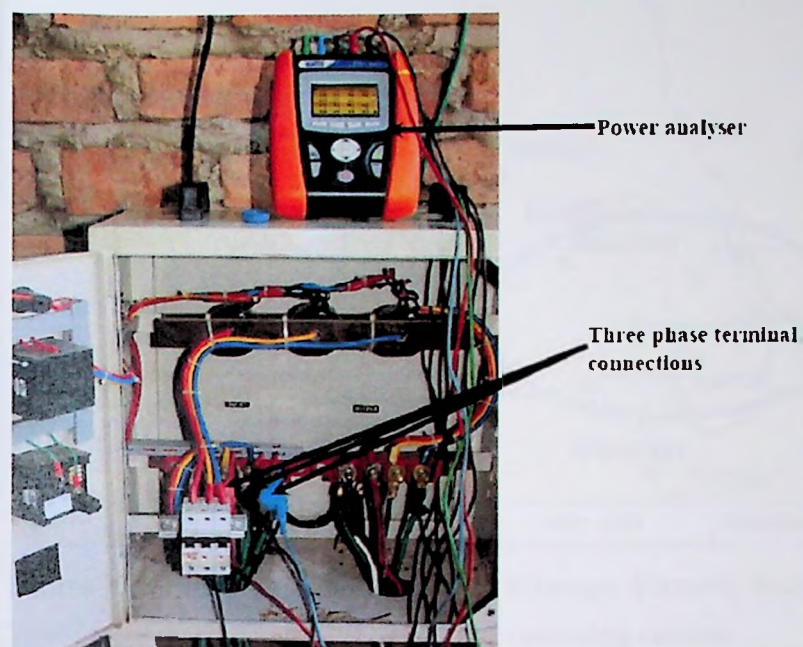


Figure 3.3: The power analyser “Top View HT PQA 824”

3.3.3. *Assessment of Local Interest to Adopt and Operate HPSs in Coffee and Rice Processing Centers*

A sampled population of 120, 109, and 72 respondents from selected villages of Pallisa, Butaleja, and Ssembabule Districts, respectively, were interviewed between May and August, 2012. Five trading centers (Nakelebe, Kibengo, Kamuli, Kusalira, Kijju and Manyama) in Ssembabule District (see Figure 3.4) having no access to electricity were selected for the study. The selection was based on the closeness to the coffee processing center, accessibility of grid electricity and economic activities in the area.

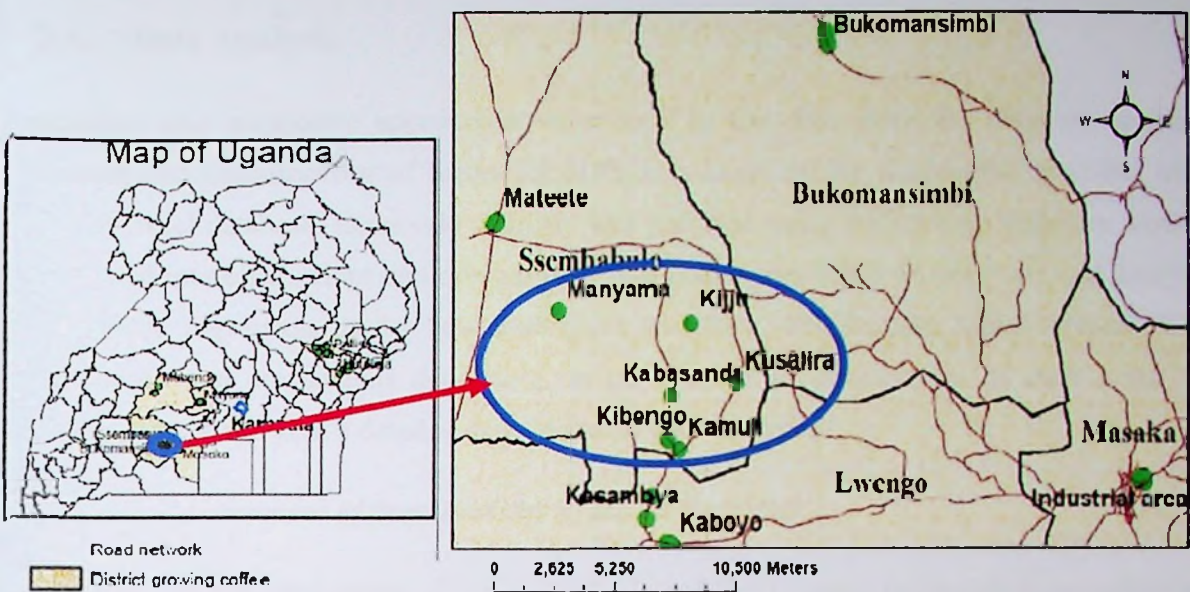


Figure 3.4: Location of study areas (Kibengo, Kamuli, Kusalira, Kijju and Manyama) for local interest to adopt HPS in coffee processing centers

Data was collected with questionnaires using an open-ended and closed ended contingent valuation approach (Claudy *et al.*, 2011). The target population was crop processing machine managers and owners, focus groups at village level, technocrats, political, opinion and civic leaders at district, sub-county, parish and village levels. In the questionnaire the target groups and suitable respondents were asked about their status of accessibility of electricity from national grid, willingness to accept and support operation and application of HPSs in their region.

3.3.4. Economic Viability of Adopting HPSs in Coffee and Rice Processing Centers

A number of sources, which included quotes from companies selling and manufacturing equipment and published data and reports, were employed in deriving investment costs for HPS. The capital cost of the local distribution network was estimated based on an average value obtained from a local energy company, called Inter-Tech Enterprises Uganda Ltd.

3.3.5. Data Collection for Generation of a Map Showing Energy Potentials

A handheld GPS (Global Positioning System) was used to get the Ground Control Points (GCP) of sites visited and having significant amounts of husks.

3.4. Data Analysis

Quantitative and qualitative approaches were used in the data analysis. Data on technical assessment and sustainability of husks for HPS was analyzed by descriptive statistics using Microsoft Excel database. Economic viability was assessed using RETScreen software whereas data on local interest to adopt and operate HPS was coded into SPSS 16 software and analyzed using logistic regression model and descriptive statistics. Graphs and tables presented the interpretations and conclusions depending on the number of occurrences of each item. The following subsections give a detailed description of data analysis.

3.4.1. Assessment of Sustainability of Husks for HPSs

During data analysis, the amount of husks available and their energy potentials from coffee and rice processing centers were determined using different mathematical models developed in Microsoft Excel 2007 software. The amount of husks and their energy potential per year, considering crop productivity from a given piece of land, was estimated using Equations 3.2, 3.3 and 3.4.

$$\pi_i = r_i \cdot A_i \cdot n_i \quad 3.2$$

$$M_i = \pi_i \cdot CR \quad 3.3$$

$$E_i = \frac{M_i \times Q \times 1000}{365 \times 24 \times 3600} \quad 3.4$$

Where:

r_i represents crop production/harvested (tons) in a given geographical location i , e.g district

r_i is the crop productivity (tons/ha) in a given geographical location i .

A_i represents an area of land cultivated (ha) in a given geographical location i .

n_i is the number of rice growing seasons per year in a given geographical location i .

π_i is the theoretical amount of husks (tons) generated from harvested crop, π_i , in a given geographical location i .

E_i is estimated power (MW) from husks in a given geographical location i

CR is the crop to produce residue ratio of coffee husks or rice husks.

The amount of husks available from crop processing centers was calculated using Equations 3.5 and 3.6, in accordance with Tripathi *et al.* (1998).

$$C_p = a + bt \quad 3.5$$

$$R_p = C_p \times CR \quad 3.6$$

Where C_p represents the amount of crop processed in tons/day, t , the time (days in a month or a year) (= 30days for the month of June or 365days for the year 2011-2012), and a and b the regression coefficients. R_p , symbolizes the total amount of husks (tones) available for the same crop. However, in the present study, constant a was assumed to be zero.

To estimate husks generated by milling machines per month in processing centers, two major independent variables were considered in the analysis. These included rice and coffee milling rate and hours of machine operations per day as shown in the Equation 3.7, assuming coefficient a = zero and 30 days in a month. The product of the two independent variables is equivalent to the regression coefficient, b , in Equation 3.5.

$$R_p = R_i \times H_i \times CR \times n_i \times 30 \quad 3.7$$

Where:

R_i represents an estimated mean rice and coffee milling rate (tones/hr) of machines in a given geographical location i and H_i , the hours of machine operations per day, n_i , the number of machines in a geographical location i .

Based on work done by Antonio *et al.* (2010), power potential (kW_{th}) from available husks generated in a given crop processing center per year was estimated by Equation 3.8 using a spreadsheet.

$$E = \frac{\left(\sum_{\text{January}}^{\text{December}} R_p \right) \times Q \times 10^6}{(3600 \times 24 \times 365)} \quad 3.8$$

Where: Q are the lower heating values (LHV_s) of coffee husks; 15.97 MJ/kg (Okello, 2010) and rice husks; 12.3 MJ/kg (Fang *et al.* 2004), respectively.

Multiplying Equation 3.8 by the net plant electrical efficiency, the total amount of electricity (P) that would be generated by husks from a crop processing center was calculated using Equation 3.9. Husks were sustainable for HPS at $P > 34\text{kW}_e$ (power rating of HPS).

$$P = E \times \eta \quad 3.9$$

3.4.2. Estimation of Energy Conversion Efficiency and Operating Parameters of HPS

The plant was simply modeled in accordance with Caputo *et al.* (2005) as a black box having a transfer function between the input biomass flow rate M ($\text{kg}\cdot\text{hr}^{-1}$) and the net electrical power output W_{NE} (kW). More specifically W_{NE} is directly proportional to the biomass amount M , the biomass low heating value (LHV) (kJ kg^{-1}), the plant energy conversion efficiency η , and inversely proportional to the plant operating time (seconds per hour), as shown in Figure 3.5.

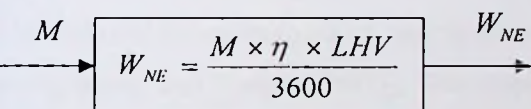


Figure 3. 5: Plant model and the relative transfer function.

Therefore, the overall plant energy conversion efficiency was calculated basing on Equation 3.10

$$\eta = \frac{W_{NE} \times 3600}{M \times LHV} \quad 3.10$$

Capacity Utilization Factor (CUF) was estimated according to Angevine *et al.* (2012) as the percentage of the number of plant operational hours per day, throughout the year.

3.4.3. Data Analysis on Local Interest to Adopt and Operate HPSs in Coffee and Rice Processing Centers.

3.4.3.1. Analysis using Binary Logistic Regression Model (LRM)

Data from key informants was summarized, put into coding categories and analyzed using the binary LRM in SPSS 16. LRM enables the research to isolate statistically robust explanatory variables that offer accurate estimates of willingness to acquire different energy technologies (Byrne *et al.*, 2007). Regression models are used to predict one variable from one or more other variables. The analysis was conducted to predict local interest to adopt and operate HPSs in crop processing centers. Information from 120, 109, and 72 respondents from respective selected villages of Pallisa, Butaleja, and Ssembabule Districts were analyzed using willingness to accept (WTA) application of HPSs, willingness to support (WTS) HPS, households connected to electricity and electricity distribution in the village as regressor variables.

3.4.3.2. Interpretation of Logistic Regression Model

Respondents' interests to adopt and operate HPSs in their areas were modeled in accordance with Montgomery and Runger (2003). The response, Y , derived by a respondent is a linear function of the regressor variable, x . The response variable was considered to take on only two possible values, 0 and 1, for example 0 for not interested and 1 for interested. This means that the expected response given by the response function $E(Y_i) = \beta_0 + \beta_1 x$ is just the probability that the response variable takes on the value 1. Generally, when the response variable is binary, there is considerable empirical evidence indicating that the shape of the response function should be nonlinear (Montgomery and Runger, 2003). A monotonically increasing (or decreasing) S-shaped (or reverse S-shaped) function, is usually employed. This function is called the **logit response function**, and has the form shown in Equation 3.11

$$E(Y) = \frac{\exp(\beta_0 + \beta_1 x)}{1 + \exp(\beta_0 + \beta_1 x)} \quad 3.11$$

or equivalently

$$E(Y) = \frac{1}{1 + \exp[-(\beta_0 + \beta_1 x)]} \quad 3.12$$

In logistic regression it is assumed that $E(Y)$ is related to x by the logit function. It is easy to show that

$$\frac{E(Y)}{1 - E(Y)} = \exp(\beta_0 + \beta_1 x) \quad 3.13$$

Where; β_0 and β_1 are the regression coefficients. The quantity $\exp(\beta_0 + \beta_1 x)$ on the right hand side of Equation 3.13 is called the odds ratio. Its interpretation is that: If the odds ratio is 2 for a particular value of x , it means that a success is twice as likely as a failure at that value of the regressor (predictor), x . Notice that the natural logarithm of the odds ratio is a linear function of the regressor variable. Therefore the slope β_1 is the change in the log odds that results from a one unit increase in x . This means that the odds ratio changes by e^{β_1} when x increases by one unit.

3.4.4. Estimation of Levelized Unit Cost of Electricity (LUCE) and Economic Analysis

Details of plant investment cost, main operating parameters, plant operating costs, and Operation and Maintenance (O&M) costs of HPS have been investigated. Levelized unit cost of electricity (LUCE) was estimated as the ratio of the total annualized cost (AC) of HPS to the annual electricity (E_o, kWh) delivered by the same; basing on the work of Nouni *et al.* (2007) Equations 3.14 and 3.15).

$$LUCE = \frac{AC}{E_o} = \frac{AC_c + AC_{O\&M} + AC_F}{E_o} \quad 3.14$$

$$\text{Where, } E_o = p(8760 \times CUF)(1 - a)(1 - l) \quad 3.15$$

p = power output of HPS electricity generator (kW), CUF is capacity utilization factor, a is the fraction of generated power consumed by the auxiliaries of the HPS, and l is the fraction of electrical losses in the local distribution network.

AC_c is the total annualized capital cost for the project which comprises of four components viz. Turbine, engine-generator, civil works and distribution network. This cost is annualized using a capital recovery factor as shown in equation 3.16. (Nouni *et al.*, 2007)

$$AC_c = C_{hps} R_{hps} + C_{cw} R_{cw} + C_{dn} R_{dn} ; \quad 3.16$$

Where $R = \left(\frac{d(1+d)^T}{(1+d)^T - 1} \right)$ is the capital recovery factor for discount rate d and life period of T years. Various notations are as follows: C_{hps} , C_{cw} and C_{dn} are capital costs of husk power system and civil works related to gasifier installation and electricity distribution network, respectively. The operating and maintenance cost ($AC_{O\&M}$) is expressed as a fraction of the capital cost (Equation 3.17). (Nouni *et al.*, 2007)

$$AC_{O\&M} = C_{hps}m_{hps} + C_{cw}m_{cw} + C_{dn}m_{dn} + 8760.CUF.m_l.n. \quad 3.17$$

Where m is the fraction of the total capital cost taken for maintenance and operation of the husk power system units (with subscript denoting the fraction corresponding to the component), m_l and n are the wage rate of manpower and numbers of labor required for operation of the HPS. The annualized cost of fuel consumption is expressed as in Equation 3.18. (Nouni *et al.*, 2007)

$$AC_F = 8760.CUF(c_{pf}.s_{spfc}.P + c_{bm}.s_{sbmc}.P) \quad 3.18$$

Where, c_{pf} is the unit cost of pilot fuel (diesel), c_{bm} is the unit cost of biomass fuel, while s_{spfc} and s_{sbmc} are the specific fuel consumption of pilot fuel and biomass fuel respectively, P is the power output of electricity generator per kW. Economic viability of HPS was evaluated using Internal Rate of Return (IRR), Pay Back Period (PBP), Net Present Value (NPV) and Benefit – Cost (B-C) ratio using Microsoft Excel with guidelines by Winston (2007) and RETScreen 4-1 software.

3.4.5. Generation of the Map Showing Energy Potentials of Husks

Toposheets were used as reference map in extracting some relevant available features of districts. Physical data involving estimated power potentials for coffee and rice husks was imported from Microsoft Excel and incorporated into a GIS database using ArcGIS software. This was aimed at getting a literal picture of the situation on the ground. The area of interest was processed, enhanced and geometrically rectified into Universal Transverse Mercator (UTM) projection using Ground Control Points (GCP) collected from the field by handheld GPS (Global Positioning System).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Sustainability of Husks for HPSs Application in Coffee and Rice Processing Centers

In order to determine the sustainability of husks for husk powered system (HPS), it was important to estimate the amount of husks generated by mills in each crop processing center, and electric power potential of the available husks. It was found that coffee husks and rice husks generated from the processing centers are either sold off or used for mulching in the gardens by farmers. The remaining husks are disposed off and are becoming a nuisance to the environment.

Availability of husks in this study represents the amount of husks (in totality) generated in an area all year round irrespective of whether they are sold or disposed off. The assumption used in the present study is that husk suppliers would give the first priority to HPS in selling their husks, hence it will be providing electricity to run their businesses.

Table 4.1: Estimation of crop to residual ratio (CR)

Type of crop	Exp. No	Amount before milling (kg)	Amount after milling (kg)	weight of Husks generated (kg)	crop to residual ratio (CR)
Coffee	1	69	55	14	0.203
	2	98	80	18	0.184
	3	86	68	18	0.209
	4	23	18	5	0.218
	5	66	54	12	0.181
	6	44	35	9	0.205
	7	58	47	11	0.190
	8	88	70	18	0.205
Mean $\pm$ Std. Deviation					0.199 $\pm$ 0.0128
Rice	1	1300	750	550	0.423
	2	900	489	411	0.457
	3	1000	380	620	0.620
	4	600	354	246	0.410
	5	1300	688	612	0.471
	6	1500	750	750	0.500
	7	1400	690	710	0.507
	8	1000	489	511	0.511
Mean $\pm$ Std. Deviation					0.487 $\pm$ 0.066

The amount of husks generated was estimated using Equation 3.7 and a crop to residue ratio (0.2 and 0.5 for rice and coffee, respectively) as shown in Table 4.1. Crop to residual ratio (CR) was calculated as the ratio of husks generated using a mill to the amount of crop before milling (*see* Table 4.1). Machine production rate and hours of operations per day (dependent variables) are shown in Appendix 3.

4.1.1. *Estimated Amount of Rice Husks Generated by Mills in Pallisa and Butaleja Districts.*

Using Equations 3.2, 3.3 & 3.4, estimation of the amount of rice husks generated as a result of rice production in Pallisa and Butaleja Districts, and their energy potential was done. Results showing the amount of rice husks and their power potential in Pallisa and Butaleja are summarized in Table 4.2. It was found that Butaleja District has 2 rice growing seasons and rice productivity was higher than that of Pallisa. This recorded higher values of husks generated per year by Butaleja District (30,000 tones) than in Pallisa District (16,437 tones) as depicted in Table 4.2.

Table 4.2: Estimated amount of rice husks and their power potential in Pallisa and Butaleja

Districts	Rice productivity (t/ha)	Husks (t/ha)	area of land (ha)	seasons	production (t)	husks (t)	husks (kg)	in	Estimated power (MW)
Pallisa	2.5	0.5	32873	1	82183	16437	16436500	7	
Butaleja	3	0.6	25000	2	150000	30000	30000000	13	

The amounts of rice husks from crop processing centers were also estimated in Pallisa and Butaleja Districts. It was found that rice husks were available throughout the year in Butaleja District with monthly variations in quantities (*see* Figure 4.1), whereas in Pallisa District, rice husks were not available throughout the year in all villages (*see* Figure 4.2). Two peaks (between March and June; September and November) of husk availability are portrayed in Butaleja District (*see* Figure 4.1) and one peak (between June and November) in Pallisa District (Figure 4.2). There was a significant ($p < 0.5$) difference in availability of rice husks in both districts. This is due to climatic and agronomic factors of rice production. Rice is grown on irrigated areas

in Butaleja District while in Pallisa, it is grown as rain fed crop (Hyuha *et al.*, 2005). Due to availability of water, Butaleja grows two crops a year whereas Pallisa has only one (Hyuha *et al.*, 2005).

In Butaleja District, Lwoba and Dundo villages recorded the highest amount of husks generated by mills whereas Wandegeya village recorded the lowest. This is due to the fact that Lwoba and Dundo villages are electrified (*see* Table 4.3) with high number of rice processing machines (*see* Figure 4.1) using electricity (6 in each village), and high number of operational hours per day throughout the year (*see* Appendix 3). Wandegeya village is not electrified (*see* Table 4.3) and the village has three rice machines operating on diesel with the lowest mean milling rate (672.1 ± 59.6 kg/hour) as shown in Appendix 3. It was found that Namehere, Nahasaragala and Kapisa villages in Butaleja District were not electrified (*see* Table 4.3) and the availability of husks was lower than Dundo, Leresi and Lwoba, but higher than Wandegeya (*see* Figure 4.1).

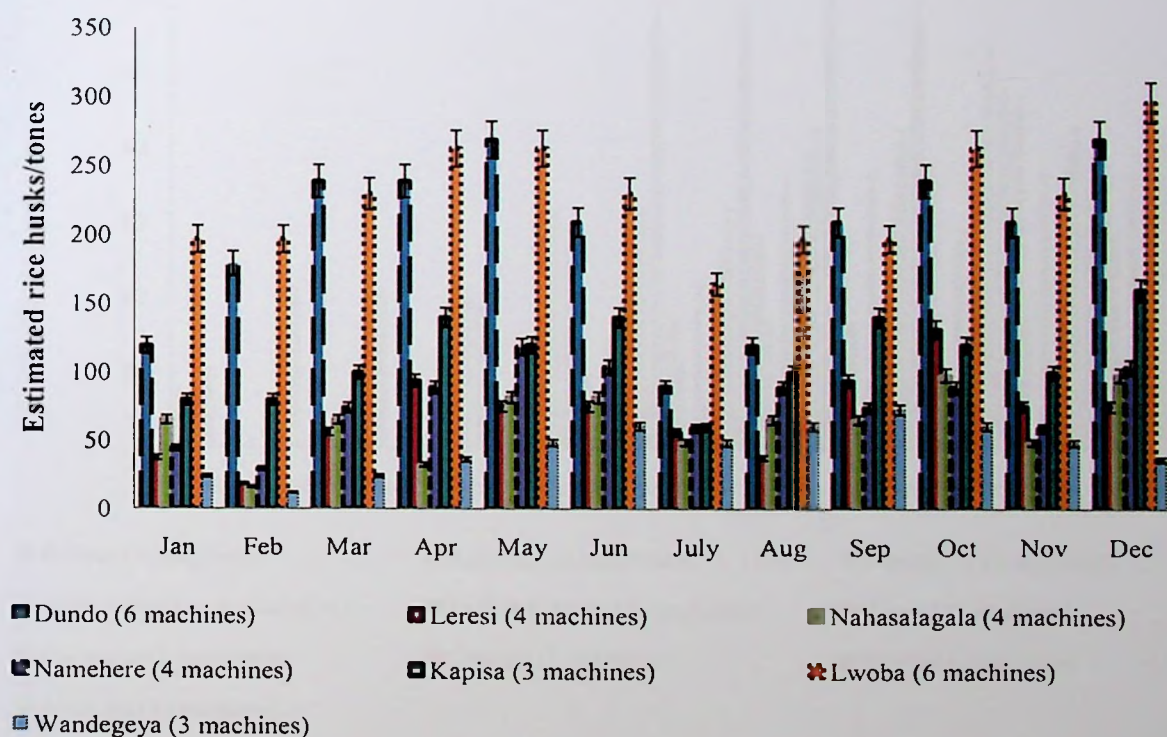


Figure 4.1: Availability of rice husks generated from crop processing centers in selected villages of Butaleja District.

Rwatama and Pallisa Central villages generated the highest amount of rice husk, and Akumi the lowest (*see* Figure 4.2) in Pallisa District. High availability of husks was due to high number (5 in Rwatama and 4 in Pallisa Central villages) of rice processing machines run by electricity compared with Akumi village, which had one machine run by diesel (*see* Table 4.3 and Figure 4.2). The study revealed that Kachoge, Mpongi A, Atida Division, Akumi and Chacha villages of Pallisa District did not have electricity and rice processing machines were using diesel (*see* Table 4.3). Low levels of rice husks generated could be attributed to lack of electricity access (*see* Figure 4.2 and Table 4.3).

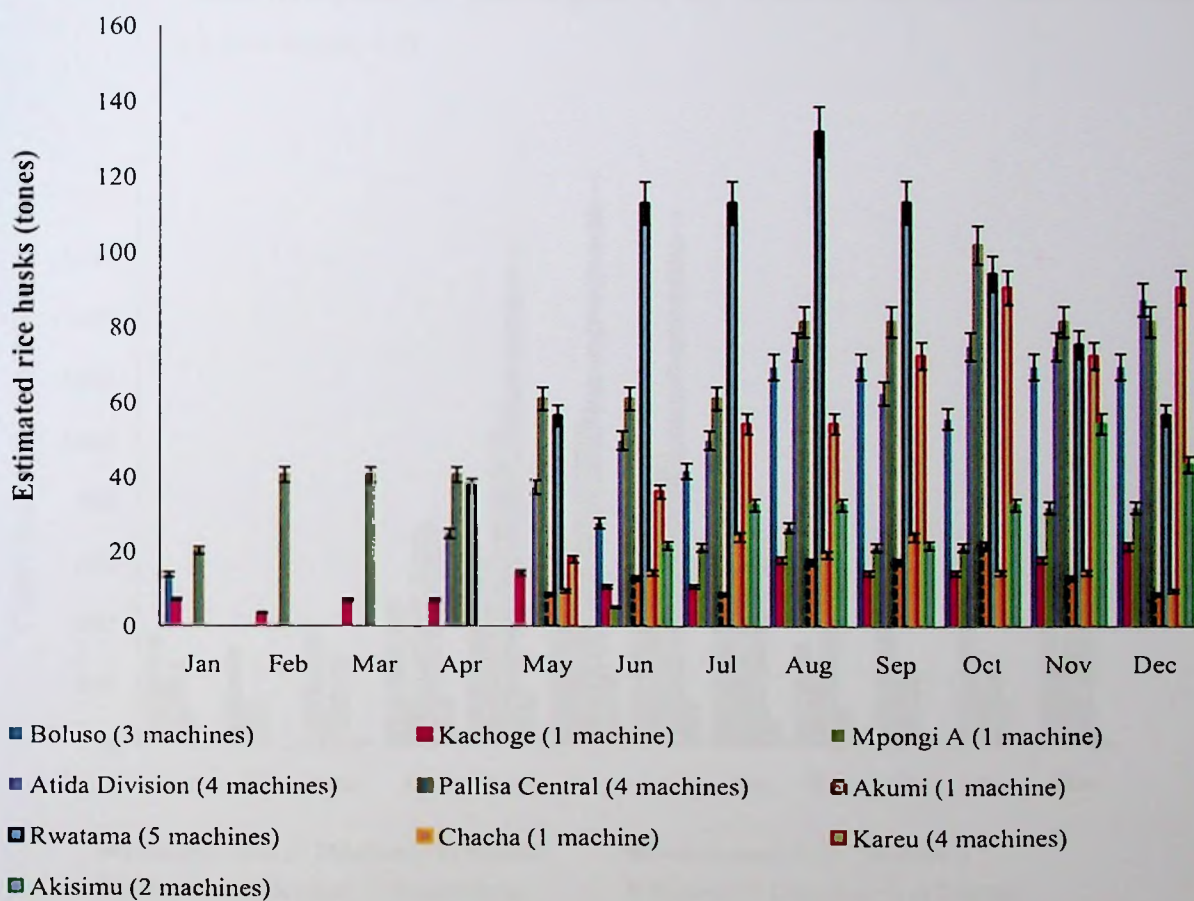


Figure 4.2: Availability of rice husks generated from crop processing centers in selected villages of Pallisa District.

4.1.2. Estimated Amount of Coffee Husks Available in Coffee Processing Centers

The availability of coffee husks in the studied areas of Masaka, Bukomansimbi, Ssembabule, Lwengo, Mubende and Mityana Districts is in one season (see Figure 4.3 and 4.4). The study revealed that all coffee processing machines are located in electrified areas and are therefore run by electricity (see Table 4.3). Comparing coffee husk availability in Masaka, Bukomansimbi, Ssembabule, and Lwengo Districts (see Figure 4.3), Kaboyo village had the highest coffee husk availability and Kasambya village in Lwengo District the lowest. This is due to high number of coffee processing machines (11 machines) in Kabiyo than Kasambya (1 machine). Availability of coffee husks in studied areas of Masaka, Bukomansimbi, Ssembabule, and Lwengo Districts follow the same trend throughout the year; highest in the month of June and lowest between October and March (see Figure 4.3).

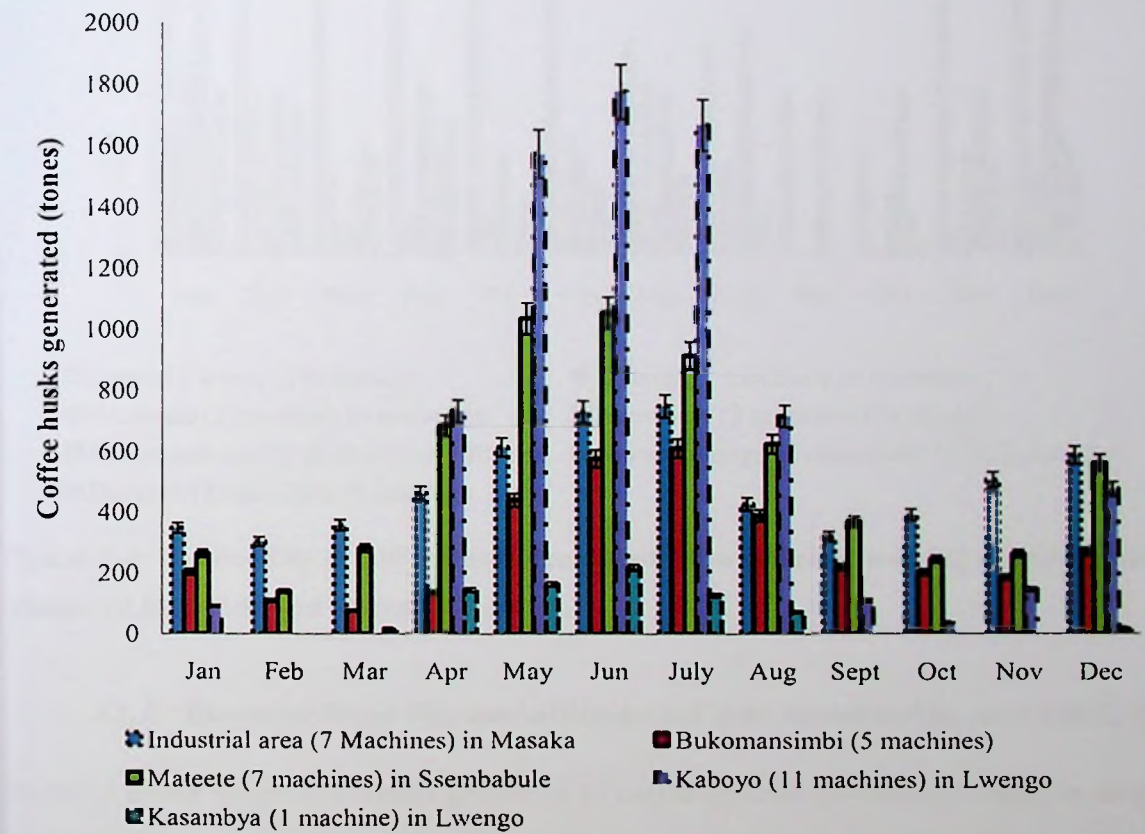


Figure 4.3: Availability of coffee husks generated from coffee processing centers in selected villages of Masaka, Bukomansimbi, Ssembabule, and Lwengo Districts.

Coffee husk availability in Mubende and Mityana Districts is generally high between November and February in all studied areas (see Figure 4.4). Kaweri coffee factory in Mubende District has the highest husk availability compared to the rest of the processing centers, as shown in Figure 4.4.

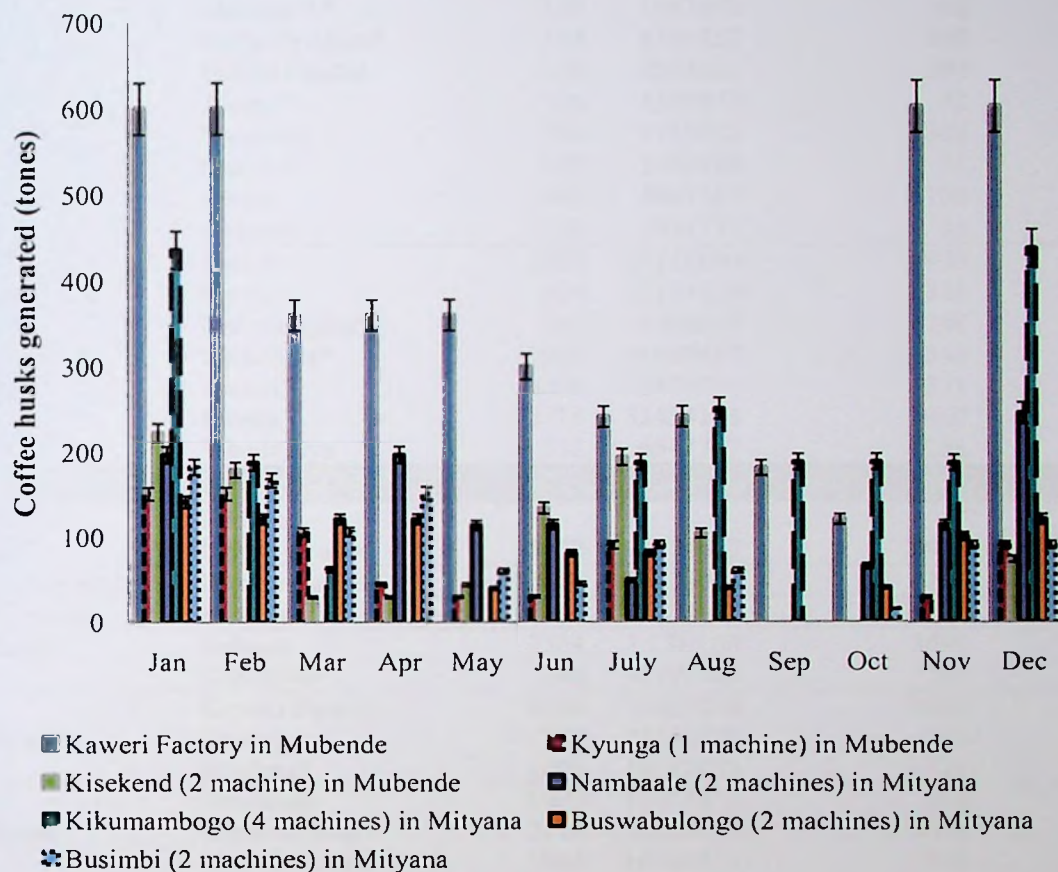


Figure 4. 4: Availability of coffee husks generated from coffee processing centers in selected villages of Mubende and Mityana Districts.

4.1.3. Electrical Power Potential of Husks and their Sustainability for a 34kWe HPS

Electrical power potential of husks generated by coffee and rice processing centers in all studied areas (see Figure 3.1) was calculated from their respective annual husks generated (see Table 4.3) using Equation 3.8 and 3.9. It was through this power potential that the sustainability of husks for a 34kW_e HPS was estimated (see Table 4.3 and Figure 4.6).

Table 4. 3: Power potential and sustainability of husks for HPS application

District	Villages	Total husks (tones/year)	Energy potential (MJ)	Thermal power potential (kW _{th})	Electrical Power potential (kW _e)
Rice husks					$\eta = 23.5\%$
Pallisa	Boluso	416	5117187	162	38
	Kachoge *	147	1803809	57	13
	Mpongi A*	159	1957492	62	15
	Atida Division*	535	6584352	209	49
	Pallisa Central	752	9245031	293	69
	Akumi*	108	1327873	42	10
	Rwatama	790	9715032	308	72
	Chacha*	130	1593795	51	12
	Kareu	488	5997157	190	45
	Akisimu	238	2931758	93	22
Mutaleja	Dundo	2383	29315890	930	218
	Leresi	824	10133120	321	76
	Nahasalagala*	765	9406843	298	70
	Namehere*	931	11455457	363	85
	Kapisa*	1336	16427374	521	122
	Lwoba	2718	33434183	1060	249
	Wandegeya	532	6547747	208	49
Coffee husks					$\eta = 28.3\%$
Masaka	Masaka				
	Industrial area	5772	92174453	2923	827
Bukomansimbi	Bukomansimbi	3408	54428060	1726	488
Sembabule	Mateete	6416	1.02E+08	3249	919
Kwango	Kaboyo	7304	1.17E+08	3699	1047
	Kasambya	764	12199084	387	109
Kibunde	Kaweri Factory	4560	72823200	2309	654
	Kyunga	722	11536728	366	104
	Kisekend	1009	16112932	511	145
Mityana	Nambaale	1093	17462237	554	157
	Kikumambogo	2118	33827654	1073	304
	Buswabulongo	1006	16069813	510	144
	Busimbi	1059	16908238	536	152

Villages having no access to grid electricity

Geographical distribution of the electrical power potentials of rice husks and coffee husks is depicted in Figure 4.5. It was found that coffee processing centers have the highest power potential compared to rice processing centers (see Figure 4.5). This is due to the difference in the HHVs (15.97 MJ/kg for coffee husks and 12.3 MJ/kg for rice husks), and high availability of coffee husks than rice husks per year (see Table 4.3). In coffee processing centers, the power

potential in all sites was above 82kW_e (see Figure 4.5), making coffee husks generated from processing machines to be sustainable for a 34kW_e (see Table 4.3).

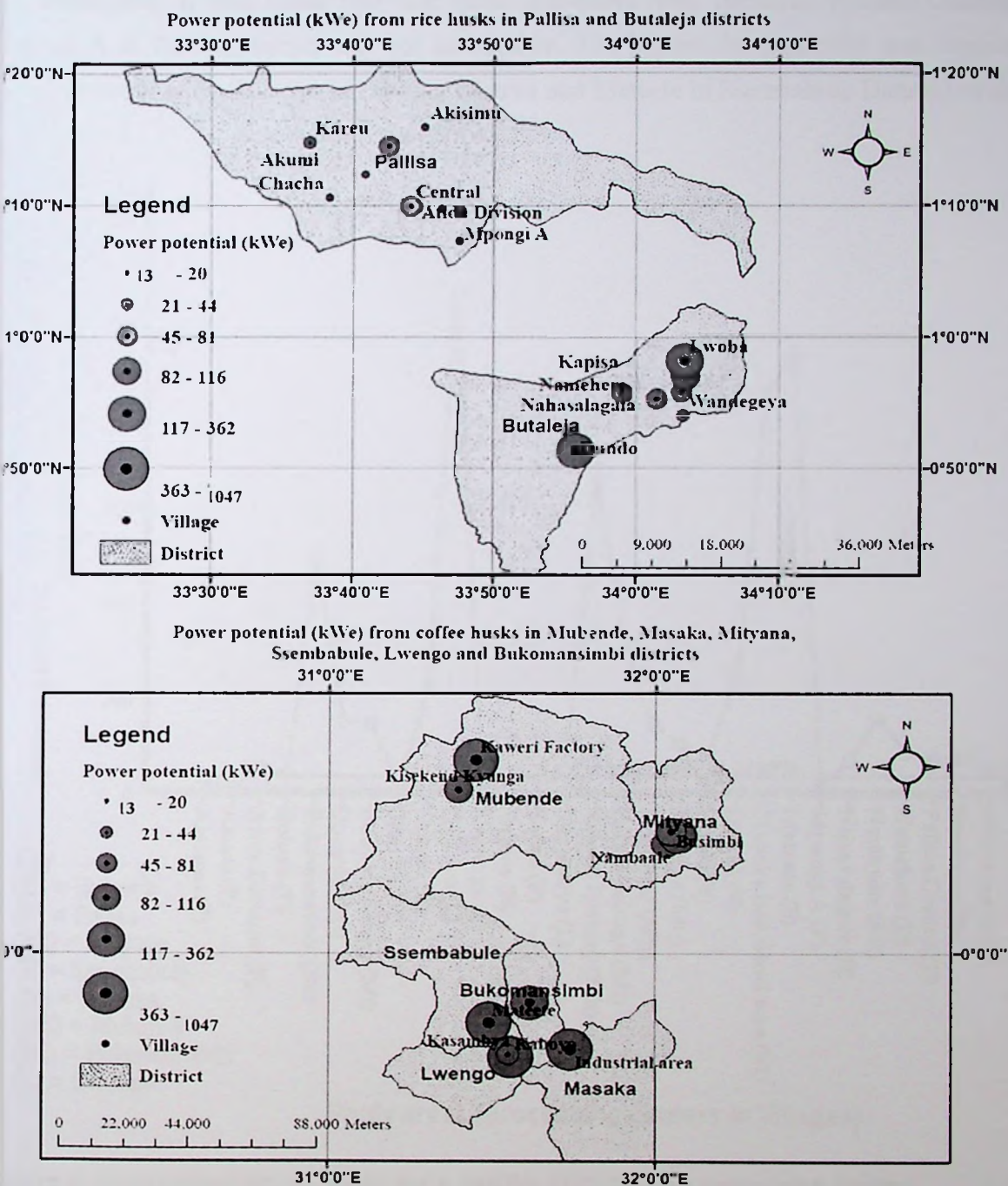


Figure 4.5: Geographical distribution of the electrical power potentials of rice husks and coffee husks.

the level of sustainability of husks for a 34kW_e HPS is diagrammatic represented in Figure 4.6, where any area having power potential more than 34kW_e was taken to be sustainable, otherwise, not sustainable. It was found that rice husks generated from Akisimu, Akumi, Chacha and Mpongi A in Pallisa District was not sustainable. The highest sustainability was depicted in coffee growing areas (Kaboyo in Lwengo District and Mateete in Ssembabule District) as shown in Figure 4.6.

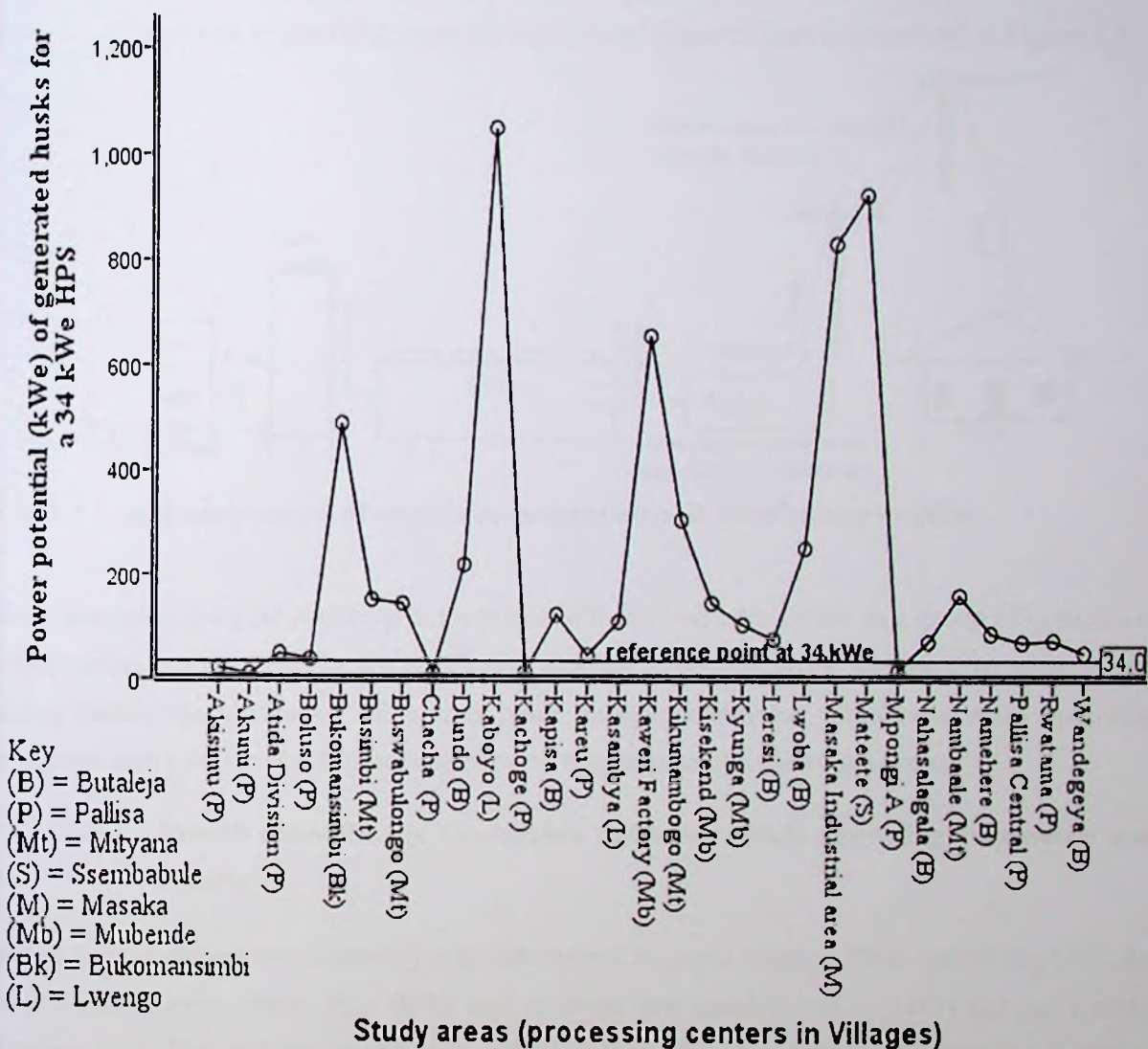


Figure 4. 6: Sustainability of husks for a 34kW_e HPS in crop processing centers

4.2. Technical Viability of a HPS

4.2.1. Pamoja Cleantech Husk Power System

A pilot Husk Power System (HPS) is managed by Pamoja Cleantech. It consists of 2 cooling water pumps and an ash extractor at the bottom of the gasifier (all motor driven with power rating of 0.75kW_e each), a gasifier, a gas cleaner, an engine-generator and a distribution network. The generic model of a pilot HPS, installed on a 502m² piece of land is presented in Figure 4.7.

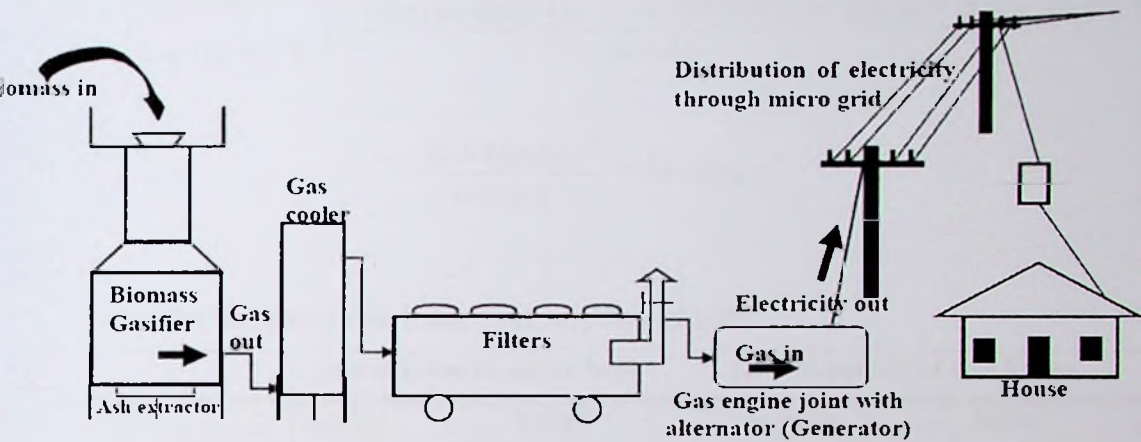


Figure 4.7: A generic model of electricity generation and distribution by HPS

The system uses pre-paid metering devices that will shut off connection to a group of consumers if their consumption exceeds the purchased amount. The following sub-sections present and discuss results on estimation of overall plant energy conversion efficiency, main operating parameters and costing of HPS, and consumers' response to electricity generated

4.2.2. Overall Plant Energy Conversion Efficiency, Main Operating Parameters and Costing

Overall energy conversion efficiency was determined by input biomass flow rate M (kg.hr⁻¹), the net electrical power output W_{NE} (kW) and biomass low heating value (LHV) (kJ kg⁻¹) using equation 3.10. The average input biomass flow rate (kg/hr) was determined from the recorded average daily biomass consumption (Table 4.4), divided by 6hrs of daily HPS operation (see equations 4.1 and 4.2).

$$\left(\begin{array}{l} \text{average coffee husk} \\ \text{consumption (kg.hr}^{-1}) \end{array} \right) = \frac{\text{average daily coffee husk consumption (kg.day}^{-1})}{6\text{hr.day}^{-1} \text{ of machine operation}}$$

4.1

$$= \frac{162.8\text{kg.day}^{-1}}{6\text{hr.day}^{-1}} = 27.1\text{kg.hr}^{-1}$$

$$\left(\begin{array}{l} \text{average rice husk} \\ \text{consumption (kg.hr}^{-1}) \end{array} \right) = \frac{\text{average daily rice husk consumption (kg.day}^{-1})}{6\text{hr.day}^{-1}}$$

4.2

$$= \frac{254.2\text{kg.day}^{-1}}{6\text{hr.day}^{-1}} = 42.4\text{kg.hr}^{-1}$$

Table 4.4: Coffee husk and rice husk consumption of HPS

	consumption of coffee husk		consumption of rice husks	
day	kg/day	kg/hr	kg/day	kg/hr
	162	27.0	258	43.0
	170	28.3	230	38.3
	156	26.0	267	44.5
	168	28.0	244	40.7
	158	26.3	272	45.3
Average	162.8	27.1	254.2	42.4
Standard Error	2.7276	0.4546	7.6968	1.2828
Standard Deviation	6.0992	1.0165	17.2105	2.8684

The variation in the consumption of rice husks and coffee husks on any day could have been attributed to limited operational skills related to inconsistency in biomass feeding, since machine operators were still on training. The consumption (kg/hr) of rice husks was generally 1.5 times higher than for coffee. This could have been attributed to higher ash content and lower calorific value associated with rice husks than coffee husks (Rahardjo, 2013). Therefore to generate the same electrical energy output, a gasifier consumes more rice husks than coffee husks.

results of the electrical power output (W) were recorded using a power analyser as summarized in Table 4.5. It was found that the net electrical power output W_{NE} (kW) was 34.06 ± 0.764 kW (average $\pm$ SD), Table 4.5.

Table 4.5: Estimation of net electrical power output of HPS

	Average Power	Power at different Phases		
	Pt+_Avg [W]	P1+_Avg [W]	P2+_Avg [W]	P3+_Avg [W]
	35212.33	34917	36245	34475
	34009.00	34217	34895	32915
	34436.00	33460	37044	32804
	34036.33	33119	35840	33150
	34360.33	34021	35021	34039
	34362.67	35148	33700	34240
	34327.00	34891	33840	34250
	34232.33	35217	33629	33860
	32374.00	33412	31130	32580
	33250.00	33220	33190	33340
Averages computed	34060.00	34162.20	34452.50	33565.30
Standard Error (SE)	241.61	263.32	544.06	217.55
Standard Deviation (SD)	764.05	832.67	1720.48	687.94

Therefore specific fuel consumption of coffee husks and rice husks can be estimated using Equation 4.3 (Nouni *et al.*, 2007).

$$\begin{aligned}
 & \frac{\text{average biomass fuel consumption (kg.hr}^{-1}\text{)}}{\text{net electrical power output (kW)}} \\
 & = \frac{27.1 \text{ kg.hr}^{-1}}{34 \text{ kW}} \approx 0.8 \text{ kg.kWh}^{-1}, \text{ when using coffee husks} \\
 & = \frac{42.4 \text{ kg.hr}^{-1}}{34 \text{ kW}} \approx 1.25 \text{ kg.kWh}^{-1}, \text{ when using rice husks as fuel}
 \end{aligned}
 \tag{4.3}$$

Assuming lower heating values of rice husks and coffee husks to be 12.3 MJ/kg (Fang *et al.* 2004) and 15.97 MJ/kg (Okello, 2010), respectively, the overall plant energy conversion efficiency (η) from coffee husks or rice husks was obtained as shown in Equation 4.4 (Caputo *et al.*, 2005).

$$\eta = \frac{\text{net electrical power output (kW)} \times 3600s}{\text{biomass consumption (kg.hr}^{-1}) \times \text{lower heating value (LHV), kJ.kg}^{-1}} \quad 4.4$$

$$= \frac{34kW \times 3600s}{42.4kg.hr^{-1} \times 12300kJ.kg^{-1}} \times 100\% = 23.5\%$$

when using rice husks as biomass feedstock

Or

$$= \frac{34kW \times 3600s}{27.1kg.hr^{-1} \times 15970kJ.kg^{-1}} \times 100\% = 28.3\%$$

when using coffee husks as biomass feedstock

The high efficiency obtained when using coffee husks as feed stock is due to its high LHV. In support of previous studies (Bridgwater 1995; Caputo *et al.*, 2005; Boukis *et al.*, 2009) overall energy conversion efficiency of biomass gasification power plants (BGPP) increases with an increase in plant size. Wu *et al.* (1998) in their study compared a 200kW BGPP with newly installed 1000kW BGPP, both using rice husks as fuel source, and found an improvement in overall efficiency from 12.5% to 17%, which was lower than the overall efficiency of HPS in the present work. However, considering wood as a fuel source for BGPP, Fischer and Pigneri (2011) found that the overall energy conversion efficiency was 22.5% by a 32kW_e rated capacity BGPP, at a feeding rate of 42 kg wood /hour. Based on the present work and existing literature, an HPS has a higher overall energy conversion efficiency especially when using coffee husks as a feedstock. Furthermore, its performance would improve with an increased plant size.

4.2.3. Levelized Unit Cost of Electricity (LUCE)

A summary of the operating parameters, costs and assumptions used in the estimation of LUCE generated by HPS is depicted in Table 4.6. It was found that the HPS operated for 6 hours per day and this was the time when it could be relied upon to produce electricity. The factor that

indicates the portion of time an electric generation facility can be relied upon to produce electricity is called capacity utilization factor (CUF). In the present work, CUF was calculated using Equation 4.5 (Angevine *et al.*, 2012).

$$CUF = \frac{\text{hours of electricity generation in a day}}{24 \text{ hours in a day}} = \frac{6 \text{ hrs}}{24 \text{ hrs}} = 0.25 \quad 4.5$$

Two machine operators each earning about 450,000 UGX per month, were required to run the plant. Basing on exchange rate of 1 United States dollar (US\$) equivalent to 2,500 Ugandan currency (UGX) as of September 2012 (BOU, 2012), manpower wage was calculated by;

$$\begin{aligned} & \frac{\text{monthly earning (UGX.person}^{-1}\text{)}}{\text{plant operational hours per day} \times \text{days in a month}} \times \frac{1 \text{ US\$}}{2,500 \text{ UGX}} \\ &= \frac{450,000 \text{ UGX.month}^{-1}.\text{person}^{-1}}{6 \text{ hrs.day}^{-1} \times 30 \text{ days.month}^{-1}} \times \frac{1 \text{ US\$}}{2,500 \text{ UGX}} = 1 \text{ US\$}.\text{person}^{-1}.\text{hr}^{-1} \end{aligned} \quad 4.6$$

Generated power consumed by the auxiliaries was also estimated as:

Summation of power rating of 3 bulbs @ 20W and 2 motors (water pump and ash remover) @ 0.75kW

$$= \frac{3 \times 20}{1000} \text{ kW} + 2 \times 0.75 \text{ kW} = 1.56 \text{ kW} \quad 4.7$$

This was used to calculate the percentage of generated power consumed by HPS as;

$$\begin{aligned} & \frac{\text{generated power consumed by the auxiliaries (kW)}}{\text{net electrical power output of HPS (kW)}} \times 100\% \\ &= \frac{1.56 \text{ kW}}{34 \text{ kW}} \times 100\% = 4.6\% \end{aligned} \quad 4.8$$

Table 4.6: Summary of HPS operating parameters, assumptions and project investment, used for LUCE estimation

<i>No-</i>	<i>Parameter</i>	<i>Units</i>	<i>Value</i>
1	Capital cost of HPS (gasifier, gas cleaner and engine-generator) including shipping	US\$	60,000
2	Capital cost of civil works	US\$	10,000
3	Number of poles @ at 65US\$	Numbers	100
4	Specific capital cost of local distribution network	US\$.km ⁻¹	5,000
5	Size of local distribution network	km	3
6	Generated power consumed by the auxiliaries	kW _e	1.56
7	Generated power consumed by BGPP	%	4.6
8	Electrical losses in local distribution network	%	10
9	Useful lifetime of HPS	y	10
10	Useful lifetime of civil works	y	20
11	Useful lifetime of local distribution network	y	20
12	Manpower required by BGPP	Numbers	2
13	manpower wage	US\$.man ⁻¹ .h ⁻¹	1
14	Maintenance cost of HPS (function of its capital cost)	%	3
15	Maintenance cost of distribution network (function of its capital cost)	%	2
16	Maintenance cost of civil works (function of its capital cost)	%	0.5
17	1 bag of rice husks (weighing 40kg) costs 4,000UGX*	US\$.kg ⁻¹	0.04
18	1bag of coffee husks (weighing 60kg) costs 10,000UGX	US\$.kg ⁻¹	0.067
19	1litre of pilot fuel (petrol) costs 3,500UGX	US\$.l ⁻¹	1.4
20	Biomass fuel Consumption (rice husks and coffee husks, respectively)	Kg.hr ⁻¹	42.4 and 27.1
21	Plant operational hours per day	Hours.day ⁻¹	6
22	Consumption of petrol (for startup) by HPS	L.hr ⁻¹	0.083
23	Capacity Utilization Factor (CUF)	-	0.25
24	Specific fuel consumption of petrol (referred to the electric output)	L.kW _e h ⁻¹	0.00245
25	Specific fuel consumption of rice husks and coffee husks, respectively**	Kg.kW _e h ⁻¹	1.25 and 0.80

United States dollar (US\$) =2,500 Ugandan currency (UGX), in September 2012 (BOU, 2012)

Referred to the electric power output

The supplier of HPS was interviewed on its specifications and capital cost. Its capital cost including shipping was about 60,000 US\$ and would require about 100 electric poles for power distribution. Inter-Tech Enterprises Uganda Ltd was contracted by Pamoja Cleantech, who manages HPS, to install its power distribution network. The cost of a 3km electric distribution network was estimated at 15,000 US\$. Therefore, Specific capital cost of local distribution network is:

$$\frac{\text{total cost of electric distribution network (US\$)}}{\text{total size of electric distribution network (km)}} = \frac{15,000 \text{ US\$}}{3 \text{ km}} = 5,000 \text{ US\$.km}^{-1} \quad 4.9$$

Capital cost of civil works was estimated at 10,000 US\$ in accordance with Pamoja Cleantech. Therefore, total investment cost (I_n) and specific investment cost of HPS were calculated as:

$$\begin{aligned} \text{investment cost, } I_n &= \left(\begin{array}{l} \text{capital cost of HPS} + \\ \text{capital cost of electric distribution network} + \\ \text{capital cost of civil works} \end{array} \right) \quad 4.10 \\ &= 60,000 \text{ US\$} + 15,000 \text{ US\$} + 10,000 \text{ US\$} = 85,000 \text{ US\$} \end{aligned}$$

Where as

$$\begin{aligned} \text{specific investment cost (US\$.kW}^{-1}\text{)} &= \frac{\text{investment cost (US\$)}}{\text{net electrical power out put (kW)}} \quad 4.11 \\ &= \frac{85,000 \text{ US\$}}{34 \text{ kW}} = 2,500 \text{ US\$.kW}^{-1} \end{aligned}$$

The useful lifetime of HPS was assumed to be 10years, operating in a radius of about 1km. The maintenance cost of HPS, distribution network and civil works were also assumed to be 3%, 2%, and 0.5% of their capital costs, respectively. Table 4.7 shows the cost of rice husks and coffee husks. A survey that was carried out in coffee and rice processing centers revealed that a sack of rice husks (weighing about 40kg) and coffee husks (weighing about 60kg) costs about 4,000 UGX and 10,000UGX, respectively (see Table 4.7). Therefore, cost of biomass fuel per kilogram was estimated as:

$$\frac{\text{cost of one bag of husks}}{\text{its wieght}}$$

4.12

$$\text{cost of rice husks} = \frac{4,000 \text{ UGX}}{40\text{kg}} \times \frac{1 \text{ US\$}}{2,500 \text{ UGX}} (\text{exchange rate}) = 0.04 \text{ US\$.kg}^{-1}$$

$$\text{cost of coffee husks} = \frac{10,000 \text{ UGX}}{60\text{kg}} \times \frac{1 \text{ US\$}}{2,500 \text{ UGX}} (\text{exchange rate}) \approx 0.067 \text{ US\$.kg}^{-1}$$

This implies that the specific cost of coffee husks was higher than rice husks.

Table 4. 7: Cost of coffee husks and rice husks

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Cost of rice Husks UGX/sack of 40kg)	100	.00	10000.00	3987	193.342	1933.41980
Cost of coffee Husks UGX/sack of 60kg)	34	5000	16000	10200	568.750	3316.356
Valid N (listwise)	1					

From the interview conducted on the HPS operators, it was also found that 1 liter of petrol was purchased at about 3,500UGX, equivalent to 1.4 US\$.L⁻¹ (at an exchange rate of 2,500UGX per US\$). Records from the HPS operators show that for a period of 10days, 5 liters of Pilot fuel (petrol) had been used for startup of the plant and the HPS operated for 6 hours per day. Basing on this data, consumption of pilot fuel is given by;

$$\frac{\text{amount of pilot fuel used in a given period}}{\text{number of days in the same period} \times \text{operational hours per day}}$$

4.13

$$= \frac{5 \text{ liters}}{10 \text{ days} \times 6 \text{ hours.day}^{-1}} = 0.0833 \text{ L.hr}^{-1}$$

Therefore, specific fuel consumption of petrol is obtained as;

$$\frac{\text{consumption of petrol (L.hr}^{-1}\text{)}}{\text{net electric power out put (kW)}} \quad 4.14$$

$$= \frac{0.0833 \text{ L.hr}^{-1}}{34 \text{ kW}} = 0.00245 \text{ L.kWh}^{-1}$$

4.2.4. Consumers' Response to Electricity Generated

A survey of 54 households, a focus group discussion (involving 42 people; 25 connected and 17 not connected to power) and an interview conducted on the operators and electricity supplier (Pamaja cleantech), was done in Tiribogo Village, where a Pilot HPS is installed. It was found that HPS has been in operation for a period of about 8 month but only 29 people were connected to power and the majority of respondents who were connected had only spent not more than 2 month with power (see Figure 4.8).

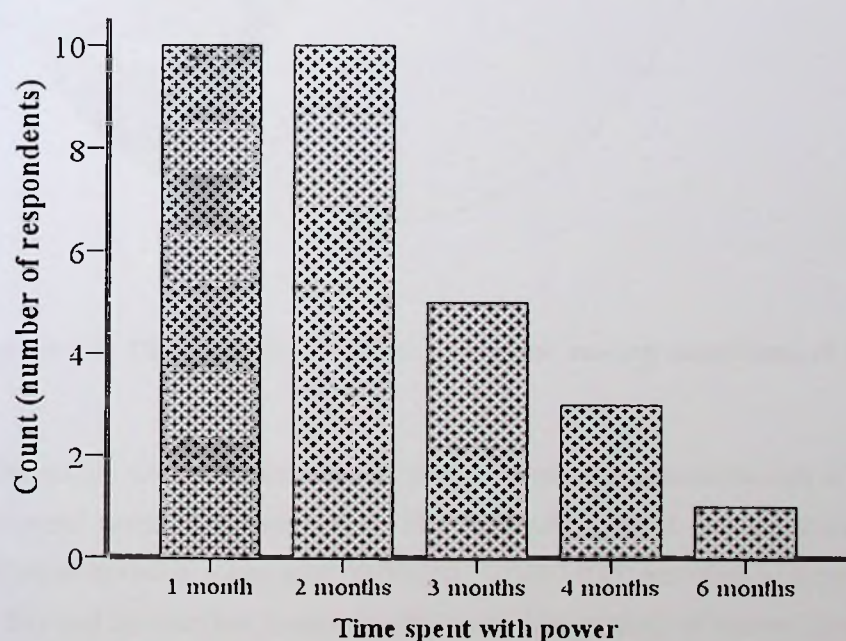


Figure 4.8: The period (months) of which households have spent with electricity generated by HPS

The response from focus group discussion was that low rate of electricity connection is due to delayed contract agreement between the customers and the electricity supplier on how to pay, handle and use power. However, those connected to electricity are using power at a free cost till terms and conditions of payments are clearly defined. The other challenge hindering electricity connection is the affordability of customers to pay 100,000 UGX as connection fee. Among the people interviewed during household survey, it was found that the majority of the respondents (57%) were peasants (*see* Figure 4.9) whose levels of income were low.

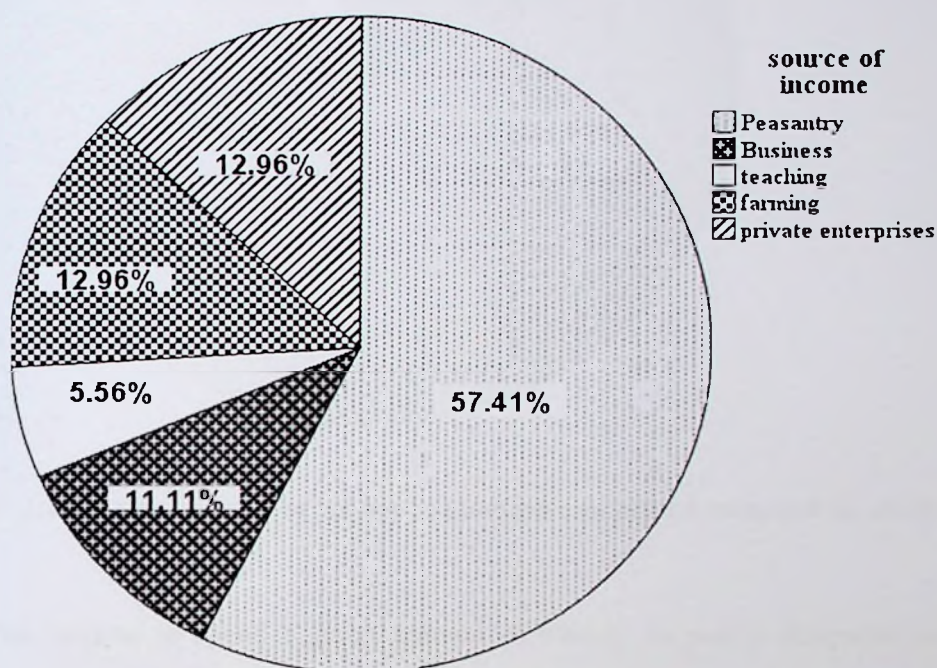


Figure 4.9: Distribution of source of income among customers of HPS

Information about the amount of money/month the customers can afford to spend on power was collected from 54 respondents. The researcher found that the number of customers who can afford to spend in a range of 10,000 to 20,000 UGX per month on power was the highest (18 out of 54) and the number dropped with increasing amount of money (*see* Figure 4.10). As shown in Figure 4.10, over 75% of the respondents expressed their interest to spend in a range of 2,000 to 20,000 UGX/month and these were mainly peasants (*see* Figure 4.11). Only 5.6% could afford to

spend between 50,000 and 100,000 UGX/month on power, and none of the respondents would afford above 100,000 UGX/month.

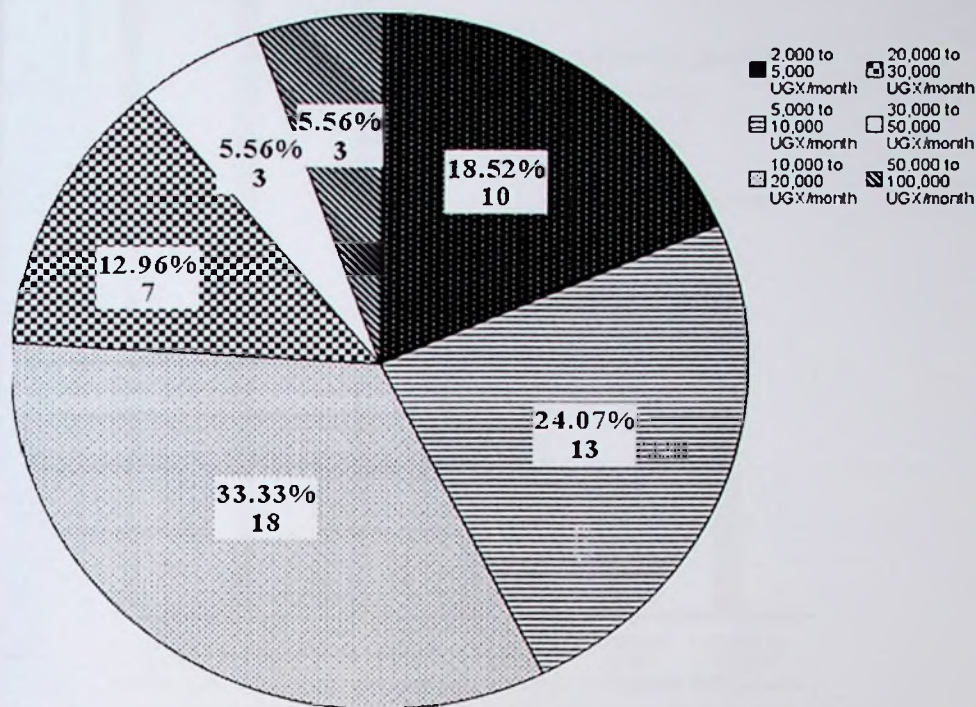


Figure 4. 10: Amount of money customers can afford to spend on electricity per month

The interest to spend a given amount of money on power depended on the type of income generating source of the local people. This information was got and is graphically represented in Figure 4.11. It was found that a total of 30 out of 54 peasants (55.6%) could only afford to spend money in a range of 2,000 and 20,000 UGX/month on power; whereas between 50,000 and 100,000 UGX per month, only businessmen could afford though they were small in number (3 out of 54).

This gives an impression that the majority of the people in Tiribogo village are peasants who are low income earners. However, if they could do some businesses using electricity, it would supplement on their income. This could probably increase on the level of power consumption and the affordability to pay for power consumed.

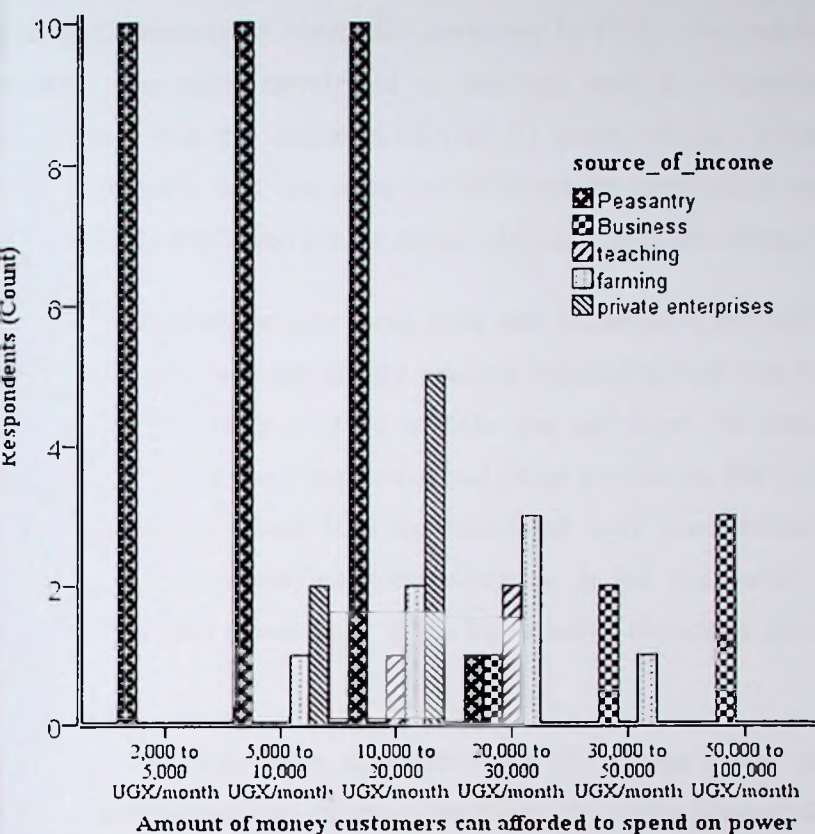


Figure 4.11: Relationship between income generating sources of respondents (customers) and the amount of money they can afford to spend on power.

Respondents who were connected to power also gave in their experience with HPS during focus group discussion. They stated that HPS has changed their lives and they can now charge their phones, watch TVs, have enough light for security and for scholars to read books and do their home work. However, they requested to have more hours per day of power supply, at least 12 hours (especially during night to give security light). They also need to be educated on safety precautions of power use, electric gadgets and on what electric appliances they can use to do businesses and earn a living. Nevertheless, those not connected to power requested to have a short term loan from the supplier for initial payment as connection fee. They expressed that after starting businesses (eg. Salons, phone and battery charging, film shows, etc), they can pay back in installments.

The first consumer of electricity generated by HPS, who had been connected for a period of 6 months, was also interviewed to find out how his experience had been with HPS. The interviewee was the chairman LCI of his home village (Tiribogo), the community leader for HPS customers, and the collector of electricity connection fee. According to him, HPS has improved his livelihood for the period of 6 months of electricity connection.

Before HPS came, he was using solar and kerosene to provide light in his chicken houses yet solar could not meet the energy demand and initial cost was high. But now he has found that electricity from HPS is more reliable and can meet his energy demand. "No more buying kerosene which is more expensive and prone to risks of fire outbreak and indoor air pollution", he said. Electricity from HPS has facilitated work even during night hours. Full time charged phones has also simplified communication in his businesses. His future plan is to produce chicken feed and maize flour at his home using electricity generated by HPS and expands his businesses.

However, the interviewee also added that his village mates and neighbors totaling to 100 in number approached him showing interest in electricity generated by HPS. They also requested to have power connection. In his concluding remarks, he requested that plans should be made to expand the HPS. He requested the management to expedite the connection of power to the enthusiastic customers so as to avoid deterrent.

4.3. Assessment of Local Interest to Adopt and Operate HPSs in Coffee and Rice Processing Centers

This section presents results and discussion on assessment of local interest to adopt HPS in Ballisa, Butaleja and Ssembabule Districts. The study revealed that all coffee processing centers in selected areas of Masaka, Lwengo, Ssembabule and Bukomansimbi Districts were connected to electricity and all the machines were using electricity (*see* Table 4.3). However, trading centers close to coffee processing plants including Nakelebe, Kibengo, Kamuli, Kusalira, Kijju and Manyama located (*see* Figure 3.4) in Ssembabule District did not have electricity. Assessment of local interest to adopt HPS in coffee processing centers was limited to areas with access to grid electricity, since it is in such areas that people are in need of power. In Butaleja

and Pallisa (rice growing areas), processing machines were found in areas with and without grid electricity (*see* Table 4.3). It was found that machines in rice growing areas with no access to grid electricity used diesel as the source of energy for rice hulling. Willingness to accept and support application of HPSs was compared for areas with and without grid electricity access. It was found that local interest to adopt HPS was higher in areas without electricity than areas with electricity.

4.3.1. Assessment of Local Interest to Adopt HPS in Pallisa District

A test of the full model against a constant only model was statistically significant, indicating that the predictors as a set reliably distinguished between interest and no interest in adoption of HPS (chi square = 24.306, $p < 0.001$ with $df = 4$). However, Nagelkerke's R^2 of 0.450 indicated a weak relationship between prediction and grouping. Prediction success overall was 90.1% (98.9% for interest and 10% for no interest). The Hosmer-Limeshow goodness-of-fit test shows that the model is a good fit with an insignificant p-value of 0.515. Wald criterion demonstrated that only willingness to accept application of HPSs (WTA) made a significant contribution to prediction ($p = 0.001$). Willingness to support HPS (WTS), households connected to electricity and electricity distributions in villages were not significant predictors. EXP (B) value indicates that when WTA is raised by one unit (one respondent), a threshold value, the odds ratio is 57.85 times as large and therefore respondents are 57.85 more times likely to be interested in adoption of HPS.

Cross tabulation analysis of WTA and WTS application of HPS in each selected village of Pallisa District was done. It was found that over 60% of respondents in each village of Pallisa were willing to accept and support application of HPS (*see* Table 4.8 and 4.9). High levels of WTA are influenced by the ability of households having access to electricity (*see* Figure 4.12). It was found that over 50% respondents in each village not connected to electricity were willing to accept application of HPS apart from Kachoge village whose percentage was about 48% (*see* Figure 4.12). Nevertheless WTA for respondents from each selected village connected to electricity was less than 50% (Figure 4.12). This implies that local interest to adopt HPS in areas having no access to grid electricity was higher than in areas having access to grid electricity.

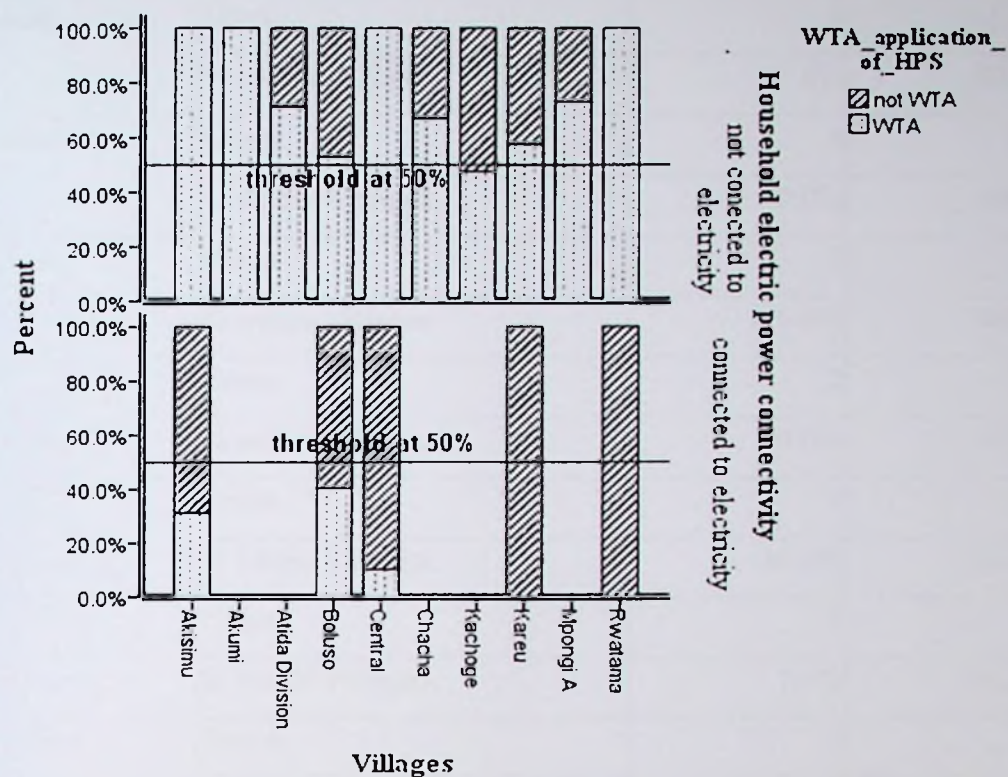


Figure 4. 12: Relative willingness to accept application of HPS and electricity connectivity in villages of Pallisa District.

Table 4. 8: Willingness to accept application of a HPS (WTA) in villages of Pallisa District.

Villages		WTA_application_of_HPS		Total
		not WTA	WTA	
Akisimu	Count	2	11	13
	% within Villages	15.4%	84.6%	100.0%
Akumi	Count	0	11	11
	% within Villages	.0%	100.0%	100.0%
Atida Division	Count	1	11	12
	% within Villages	8.3%	91.7%	100.0%

Boluso	Count	3	14	17
	% within Villages	17.6%	82.4%	100.0%
Central	Count	4	6	10
	% within Villages	40.0%	60.0%	100.0%
Chacha	Count	1	9	10
	% within Villages	10.0%	90.0%	100.0%
Kachoge	Count	2	8	10
	% within Villages	20.0%	80.0%	100.0%
Kareu	Count	4	6	10
	% within Villages	40.0%	60.0%	100.0%
Mpongi A	Count	1	12	13
	% within Villages	7.7%	92.3%	100.0%
Rwatama	Count	3	6	9
	% within Villages	33.3%	66.7%	100.0%
Total	Count	21	94	115
	% within Villages	18.3%	81.7%	100.0%

Table 4. 9: Willingness to support application of a HPS (WTS) in villages of Pallisa District.

Villages		WTS_HPS		Total
		not willing to support HPS	willing to support HPS	
Akisimu	Count	3	10	13
	% within Villages	23.1%	76.9%	100.0%
Akumi	Count	1	8	9
	% within Villages	11.1%	88.9%	100.0%

Atida Division	Count	0	11	11
	% within Villages	.0%	100.0%	100.0%
Boluso	Count	6	11	17
	% within Villages	35.3%	64.7%	100.0%
Central	Count	3	5	8
	% within Villages	37.5%	62.5%	100.0%
Chacha	Count	0	8	8
	% within Villages	.0%	100.0%	100.0%
Kachoge	Count	1	9	10
	% within Villages	10.0%	90.0%	100.0%
Kareu	Count	2	7	9
	% within Villages	22.2%	77.8%	100.0%
Mpongi A	Count	0	11	11
	% within Villages	.0%	100.0%	100.0%
Rwatama	Count	2	6	8
	% within Villages	25.0%	75.0%	100.0%
Total	Count	18	86	104
	% within Villages	17.3%	82.7%	100.0%

4.3.2. Local Interest to Adopt HPS in Butaleja District

In Butaleja District, a test of the full model against a constant only model was statistically significant, indicating that the predictors as a set reliably distinguished between interest and no interest in adoption of HPS (chi square = 32.694, $p < 0.001$ with $df = 4$). The Hosmer-Limeshow goodness-of-fit test shows that the model is a good fit with an insignificant p-value of 0.615. However, Nagelkerke's R^2 of 0.50 indicated a moderate relationship between prediction and grouping. Prediction success overall was 89.9% (94.8% for interested and 53.8% for not

interested). The Wald criterion demonstrated that only willingness to accept application of HPSs made a significant contribution to prediction ($p < 0.05$). Willingness to support HPS, households connected to electricity and electricity distributions in villages were not significant predictors. EXP (B) value indicates that when WTA is raised by one unit (one respondent), a threshold value, the odds ratio is 7.364 times as large and therefore respondents are 7.364 more times likely to be interested in adoption of HPS.

Cross tabulation analysis of WTA and WTS application of HPS in each selected village of Butaleja District was done. It was found that over 60% of respondents in each village of Butaleja District were willing to accept and support application of HPS (*see* Table 4.10 and 4.11). High levels of WTA are influenced by the ability of households having access to electricity (*see* Figure 4.13). It was found that over 50% respondents in each village of Dundo, Kapisa, Leresi, Namehere and Wandegeya, not connected to electricity, were willing to accept application of HPS; Whereas Lwoba and Nahasaragala villages recorded values less than 50% (*see* Figure 4.13). Nevertheless WTA for respondents from each selected village connected to electricity was less than 50% (*see* Figure 4.13). This implies that local interest to adopt HPS in areas having no access to grid electricity was higher than in areas having access to grid electricity.

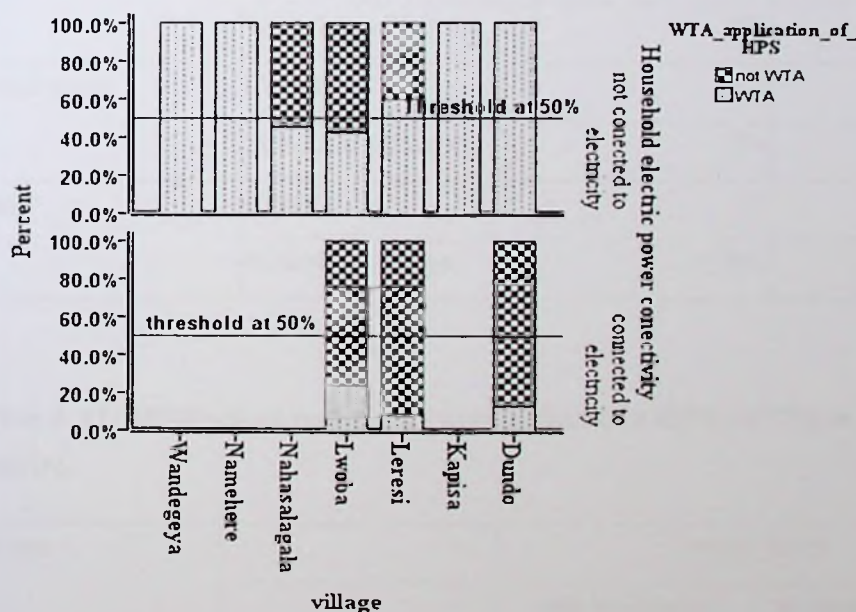


Figure 4.13: Relative willingness to accept (WTA) application of HPS and electricity connectivity in villages of Butaleja District.

Table 4.10: Willingness to accept application of a HPS (WTA) in villages of Butaleja District.

village		WTA_application_of_HPS		Total
		not WTA	WTA	
Dundo	Count	5	9	14
	% within village	35.7%	64.3%	100.0%
Kapisa	Count	0	17	17
	% within village	.0%	100.0%	100.0%
Leresi	Count	6	11	17
	% within village	35.3%	64.7%	100.0%
Lwoba	Count	4	9	13
	% within village	30.8%	69.2%	100.0%
Nahasalagala	Count	2	16	18
	% within village	11.1%	88.9%	100.0%
Namehere	Count	0	16	16
	% within village	.0%	100.0%	100.0%
Wandegeya	Count	0	14	14
	% within village	.0%	100.0%	100.0%
Total	Count	17	92	109
	% within village	15.6%	84.4%	100.0%

Table 4. 11: Willingness to support application of a HPS (WTS) in villages of Butaleja District.

village		WTS_HPS		Total
		not willing to support HPS	willing to Support HPS	

Dundo	Count	4	10	14
	% within village	28.6%	71.4%	100.0%
Kapisa	Count	0	17	17
	% within village	.0%	100.0%	100.0%
Leresi	Count	6	11	17
	% within village	35.3%	64.7%	100.0%
Lwoba	Count	1	12	13
	% within village	7.7%	92.3%	100.0%
Nahasalagala	Count	4	14	18
	% within village	22.2%	77.8%	100.0%
Namehere	Count	0	16	16
	% within village	.0%	100.0%	100.0%
Wandegeya	Count	3	11	14
	% within village	21.4%	78.6%	100.0%
Total	Count	18	91	109
	% within village	16.5%	83.5%	100.0%

4.3.3. Local Interest to Adopt HPS in Ssembabule District

In selected villages of Ssembabule District, a test of the full model against a constant only model was also statistically significant, indicating that the predictors as a set reliably distinguished between interest and no interest in adoption of HPS (chi square = 27.829, $p < 0.001$ with $df = 3$). Nagelkerke's R^2 of 0.674 indicated a moderately strong relationship between prediction and grouping. The Hosmer-Limeshow goodness-of-fit test shows that the model is a good fit with an insignificant p-value of 0.423. Prediction success overall was 95.2% (100% for interested and 62.5% for not interested). The Wald criterion demonstrated that only willingness to support HPSs (WTS) made a significant contribution to prediction ($p = 0.001$). Willingness to accept application of HPS (WTA) and households connected to electricity were not significant predictors. EXP (B) value indicates that when WTS is raised by one unit (one respondent), a

threshold value, the odds ratio is 63.349 times as large and therefore respondents are 63.349 more times likely to be interested in adoption of HPS.

Cross tabulation analysis of WTA and WTS application of HPS in each studied village of Ssembabule District revealed that, Manyama village had the highest percentage of respondents not willing to accept (58.3%) and not willing to support (50%) application of HPS (*see* Table 4.12 and 4.13). Whereas in Kamuli, Kibengo, Kijju, Kusalira and Nakelebe, it was found that over 50% of respondents in each village of Ssembabule District were willing to support application of HPS (*see* Table 4.13). High levels of WTS application of HPS are influenced by the ability of households having access to electricity (*see* Figure 4.14). It was found that over 50% respondents in each village not connected to electricity were willing to support application of HPS (*see* Figure 4.14). The highest values of WTS in areas without electricity were recorded in Kamuli, Kijju and Kusalira villages (100%); whereas Manyama village recorded the lowest value of about 50% (*see* Figure 4.14). A low value of WTS at Manyama village is attributed to the fact that local people use coffee husks for mulching banana plantations, since banana growing is their major agricultural activity. Their perception was that HPS will be competing with their banana plantations for husks, leading to less productivity. They pointed out that it is better to live with food other than power, since they have been surviving without power for so many years.

Generally, the study found that local interest to adopt HPS in areas having no access to grid electricity was higher than in areas having access to grid electricity.

Manyama	Count	7	5	12
	% within village	58.3%	41.7%	100.0%
Nakelebe	Count	1	9	10
	% within village	10.0%	90.0%	100.0%
Total	Count	9	60	69
	% within village	13.0%	87.0%	100.0%

Table 4.13: Willingness to support application of a HPS (WTS) in villages of Ssembabule District.

village		WTS_HPS		Total
		not willing to support HPS	willing to Support HPS	
Kamuli	Count	0	10	10
	% within village	.0%	100.0%	100.0%
Kibengo	Count	2	10	12
	% within village	16.7%	83.3%	100.0%
Kijju	Count	1	11	12
	% within village	8.3%	91.7%	100.0%
Kusalira	Count	0	12	12
	% within village	.0%	100.0%	100.0%
Manyama	Count	6	6	12
	% within village	50.0%	50.0%	100.0%
Nakelebe	Count	2	8	10
	% within village	20.0%	80.0%	100.0%
Total	Count	11	57	68
	% within village	16.2%	83.8%	100.0%

4.4.Economic Viability of Adopting HPSs

Once the main parameters of the HPS, the total plant costs and the total operating costs have been established and correlated with the plant's main operating parameters, the viability of the project can be further examined. The figures related to project investment (with regard to total plant costs) and power plant operations are summarized in Table 4.3. There was no subsidy paid to HPS by the Government of Uganda.

4.4.1. Estimation of Levelized Unit Cost of Electricity (LUCE)

One of the measures of the economic feasibility of the biomass gasifier for decentralized power generation is the levelized unit cost of electricity (LUCE) produced by the gasifier (Nouni *et al.*, 2007). In the present work, LUCE was estimated as;

$$= \frac{\text{total annualized cost (AC) of HPS}}{\text{annual electricity (E}_o\text{, kWh) delivered by the same}} \quad 4.15$$

$$= \frac{\left(\text{total annualized} \begin{pmatrix} \text{capital cost of HPS (AC}_c\text{)} \\ + \text{operating and maintenance cost (AC}_{O\&M}\text{)} \\ + \text{cost of fuel consumption (AC}_F\text{)} \end{pmatrix} \right)}{E_o} \quad 4.16$$

The capital cost of the project was annualized using a capital recovery factor R at a discount rate d and life period T . Assuming 10 years useful life of the gasification power plant (HPS), 20 years useful life of civil works and distribution network, and 12% discount rate, R was calculated using Equation 4.17 and was a constant value (see Table 4.14).

$$R = \left(\frac{d(1+d)^T}{((1+d)^T - 1)} \right) \quad 4.17$$

Table 4.14: Capital recovery factor for a 20year and 10year life of HPS equipments at 12% discount

Recovery factor, R at T = 20 years	Recovery factor, R at T = 20 years
0.13388	0.17698

Therefore, total annualized capital cost (see Equation 3.16) of the project (AC_c) was estimated as;

$$\begin{aligned}
 AC_c &= \left(\begin{aligned} & \left(R_{at\ 10\ years} \times \text{capital cost of gasification power plant (HPS)} \right) \\ & + R_{at\ 20\ years} \times \left(\begin{aligned} & \text{capital cost of civil work} \\ & + \text{capital cost of distribution network} \end{aligned} \right) \end{aligned} \right) \qquad 4.18 \\
 &= (0.17698 \times 60,000) + 0.13388 \times (10,000 + 15,000) = 13,966\ US\$.year^{-1}
 \end{aligned}$$

Operating and maintenance cost ($AC_{O\&M}$) was estimated using Equation 3.17 (operating parameter values are summarized in Table 4.3) as;

$$\begin{aligned}
 AC_{O\&M} &= \left(\begin{aligned} & (60,000\ US\$ \times 0.03) + (15,000\ US\$ \times 0.02) + (10,000\ US\$ \times 0.005) \\ & + (8760\ h.year^{-1} \times 0.25 \times 1US\$.person^{-1}h^{-1} \times 2\ persons) \end{aligned} \right) \qquad 4.19 \\
 &= 6,530\ US\$.year^{-1}
 \end{aligned}$$

The annualized cost of fuel consumption (AC_F) was calculated as in Equation 3.18.

When using coffee husks as fuel, AC_F was estimated as;

$$\begin{aligned}
 8760 \times CUF &\left(\begin{aligned} & \left(\begin{aligned} & \text{unit cost of pilot fuel} \times \text{specific fuel consumption of pilot fuel} \\ & \times \text{power output of electricity generator} \end{aligned} \right) \\ & + \left(\begin{aligned} & \text{unit cost of coffee husks} \times \text{specific fuel consumption of coffee husks} \\ & \times \text{power output of electricity generator} \end{aligned} \right) \end{aligned} \right) \qquad 4.20 \\
 AC_F &= 8760\ h.year^{-1} \times 0.25 \left(\begin{aligned} & (1.4\ US\$.L^{-1} \times 0.00245\ L.kWh^{-1} \times 34\ kW) \\ & + (0.067\ US\$.kg^{-1} \times 0.7941\ kg.kWh^{-1} \times 34kW) \end{aligned} \right)
 \end{aligned}$$

$$= 4,217 \text{ US}\$.year^{-1}$$

When using rice husks as fuel, AC_F was estimated as;

$$8760 \times CUF \left[\left(\frac{\text{unit cost of pilot fuel} \times \text{specific fuel consumption of pilot fuel}}{\text{power output of electricity generator}} \right) + \left(\frac{\text{unit cost of rice husks} \times \text{specific fuel consumption of rice husks}}{\text{power output of electricity generator}} \right) \right] \quad 4.21$$

$$AC_F = 8960 \text{ h.year}^{-1} \times 0.25 \left[\left(\frac{1.4 \text{ US}\$.L^{-1} \times 0.00245 \text{ L.kWh}^{-1} \times 34 \text{ kW}}{\text{power output of electricity generator}} \right) + \left(\frac{0.04 \text{ US}\$.kg^{-1} \times 1.2353 \text{ kg.kWh}^{-1} \times 34 \text{ kW}}{\text{power output of electricity generator}} \right) \right] \\ = 3,935 \text{ US}\$.year^{-1}$$

Assuming 10% electrical losses in the local distribution network, annual electricity generated by HPS (E_o) was also calculated using Equation 3.15 as;

$$E_o = \left[\frac{\text{power output of electricity generator (kW)} \times (8760 \times CUF)}{\left(1 - \text{fraction of generated power consumed by the auxiliaries} \right) \times \left(1 - \text{fraction of electrical losses in the local distribution network} \right)} \right] \quad 4.22$$

$$E_o = 34 \text{ kW} \times (8760 \text{ h.year}^{-1} \times 0.25) \times (1 - 0.046) \times (1 - 0.1) \\ = 63,931 \text{ kWh.year}^{-1}$$

Therefore, in support of Equation 3.14 and estimated plant operating parameters in section 4.2.2, LUCE generated by HPS using either coffee husks or rice husks can be calculated. LUCE of HPS using coffee husks as fuel was estimated by substituting Equations 4.18, 4.19, 4.20 and 4.22 into Equation 3.14 as;

$$LUCE_{\left(\begin{smallmatrix} \text{when using coffee} \\ \text{husks as fuel} \end{smallmatrix} \right)} = \frac{13,966 \text{ US}\$.year^{-1} + 6,530 \text{ US}\$.year^{-1} + 4,217 \text{ US}\$.year^{-1}}{63,931 \text{ kWh.year}^{-1}} \\ = 0.38625 \text{ US}\$.kWh^{-1}$$

Whereas LUCE using rice husks as fuel was estimated by substituting Equations 4.19, 4.20, 4.21 and 4.22 into Equation 3.14 as;

$$LUCE_{\substack{\text{(when using rice} \\ \text{husks as fuel)}}} = \frac{13,966 \text{ US}\$.year^{-1} + 6,530 \text{ US}\$.year^{-1} + 3,935 \text{ US}\$.year^{-1}}{63,931 \text{ kWh}.year^{-1}}$$

$$= 0.38214 \text{ US}\$.kWh^{-1}$$

On comparing the LUCE of HPS using two different biomass as fuel, it is noted that LUCE using coffee husks ($0.38625 \text{ US}\$.kWh_c^{-1}$) is higher than when using rice husks ($0.38214 \text{ US}\$.kWh_c^{-1}$) by only approximately 1.2%. The small difference is due to the variations in cost of biomass fuels (see Table 4.6), supported by high level of sensitivity to LUCE (see Figure 4.18).

Basing on existing literature, a similar study on financial evaluation of biomass gasifier power projects (BGPP) for electricity generation was done in areas including Uganda, India and Brazil. Buchholz and Da Silva (2010) estimated electricity production costs (from an installed capacity of 25.1kW wood-based biopower system in Uganda) at $0.11 \text{ US}\$.kWh^{-1}$, which is over 3 times lower than the cost of electricity generated by HPS in the present work. High value of LUCE generated by HPS could be attributed to its low CUF (25%), high capital cost ($2,500 \text{ US}\$.kW^{-1}$), high annual operation and maintenance cost ($6,530 \text{ US}\$.year^{-1}$) and high annual fuel cost (rice husks: $3,935 \text{ US}\$.year^{-1}$ and coffee: $4,217 \text{ US}\$.year^{-1}$) visa-avis 50%, $2,300 \text{ US}\$.kW^{-1}$, $3,500 \text{ US}\$.year^{-1}$ and $3053 \text{ US}\$.year^{-1}$; capacity factor (CUF), capital cost, annual operation and maintenance cost, and annual fuel cost, respectively (Buchholz and Da Silva, 2010).

Nouni *et al.* (2007) estimated LUCE at 13.72 Rs. kWh^{-1} ($0.31083 \text{ US}\$.kWh^{-1}$) for a 30kW power plant In India, which is also slightly lower than the value estimated in the present work. The slight difference is probably due to high initial investment cost of HPS ($2,500 \text{ US}\$/kW$) in Uganda compared to BGPP ($1,181 \text{ US}\$/kW$) in India. High cost of HPS in Uganda is caused by shipping and import tax revenue charges, as opposed to India where the system is manufactured within, hence exempted from these charges. Fracaro *et al.* (2011) also estimated LUCE for 100kW power plant in Brazil at $459.83\text{€}.MWh^{-1}$ ($0.64061 \text{ US}\$.kWh^{-1}$) which almost doubles the LUCE ($0.38625 \text{ US}\$.kWh_c^{-1}$ and $0.38214 \text{ US}\$.kWh_c^{-1}$) generated by HPS in Uganda. It was noted that small-scale electricity generation using biomass gasification technology is economically unfeasible in Brazil (Fracaro *et al.*, 2011).

4.4.2. Deriving Financial Parameters of HPS

In support of the estimated net electric power output (kW), heat rate (kJ/kWh), investment cost (\$), electricity export rate (\$/MWh) for coffee husks and rice husks, fuel rate (\$/ton), operation and maintenance cost (\$) and project life time (years), the financial evaluation of the proposed project (i.e. the implementation and operation of 34 kW_e HPS) was done using RETScreen and Microsoft excel. Table 4.6 provides a summary of operating parameters and assumptions used in the financial analysis, and Appendix 5 shows the analysis done by RETScreen.

Heat rate (see RETScreen in Appendix 5) was estimated as;

$$\frac{\text{biomass consumption (kg.h}^{-1}\text{)} \times \text{LHV (kJ.kg}^{-1}\text{)}}{\text{net electric power output (kW)}} \quad 4.22$$

$$= \frac{42.4 \text{ kg.h}^{-1} \times 12,300 \text{ kJ.kg}^{-1}}{34 \text{ kW}} = 15,339 \text{ kJ.kWh}^{-1} \text{ (for rice husks)}$$

Or

$$= \frac{27.1 \text{ kg.hr}^{-1} \times 15,970 \text{ kJ.kg}^{-1}}{34 \text{ kW}} = 12,729 \text{ kJ.kWh}^{-1} \text{ (for coffee husks)}$$

Electricity export rate was estimated by;

$$\text{LUCE } \$.\text{kWh}^{-1} \times 1000 \text{ kW.MW}^{-1} = 382.14 \$.\text{MWh}^{-1} \text{ for rice husks, and} \\ 386.25 \$.\text{MWh}^{-1} \text{ for coffee husks}$$

Whereas fuel rate was calculated by;

$$\text{fuel cost } (\$. \text{kg}^{-1}) \times 1000 \text{ kg.ton}^{-1} = 40 \$.\text{ton}^{-1} \text{ for rice husks and} \\ 67 \$.\text{ton}^{-1} \text{ for coffee husks}$$

From the analysis, it was found that the project's pay-back period on own capital was 5.2 years and 4.6 years when using rice husks and coffee husks as fuel, respectively, as shown graphically in Figures 4.15 and 4.16. The internal rate of return (IRR) of the project was 13.20% and 16.4% for rice husks and coffee husks, respectively (see Table 4.15). The project's Net Present Value (NPV) was found positive (US\$ 4,039 and US\$ 15,275 for rice husks and coffee husks,

respectively) and Benefit – Cost (B-C) ratio greater than 1 (1.05 and 1.18 for rice husks and coffee husks, respectively) (see Table 4.15). This shows that the project is economically viable for both types of biomass feedstock.

Table 4.15: Summary of economic parameters and financial evaluation of a 34kWe HPS

Parameter	Units	Values (rice husks as fuel)	Values (coffee husks as fuel)
Initial capital investment of HPS (I_n)	US\$	85,000	85,000
Specific investment cost	US\$ kW^{-1}	2,500	2,500
Annualized capital cost (AC_c)	US\$	13,966	13,966
Annualized cost of operation and maintenance ($AC_{o\&m}$)	US\$	6,530	6,530
Annualized cost of fuel (AC_F)	US\$	3,935	4,217
Annual Electricity generated (E_o)	kWh_e	63,931	63,931
Discount rate	%	12	12
Levelized unit cost of Electricity (LUCE)*	US\$. kWh_e^{-1}	0.38214	0.38625
Simple Payback period (PBP)	Years	4.8	4.3
Equity (PBP)	Years	5.2	4.6
Pre-tax Internal rate of return (IRR) – assets	%	13.2	16.4
Net Present Value (NPV)	US\$	4,039	15,275
Benefit – Cost (B-C) ratio		1.05	1.18
Uganda's reference tariffs as of the year 2012		Source:	
Household	US\$. kWh_e^{-1}	0.2098	(UMEME, 2012)
Low voltage supply for Commercial	US\$. kWh_e^{-1}	0.19504	
Low voltage supply for medium scale			
Industrial	US\$. kWh_e^{-1}	0.18356	

*1United States dollar (US\$)=2,500 Ugandan currency (UGX), in September 2012 (BOU, 2012)

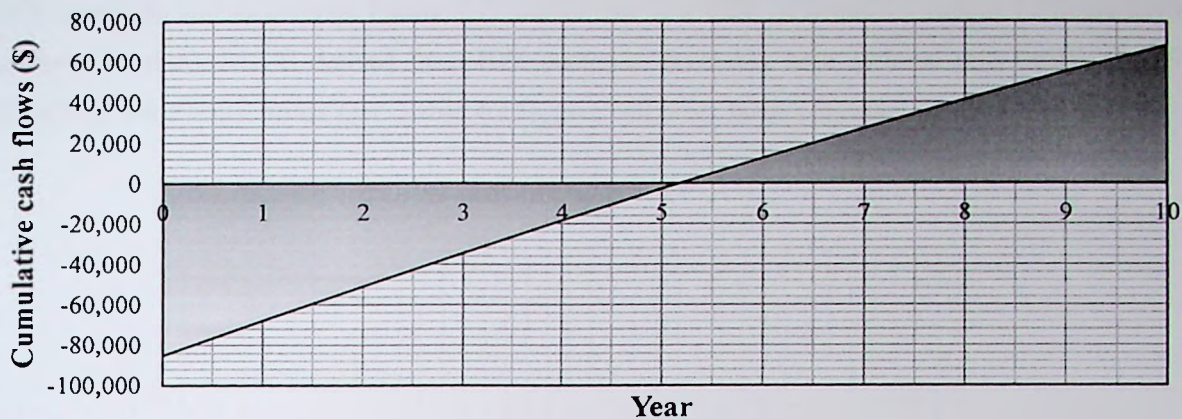


Figure 4.15: Project's pay-back period on own capital, using rice husks as fuel for HPS.

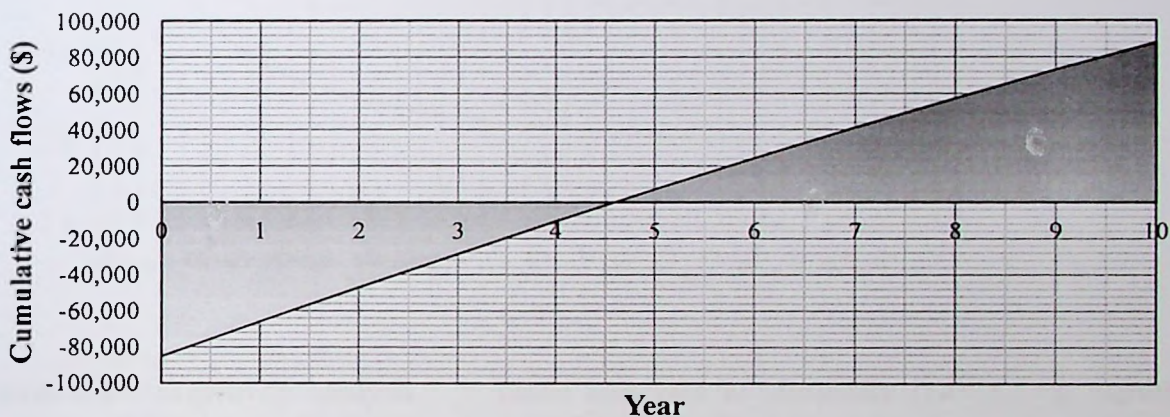


Figure 4.16: Project's pay-back period on own capital, using coffee husks as fuel for HPS.

4.4.3. Sensitivity Analysis

Levelised unit cost of electricity (LUCE) depends on a variety of factors including capacity utilization factor (CUF), initial capital investment of the project and cost of fuel. It was found that rice husks and coffee husks were available at a cost and their prices are shown in Table 4.6. In order to assess the influence the different variables produce on the final unit cost of electricity, a sensitivity analysis was carried out. The sensitivity analysis revealed that LUCE gradually reduces with an increase in capacity utilization factor, CUF (Figure 4.17). The lower the CUF, the higher the

LUCE would be and vice-versa. Figure 4.17 shows that at a CUF of about 0.7 (about 17 hours/day of machine operation), LUCE derived from HPS competes favorably with national grid tariffs (0.2098 US\$.kWh⁻¹) for households (see Table 4.15), given all other factors constant.

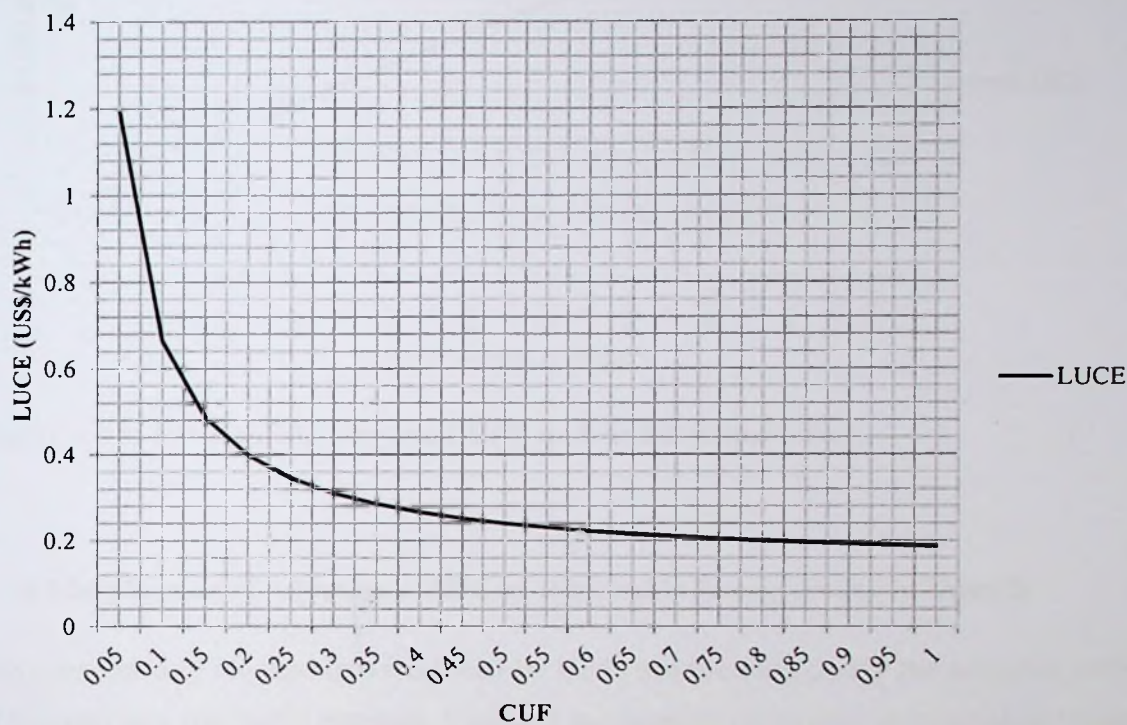


Figure 4.17: Sensitivity analysis – levelised unit cost of electricity (LUCE) vs. capacity utilization factor.

The relationship between LUCE and cost of biomass fuel was also determined (see Figure 4.18) and it was found that the cost of biomass fuel increases with LUCE. Assuming biomass fuel was available at a zero cost, LUCE would be 0.28US\$.kWh⁻¹ (see Figure 4.18), which is still higher than the current Uganda’s national grid tariffs for households (see Table 4.15), but much cheaper than solar and diesel-derived electricity (Szab’o, *et al.*, 2011). Hence the need for introducing cheaper feedstock in the plant’s fuel mix (such as rice straw) becomes an essential factor of project viability.

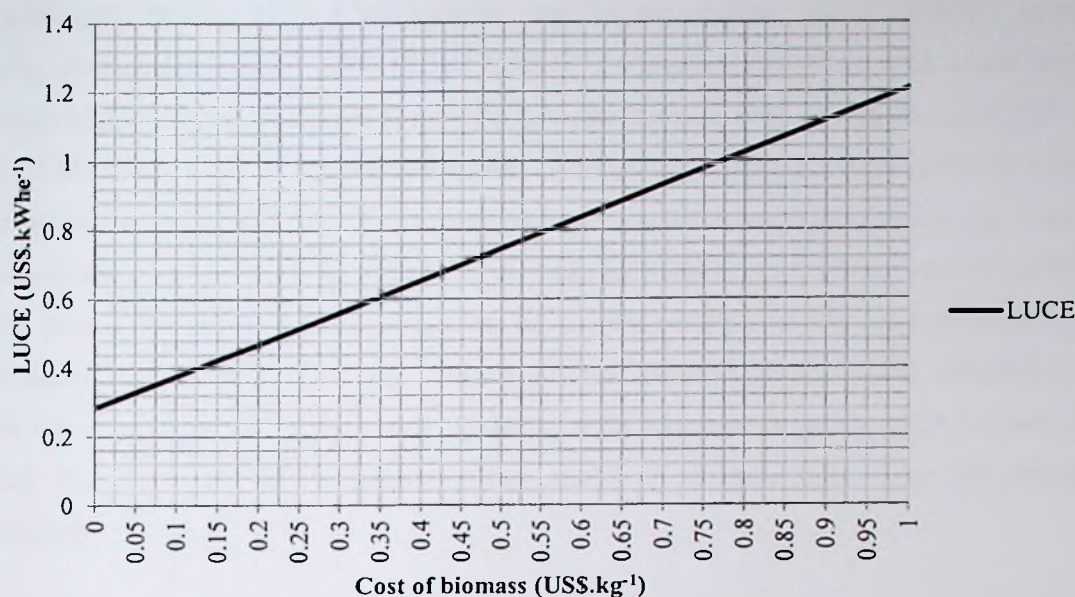


Figure 4. 18: Relationship between LUCE and cost of biomass fuel.

4.5.Implication of Adoption of HPS on Renewable Energy Policy in Uganda

The conversion of biomass into electricity by HPSs can increase greatly the potential usefulness of biomass as a renewable resource. Uganda's government renewable energy policy vision is to make modern renewable energy a substantial part of the national energy consumption (MEMD, 2007); where efficient utilization of biomass resource for energy is one of the policy objectives contributing to its sustainable management. The availability of electricity is seen as a key factor in assisting development in Uganda's rural areas. In the present research, it has been found that adoption of HPSs, a gasification based technology, can provide an alternative local source of electricity using local biomass such as agricultural residues.

Biomass, which supplies over 90% of the country's energy requirements, has continued to be used in its traditional form, largely as firewood and crop residues (MEMD, 2007). However, a high upfront cost of investment has become one of the barriers to renewable energy technology development, which result in many of them not being cost-competitive. For example, unit costs for investing in the various renewable energy technologies is: solar PV 12,000 – 15,000 US\$kW

¹; solar water heating 810 – 1,500 US\$ kW⁻¹; small hydros 2,500 – 5,000 US\$ kW⁻¹. In the present study, investment cost of HPS (2,500 US\$ kW⁻¹) competes favorably with small hydropower, though high costs are portrayed for coffee and rice husk-derived electricity using HPS (0.38625 and 0.38214 US\$. kWh_e⁻¹ respectively) than hydropower basing on tariffs (0.2098 US\$. kWh_e⁻¹) for households (Table 4.15). This is due to high operation and maintenance costs and varying biomass fuel costs, associated with HPS. A study by Szabó, *et al.* (2011) on energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension, revealed that a unit cost of electricity was about 0.420 and 0.455 US\$. kWh_e⁻¹ for solar and diesel, respectively, in Uganda. Relating with the current study, HPS-derived electricity using rice husk and coffee husks as fuel source is cheaper than solar and diesel-derived electricity.

Uganda's renewable energy policy's main goal is to increase the use of modern renewable energy, from 4% to 61% of the total energy consumption by the year 2017 (MEMD, 2007). However, the need for this policy has been reinforced by four major challenges in meeting the energy needs of its people. These challenges include: unprecedented electricity supply deficit on the national grid due to the fall in Lake Victoria water levels as a result of prolonged droughts; escalating oil prices on the international market; electricity accessibility to the rural population, through grid extension and mini-grids, considering that the level of electrification is very low; and the fulfillment of Government's commitment on greenhouse gas emissions reductions, under the Kyoto Protocol, with contribution on the global fight against climate change.

Due to the fact that coffee husks and rice husks are available on a renewable basis, it was found in this study that a 34kW_e HPS is sustainable in most of the crop processing centers in rural areas (*see* Figure 4.10). Though, some including Kachoge, Mpongi A, Atida Division, Akumi, Chacha villages in Pallisa, and Wandegeya, Namehere, Kapisa, Nahasalagala villages in Butaleja District, don't have access to electricity (*see* Table 4.3). Adoption of HPSs in such areas can increase sustainable and reliable electricity accessibility to the rural population, leading to improvement of peoples' livelihoods, along with environmental protection. Therefore, application of HPSs can both assist with the current crisis of Uganda's power shortage and global warming by providing a source of renewable energy and also deal with the environmental problem posed by the increasing quantities of agro-industrial residues produced by society.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1.Conclusion

An analysis has been carried out to investigate the technical and economic viability of Husk Powered System (HPS) application in coffee and rice processing centers in Uganda. A pilot HPS running on coffee and rice husks as fuel was evaluated and its fuel consumption estimated at 27kg.hr^{-1} and 42kg.hr^{-1} , respectively. The net electrical power output was 34kW_e and overall energy conversion efficiency was about 23.5% and 28.3% for rice and coffee husks, respectively. The equipment availability was 25% with total power output of $63,931\text{kWh.year}^{-1}$. A husk powered system was technically viable in coffee and rice processing centers when the husks generated were available and sustainable (ie. at their electric power potential greater than 34kW_e). Sustainability of husks for HPS was found high in areas having access to grid electricity than areas with no access to grid electricity. This was due to available power for coffee and rice processing that led to high milling rates, generating a significant amount of husks in processing centers powered with electricity.

The economic viability of HPS was also evaluated. An HPS was found an economically attractive alternative to diesel generated electricity and solar in Uganda considering increasing fossil fuel prices and high upfront cost of solar PV investment. The initial investment cost of the HPS was 85,000 US\$ (equivalent to $2,500\text{US}\$.\text{kW}^{-1}$), which competes favorably with small hydropower and solar PV. However, electricity generated by HPS is approximately twice as expensive as electricity from the national grid. The HPS produced electricity using rice husks and coffee husks at rates (0.38214 and $0.38625\text{US}\$.\text{kWh}_e^{-1}$, respectively) slightly lower than solar and diesel-derived electricity, but higher than national grid electricity for households in a comparable scale (0.420 , 0.455 and $0.2098\text{US}\$.\text{kWh}_e^{-1}$, respectively). Investing in HPS running on rice husks and coffee husks gives an attractive pay-back period of 5.2 years and 4.6 years, and a 10 year IRR of 13.20% and 16.4%, respectively. The project's NPV was found positive and Benefit – Cost (B-C) ratio greater than 1. This shows that HPS is economically viable for both types of biomass feedstock.

Careful regard of local conditions such as customers' willingness to support and accept application of HPS is important when assessing its economic feasibility. The willingness to support and accept application of HPS was found higher in areas having no access to grid electricity than areas with access to electricity. It is therefore not economical to install HPSs in areas having access to grid electricity since power from HPS would be more expensive than grid electricity, and few people are willing to support and accept the HPS. Although the local communities were highly interested in having electricity from HPS, they had no idea of how much they would pay for power. Their perception is that power generated by HPS is reliable and cheaper than power from the national grid. This gives an over expectation of peoples demand and willingness to pay for electricity they have not received yet.

5.2.Recommendations

Based on the study, the following recommendations can be made.

5.2.1. Recommendations to Entrepreneurs

- Before installation of a HPS in a potential area, local communities should be sensitized and educated on the operation of HPS, biomass consumption and safety precautions. They should be involved in the initial decision making and integrated in its management system. This helps them to know the benefits of HPS, know where, how and when they can come in to support its operation. Support may be in terms of providing security, identifying areas with significant amount of biomass fuel and supplying biomass fuel to HPS.
- Availability of coffee husks and rice husks is seasonal. Therefore, there should be a proper management system for biomass fuel utilization. Proper planning should always be done to make sure that husks are sustainable for HPS throughout the year. Significant amount of husks should be stored during the harvesting season to cater for the time husks are scanty. This may increase the costs but assures higher capacity utilization and availability of power.
- The capacity utilization of HPS, purchasing price of HPS and price of biomass fuel has a significant effect on the levelized unit cost of electricity. Therefore, efforts should be

made to bring down the prices of HPSs by the manufacturers and also to improve its capacity utilization factor. If the gasifier is fabricated within Uganda, investment cost of HPS would reduce since there would be no importation costs of the system.

- Wastewater generated during gasification should be treated and the solid waste (bio-char) compressed to briquettes, since it constitutes substantial amount of carbon. Briquettes would supplement on the income generated by the HPS.

5.2.2. Recommendations for Further Research

A baseline for further research has been created in this study. In order to improve the performance of HPS, the following recommendation should be followed.

- Studies on use of alternative biomass fuels as feedstock of HPS should be done. This helps to realize which type of biomass can best substitute or supplement on husks in case they are inadequate.
- Technical viability of the HPS has been evaluated but not to the fullest. The overall efficiency of the system was estimated basing on the LHV and the consumption/mass flow rate of the biomass fuel. LHV used in this study was not practically determined, but was got from the existing literature. Therefore, further research is needed to determine the biomass fuel properties – essential in the design of biomass gasification systems. The system component analysis should be done in order to assess the contribution of each component (gasifier, producer gas, gas cleaner and the generator) on the electrical power output and the fuel conversion efficiency of the HPS.
- The solid waste released after gasification of biomass, known as bio-char, is carbonaceous meaning that it has energy value. However in this study, the bio-char was not characterized to find out how much energy would be recovered from it. This therefore leaves a gap for further investigation.
- It was found that living organisms (e.g. toads, rats, lizards) that would fall in the wastewater generated during gasification process would die instantly. This was an indicator that the wastewater generated has a harmful effect on the biodiversity. Therefore research on the physico-chemical properties of this wastewater should be done to find out which chemical elements are detrimental to the environment. Emission levels

in terms of CO and NO_x should also be examined since these are the major contributors to global climate change.

- Further research on optimization of the operational costs of HPS and biomass fuel supply chain should be done. This should consider plant size, power demand, the number of HPSs connected to form a cluster, maximum distances between these clusters, biomass transportation costs and topography in a given location. In the present study, the adoption of HPS was mainly limited to crop processing centers with no access to grid electricity, but having a significant amount of biomass that can operate a 34kW_e throughout the year. Hence transportation of biomass was assumed at a zero cost. This leaves a gap to investigate the economic feasibility of adoption of HPS in areas that have high power demand, but would require importation of biomass to the site of HPS.
- Since the cost of power generated by HPS has been estimated, further studies should be done to estimate the willingness and affordability of local communities to pay for power at such an estimated rate.

5.2.3. Recommendations to Policy Makers

A Husk Powered System has the potential to improve peoples' livelihoods and to replace the use of fossil fuels, the leading contributor to global carbon dioxide (CO₂) emissions (one of the main GHGs). However, if supportive policies are not well implemented on HPS, it might lead to its failure. Therefore, the following recommendations should be followed.

- The knowledge on technology and economics of HPS should be made available to entrepreneurs and artisans through trainings for the manufacture, installation, maintenance and business. This will cause competition in innovation and business, hence improve on efficiency and reduce on investment costs.
- Ministry of Energy and Mineral Development (MEMD) should promote collaboration of HPS investors with local farmers, National Forestry Authority (NFA) and Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), in the improvement of crop production, availability of biomass and its efficient utilization for energy.
- The government should promote incentives and provide subsidies to HPS entrepreneurs. This is because HPS is an upcoming environment friendly energy source and has a strong

linkage with achieving the MDGs. If HPS is supported well by the government, its rate of development would go high.

- Stakeholders in the public sector, private sector, microfinance institutions, training institutions, NGOs, CBOs should be sensitized on the linkages between HPS, renewable energy, environmental sustainability, climate change and poverty, and specify their different roles in promoting the synergies. This will create awareness and attract more investors in HPS and related innovations, for sustainable development.

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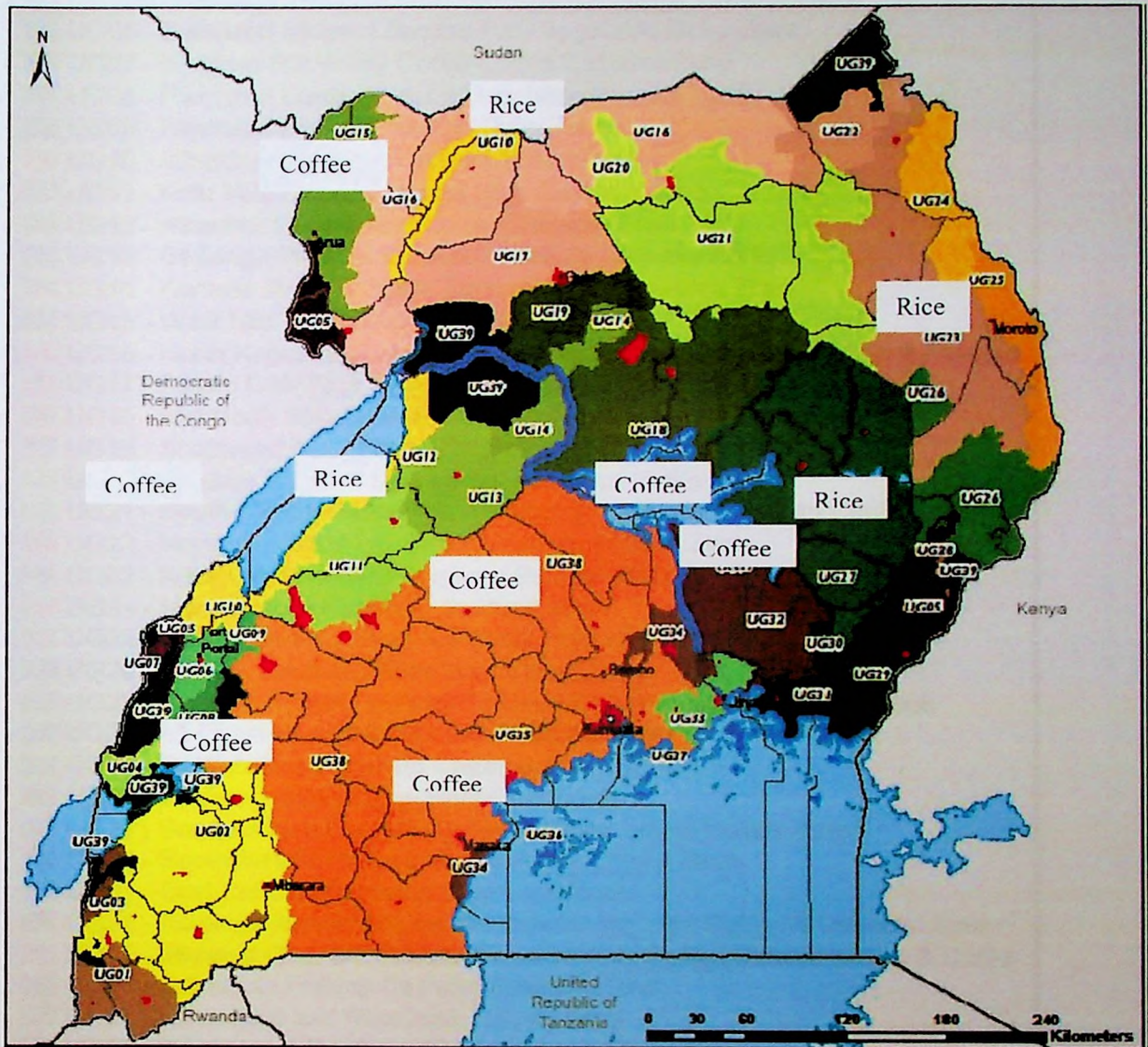
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APPENDICES

Appendix 1: Uganda – Livelihood Zones (Map); Areas where Coffee, Rice and Other Crops are Mostly Grown.



Source: FEWS-NET (2010)

Key of the Map

- UG01 - Southwestern Highland Irish Potato Sorghum Vegetable Zone
- UG02 - Southwestern Midland Banana Robusta Coffee Cattle Zone
- UG03 - Southwestern Rift Valley Tobacco Bean Millet Zone
- UG04 - Kazinga Channel Cassava Maize Fruit Vegetable Cotton Zone
- UG05 - Rwenzori Mt Elgon West Nile Arabica Coffee Banana Zone
- UG06 - Rwenzori Midland Banana Fruit Vegetable Dairy Zone
- UG07 - Western Rift Valley Cocoa Coffee Cassava Zone
- UG08 - Rwenzori Lowland Maize Vegetable Banana Zone
- UG09 - Rwenzori Midland Tea and Dairy Zone
- UG10 - Albertine West Nile Lowland Cattle Zone
- UG11 - Kafu Muzizi Maize Upland Rice Cassava Zone
- UG12 - Albertine Escarpment Cotton Cassava Zone
- UG13 - Bwijanga Pakanyi SugarcaNE Maize Cassava Zone
- UG14 - Karuma Masindi Oyam Tobacco Maize Cassava Zone
- UG15 - West Nile Tobacco Cassava Sorghum Zone
- UG16 - North Kitgum Gulu Amuru West Nile Simsim Sorghum Livestock Zone
- UG17 - Amuru Gulu Rice Groundnut Sorghum Livestock Zone
- UG18 - Mid North Simsim Maize Cassava Zone
- UG19 - Southwest Gulu Beans Groundnuts Shoat Cassava
- UG20 - Palabek Tobacco Simsim Sorghum and Cattle Zone
- UG21 - South Kitgum Pader Abim Simsim Groundnuts Sorghum Cattle Zone
- UG22 - Northeast Sorghum Simsim Maize Livestock Zone
- UG23 - Karamoja Livestock Sorghum Bulrush Millet Zone
- UG24 - Northeastern Karamoja Pastoral Zone
- UG25 - Central and Southern Karamoja Pastoral Zone
- UG26 - Eastern Lowland Maize Beans Rice Zone
- UG27 - Eastern Central Lowland Cassava Sorghum and Groundnut Zone
- UG28 - Mt Elgon Highland Irish Potato Cereal Zone
- UG29 - Southeastern Lowland Cassava Cereal Zone
- UG30 - Eastern Lowland Rice Root Crop Zone
- UG31 - Southeastern Lowland Cassava Maize Sweet Potato Zone
- UG32 - Southeastern Maize Beans Robusta Coffee Zone
- UG33 - East Central Plantation Outgrower Zone
- UG34 - Kayunga Masaka Pineapple Banana Robusta Coffee & Cassava Zone
- UG35 - Midwest Cen. & L Victoria Crescent Rob. Coffee Banana Maize & Cattle
- UG36 - Kalangala Fishing Oil Palm Cassava Zone
- UG37 - Lakeshore and Riverbank Fishing Zone
- UG38 - Central and Southern Cattle Cassava Maize Zone
- UG39 - National Park
- UG40 - Urban

Appendix 2: Areas of Study in Selected District

District	Sub-county	Parish	Village
Pallisa	Putiputi	Bolusol	Boluso
		Mpongi	Kachoge
	Pallisa Town Council	Pallisa Tc	Mpongi A
			Central
	Apopong	Katuke	Atida Division
		Kaukura	Akumi
	Olok	Apapa	Rwatama
	Gogonyo	Angodi	Chacha
Agule	Akisimu Central	Kareu	
		Akisimu	
Butaleja	Busolwe TC	Busolwe CW	Dundo
	Butaleja TC	Bungaji	Leresi
	Mazimasa	Lubembe	Nahasalagala
		Doho	Namehere
		Kapisa	Kapisa
	Himutu	Kaiti	Lwoba
		Wandegeya	
Masaka	Masaka Town	Masaka Town	Masaka Industrial area
Bukomansimbi	Bukomansimbi	Butenga	Bukomansimbi Town
Ssembabule	Matete	Katimba	Mateete Town
			Manyama
	Kiseke	Kinoni	Kabasanda
			Kijju
			Kusalira
			Kamuli
		Kibengo	
Lwengo	Kiseke	Kinoni	Nakelebe
			Kaboyo
			Kasambya
Mubende	Madudu	Kaweri	Kaweri
	Bukwekula	Mubende Town	Kayunga
			Kisekend
Mityana	Busimbi	Busimbi	Nambaale
			Kikumambogo
			Buswabulongo
			Busimbi

Buswabu														
longo	1342	2	4	3	3	3	1	2	2	1	0	1	3	3
Busimbi	1008	2	6	6	4	5	2	2	3	2	0	1	3	3

b) Milling rates (kg/h) of randomly selected rice mills in villages of Butaleja District

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Dundo	7	600.00	1010.00	8.2757E2	62.09473	164.28720
Leresi	7	598.00	899.00	7.8014E2	50.18557	132.77855
Nahasalagala	7	450.00	984.00	6.7800E2	74.24124	196.42386
Namehere	7	668.00	988.00	8.2129E2	39.13026	103.52892
Kapisa	7	560.00	928.00	8.3057E2	48.25076	127.65952
Lwoba	7	865.00	983.00	9.0971E2	15.87408	41.99887
Wandegeya	7	492.00	890.00	6.7214E2	59.63597	157.78195
Valid N (listwise)	7					

c) Milling rates (kg/h) of randomly selected rice mills in villages of Pallisa District

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Boluso	7	598.00	1000.00	7.7043E2	56.69629	150.00429
Kachoge	7	465.00	899.00	5.9614E2	59.08244	156.31744
Mpongi_A	7	698.00	1050.00	8.8414E2	49.20919	130.19527
Atida_Division	7	366.00	789.00	5.1871E2	52.66820	139.34695
Pallisa_Central	7	568.00	1002.00	8.4643E2	63.86662	168.97520
Akumi	7	486.00	987.00	7.1971E2	69.42338	183.67699
Rwatama	7	405.00	879.00	6.2686E2	71.22581	188.44577
Chacha	7	564.00	956.00	7.9986E2	51.67731	136.72531
Kareu	7	500.00	955.00	7.5243E2	66.30983	175.43931

Akisimu	7	698.00	1087.00	9.0286E2	50.80328	134.41283
Valid N (listwise)	7					

d) Milling rates (kg/h) of randomly selected coffee mills in villages of Masaka, Bukomansimbi, Ssembabule, Lwengo, Mityana and Mubende Districts

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Industrial_area	7	653	801	1454	1182.14	78.611	207.986
Bukomansiimbi	5	193	1022	1215	1124.80	37.191	83.161
Mateete	8	292	1031	1323	1167.38	45.517	128.741
Kaboyo	11	950	750	1700	1106.82	85.317	282.964
Kasambya	5	458	998	1456	1213.00	91.724	205.101
Kaweri_factory	7	1897	2859	4756	4000.29	266.005	703.783
Kayunga	7	994	586	1580	1002.86	116.646	308.616
Kisekend	7	691	784	1475	989.43	87.732	232.118
Nambaale	7	571	889	1460	1088.14	78.504	207.702
Kikumambogo	7	384	856	1240	1038.14	57.765	152.833
Buswabulongo	7	573	987	1560	1342.29	84.709	224.120
Busimbi	7	469	785	1254	1007.71	51.846	137.172
Valid N (listwise)	5						

Appendix 4: Results from Logistic Regression Analysis for Local Interest to Adopt HPSs in Pallisa, Butaleja and Ssembabule Districts.

i) PALLISA DISTRICT

```
LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS
/METHOD=ENTER WTA_application_of_HPS WTS_HPS House_connected_to_electricity Vi
llage_having_electricity_distribution_network
/CLASSPLOT
/CASEWISE OUTLIER(2)
/PRINT=GOODFIT
/CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

Logistic Regression

Notes

Output Created	13-Jul-2012 17:36:24	
Comments		
Input	Data	E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Pallisa\Pallisa.test.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	133
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing

Syntax	LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS /METHOD=ENTER WTA_application_of_HPS WTS_HPS House_conected_to_electricity Village_having_electricity_distribution_net work /CLASSPLOT /CASEWISE OUTLIER(2) /PRINT=GOODFIT /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).		
Resources	Processor Time	00:00:00.016	
	Elapsed Time	00:00:00.031	

[DataSet1] E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Pallisa\Pallisa. test.sav

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	101	75.9
	Missing Cases	32	24.1
	Total	133	100.0
Unselected Cases		0	.0
Total		133	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
not interested	0
interested	1

Block 0: Beginning Block

Classification Table^{a,b}

Observed			Predicted		
			Local_interest_to_accept_HPS		Percentage Correct
			not interested	interested	
Step 0	Local_interest_to_accept_HPS	not interested	0	10	.0
		interested	0	91	100.0
	Overall Percentage				90.1

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Step 0 Constant	2.208	.333	43.937	1	.000	9.100

Variables not in the Equation

	Score	df	Sig.
Step 0 Variables WTA_application_of_HPS	29.299	1	.000
WTS_HPS	7.847	1	.005
House_connected_to_electricity	5.749	1	.016
Village_having_electricity_distribution_network	4.694	1	.030
Overall Statistics	30.795	4	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Step 1 Step	24.306	4	.000
Block	24.306	4	.000

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	24.306	4	.000
	Block	24.306	4	.000
	Model	24.306	4	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	40.920 ^a	.214	.450

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.286	3	.515

Contingency Table for Hosmer and Lemeshow Test

		Local_interest_to_accept_HPS = not interested		Local_interest_to_accept_HPS = interested		Total
		Observed	Expected	Observed	Expected	
Step 1	1	4	5.014	6	4.986	10
	2	5	3.263	7	8.737	12
	3	1	1.142	20	19.858	21
	4	0	.111	10	9.889	10
	5	0	.470	48	47.530	48

Classification Table^a

Observed	Predicted		
	Local_interest_to_accept_HPS		Percentage Correct
	not interested	interested	
Step 1 Local_interest_to_accept_HPS not interested	1	9	10.0
interested	1	90	98.9
Overall Percentage			90.1

a. The cut value is .500

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Step 1 ^a WTA_application_of_HPS	4.058	1.240	10.709	1	.001	57.850
WTS_HPS	.260	.938	.077	1	.782	1.297
House_conected_to_electricity	1.747	1.362	1.644	1	.200	5.736
Village_having_electricity_distribution_network	1.761	1.286	1.873	1	.171	.172
Constant	.299	1.160	.066	1	.797	1.348

a. Variable(s) entered on step 1: WTA_application_of_HPS, WTS_HPS, House_conected_to_electricity, Village_having_electricity_distribution_network.

ii) BUTALEJA DISTRICT

LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS
 /METHOD=ENTER WTA_application_of_HPS WTS_HPS House_conected_to_electricity Vi
 llage_having_electricity_distribution_network
 /CLASSPLOT
 /CASEWISE OUTLIER(2)
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).

Logistic Regression

Notes

Output Created	16-Jul-2012 20:03:02	
Comments		
Input	Data	E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Butaleja\Butaleja. test.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	139
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing
Syntax	LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS /METHOD=ENTER WTA_application_of_HPS WTS_HPS House_conected_to_electricity Village_having_electricity_distribution_network /CLASSPLOT /CASEWISE OUTLIER(2) /PRINT=GOODFIT CI(95) /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).	
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.065

[DataSet1] E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Butaleja\Butaleja. test.sav

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	109	78.4
	Missing Cases	30	21.6
	Total	139	100.0
Unselected Cases		0	.0
Total		139	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
not interested	0
interested	1

Block 0: Beginning Block

Classification Table^{a,b}

Observed	Predicted		
	Local_interest_to_accept_HPS		Percentage Correct
	not interested	interested	
Step 0 Local_interest_to_accept_HPS not interested	0	13	.0
interested	0	96	100.0
Overall Percentage			88.1

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Step 0 Constant	1.999	.296	45.771	1	.000	7.385

Variables not in the Equation

	Score	df	Sig.
Step 0 Variables WTA_application_of_HPS	32.255	1	.000
WTS_HPS	9.406	1	.002
House_conected_to_electricity	27.627	1	.000
Village_having_electricity_distribution_network	18.816	1	.000
Overall Statistics	40.285	4	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)	95.0% C.I. for EXP(B)	
							Lower	Upper
Step 1 ^a WTA_application_of_HPS	1.997	.792	6.350	1	.012	7.364	1.558	34.800
WTS_HPS	.738	.882	.700	1	.403	2.092	.371	11.783
House_connected_to_electricity	-.920	1.034	.791	1	.374	.399	.053	3.025
Village_having_electricity_distribution_network	-1.857	1.323	1.972	1	.160	.156	.012	2.085
Constant	1.783	1.375	1.681	1	.195	5.948		

a. Variable(s) entered on step 1: WTA_application_of_HPS, WTS_HPS, House_connected_to_electricity, Village_having_electricity_distribution_network.

iii) SSEMBABULE DISTRICT

GET

FILE='E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Masaka\Masaka.sav'.

DATASET NAME DataSet0 WINDOW=FRONT.

LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS

/METHOD=ENTER Village_having_electricity_distribution_network House_connected_to_electricity WTA_application_of_HPS WTS_HPS

/PRINT=GOODFIT CORR

/CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).

Logistic Regression

Notes

Output Created	22-May-2013 16:50:57	
Comments		
Input	Data	E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Masaka\Masaka.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>

	N of Rows in Working Data File	193
Missing Value Handling Syntax	Definition of Missing	User-defined missing values are treated as missing LOGISTIC REGRESSION VARIABLES Local_interest_to_accept_HPS /METHOD=ENTER Village_having_electricity_distribution_network House_connected_to_electricity WTA_application_of_HPS WTS_HPS /PRINT=GOODFIT CORR /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.078

[DataSet1] E:\M.Sc REN\Year 2\Sem 2\HPS Research\Data Analysis\Masaka\Masaka.sav

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	61	31.6
	Missing Cases	132	68.4
	Total	193	100.0
Unselected Cases		0	.0
Total		193	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
not interested	0
interested	1

Block 0: Beginning Block

Classification Table^{a,b}

Observed		Predicted		
		Local_interest_to_accept_HPS		Percentage Correct
		not interested	interested	
Step 0	Local_interest_to_a not interested	0	8	.0
	ccept_HPS interested	0	54	100.0
Overall Percentage				87.1

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Step 0 Constant	1.910	.379	25.407	1	.000	6.750

Variables not in the Equation

	Score	df	Sig.
Step 0 Variables House_conected_to_electricity	2.531	1	.112
WTA_application_of_HPS	17.043	1	.000
WTS_HPS	30.626	1	.000
Overall Statistics	35.052	3	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Step 1 Step	27.829	3	.000

Block	27.829	3	.000
Model	27.829	3	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	19.854 ^a	.362	.674

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.719	2	.423

Contingency Table for Hosmer and Lemeshow Test

		Local_interest_to_accept_HPS = not interested		Local_interest_to_accept_HPS = interested		Total
		Observed	Expected	Observed	Expected	
Step 1	1	5	4.536	0	.464	5
	2	2	2.464	4	3.536	6
	3	0	.499	5	4.501	5
	4	1	.501	45	45.499	46

Classification Table^a

Observed		Predicted		
		Local_interest_to_accept_HPS		Percentage Correct
		not interested	interested	
Step 1	Local_interest_to_accept_HPS not interested	5	3	62.5

	interested	0	54	100.0
Overall Percentage				95.2

a. The cut value is .500

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Step 1 ^a House_connected_to_electricity	-1.196	3.903	.094	1	.759	.303
WTA_application_of_HPS	2.480	1.345	3.400	1	.065	11.936
WTS_HPS	4.149	1.298	10.217	1	.001	63.349
Constant	-2.119	1.281	2.737	1	.098	.120

a. Variable(s) entered on step 1: House_connected_to_electricity, WTA_application_of_HPS, WTS_HPS.

Appendix 5: Financial Analysis of HPS Using RETScreen



RETScreen® International
www.etscreen.net

Clean Energy Project Analysis Software

Project information

[See project database](#)

Project name: Economic Viability of a 34kWe HPS in Uganda
Project location: Coffee and Rice processing centers

Prepared for: MSc. Renewable Energy Dissertation
Prepared by: Turinayo Yonah Karibwije

Project type: Power

Technology: Reciprocating engine
Grid type: Isolated-grid

Analysis type: Method 2

Heating value reference: Lower heating value (LHV)

Show settings

Site reference conditions

[Select climate data location](#)

Climate data location: Ottawa Intl Airport

Show data

« » Start Energy Model Cost Analysis Emission Analysis Financial Analysis Risk Analysis Tools

Rice husks as fuel

RETScreen Energy Model - Power project

Proposed case power system

Technology	Reciprocating engine			
Availability	%	25.0%	2,190 h	
Fuel selection method	Single fuel			
Fuel type	Rice - hull			
Fuel rate	\$/t	40.000		
Reciprocating engine				
Power capacity	kW	34		
Electricity exported to grid	MWh	74		
Manufacturer	Parakash Diesel PVT. LTD			
Model				
Heat rate	kJ/kWh	15,339		
Fuel required	GJ/h	0.5	million Btu/h	0.49
			million Btu/h	0.00
Electricity export rate	\$/MWh	382.14	\$/kWh	0.014
			\$/kWh	0.382

Complete Cost Analysis sheet

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost			\$ -	
Subtotal:				\$ -	0.0%
Development					
Development	cost			\$ -	
Subtotal:				\$ -	0.0%
Engineering					
Engineering	cost			\$ -	
Subtotal:				\$ -	0.0%
Power system					
Reciprocating engine	kW	34.00	\$ 1.765	\$ 60,000	
Road construction	km			\$ -	
Transmission line	km	3	\$ 5,000	\$ 15,000	
Substation	project			\$ -	
Energy efficiency measures	project			\$ -	
User-defined	cost			\$ -	
Civil work	cost	1	\$ 10,000	\$ 10,000	
Subtotal:				\$ 85,000	100.0%
Balance of system & miscellaneous					
Spare parts	%			\$ -	
Transportation	project			\$ -	
Training & commissioning	p-d			\$ -	
User-defined	cost			\$ -	
Contingencies	%		\$ 85,000	\$ -	
Interest during construction			\$ 85,000	\$ -	
Subtotal:		Enter number of months		\$ -	0.0%
Total initial costs				\$ 85,000	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project	1	\$ 6,530	\$ 6,530
User-defined	cost		\$	-
Contingencies	%		\$ 6,530	\$ -
Subtotal:				\$ 6,530
Fuel cost - proposed case				
Rice - hull	t	107	\$ 40,000	\$ 4,294
Subtotal:				\$ 4,294

RETScreen Emission Reduction Analysis - Power project

Emission Analysis

- ☒ Method 1
- ☐ Method 2
- ☐ Method 3

Base case electricity system (Baseline)

Country - region		GHG emission factor (excl. T&D) tCO ₂ /MWh	T&D losses %	GHG emission factor tCO ₂ /MWh
Uganda	All types			0.000

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO ₂ /MWh	GHG emission tCO ₂
Electricity	100.0%	74	0.000	0.0
Total	100.0%	74	0.000	0.0

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO ₂ /MWh	GHG emission tCO ₂
Rice - hull	100.0%	317	0.007	2.3
Total	100.0%	317	0.007	2.3
Electricity exported to grid	MWh	74	T&D losses 10.0%	0.0
Total				2.3

GHG emission reduction summary

	Base case GHG emission tCO ₂	Proposed case GHG emission tCO ₂	Gross annual GHG emission reduction tCO ₂	GHG credits transaction fee %	Net annual GHG emission reduction tCO ₂
Power project	0.0	2.3	-2.3		-2.3
Net annual GHG emission reduction	-2.3	tCO ₂	is equivalent to	-983.2	Litres of gasoline not consumed

RETScreen Financial Analysis - Power project

Financial parameters

General			
Fuel cost escalation rate	%		
Inflation rate	%	5.4%	
Discount rate	%	12.0%	
Project life	yr	10	

Finance			
Incentives and grants	\$		
Debt ratio	%		

Income tax analysis ☐

Annual income

Electricity export income			
Electricity exported to grid	MWh	74	
Electricity export rate	\$/MWh	382.14	
Electricity export income	\$	28,454	
Electricity export escalation rate	%		

GHG reduction income ☐

Project costs and savings/income summary

Initial costs			
Power system	100.0%	\$	85,000
Balance of system & misc.	0.0%	\$	0
Total initial costs	100.0%	\$	85,000

Annual costs and debt payments			
O&M		\$	6,530
Fuel cost - proposed case		\$	4,294
Total annual costs		\$	10,824

Periodic costs (credits)

Annual savings and income			
Fuel cost - base case		\$	0
Electricity export income		\$	28,454
Total annual savings and income		\$	28,454

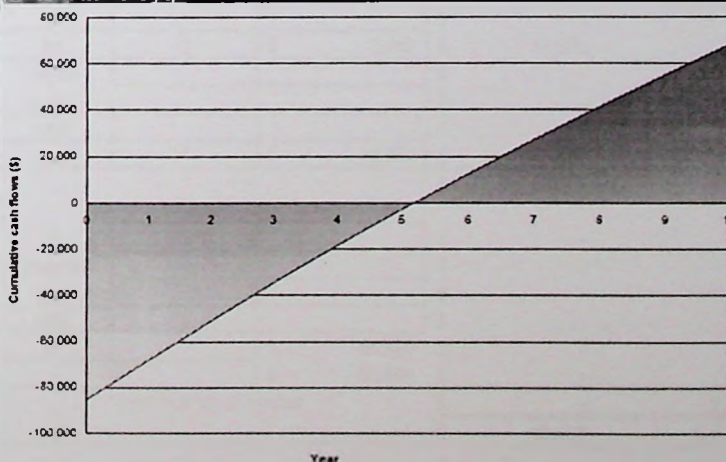
Yearly cash flows

Year #	Pre-tax \$	After-tax \$	Cumulative \$
0	-85,000	-85,000	-85,000
1	17,277	17,277	-67,723
2	16,906	16,906	-50,817
3	16,514	16,514	-34,303
4	16,101	16,101	-18,201
5	15,666	15,666	-2,535
6	15,207	15,207	12,672
7	14,724	14,724	27,396
8	14,214	14,214	41,610
9	13,677	13,677	55,287
10	13,111	13,111	68,398

Financial viability

Pre-tax IRR - equity	%	13.2%
Pre-tax IRR - assets	%	13.2%
After-tax IRR - equity	%	13.2%
After-tax IRR - assets	%	13.2%
Simple payback	yr	4.8
Equity payback	yr	5.2
Net Present Value (NPV)	\$	4,039
Annual life cycle savings	\$/yr	715
Benefit-Cost (B-C) ratio		1.05
Energy production cost	\$/MWh	372.54
GHG reduction cost	\$/tCO2	No reduction

Cumulative cash flows graph



Coffee husks as fuel

RETScreen Energy Model - Power project

Proposed case power system

Technology	Reciprocating engine			
Availability	%	25.0%	2,190 h	
Fuel selection method	Single fuel			
Fuel type	Coffee refuse			
Fuel rate	\$/h	67,000		
Reciprocating engine				
Power capacity	kW	34		
Electricity exported to grid	MWh	74		
Manufacturer	Parakash PVT. LTD			
Model				
Heat rate	kJ/kWh	12,729		
Fuel required	GJ/h	0.4	million Btu/h	0.41
			million Btu/h	0.00
Electricity export rate	\$/MWh	386.25	\$/kWh	0.010
			\$/kWh	0.386

Complete Cost Analysis sheet

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost			\$ -	
Subtotal:				\$ -	0.0%
Development					
Development	cost			\$ -	
Subtotal:				\$ -	0.0%
Engineering					
Engineering	cost			\$ -	
Subtotal:				\$ -	0.0%
Power system					
Reciprocating engine	kW	34.00	\$ 1,765	\$ 60,000	
Road construction	km			\$ -	
Transmission line	km	3	\$ 5,000	\$ 15,000	
Substation	project			\$ -	
Energy efficiency measures	project			\$ -	
User-defined	cost			\$ -	
Civil work	cost	1	\$ 10,000	\$ 10,000	
Subtotal:				\$ 85,000	100.0%
Balance of system & miscellaneous					
Spare parts	%			\$ -	
Transportation	project			\$ -	
Training & commissioning	p-d			\$ -	
User-defined	cost			\$ -	
Contingencies	%		\$ 85,000	\$ -	
Interest during construction			\$ 85,000	\$ -	
Subtotal:		Enter number of months		\$ -	0.0%
Total initial costs				\$ 85,000	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project	1	\$ 6,530	\$ 6,530
User-defined	cost			\$ -
Contingencies	%		\$ 6,530	\$ -
Subtotal:				\$ 6,530
Fuel cost - proposed case				
Coffee refuse	t	39	\$ 67,000	\$ 2,612
Subtotal:				\$ 2,612

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			\$ -
				\$ -
End of project life	cost			\$ -

Go to Emission Analysis sheet

Screen Emission Reduction Analysis - Power project

Emission Analysis

- ☒ Method 1
- ☐ Method 2
- ☐ Method 3

Base case electricity system (Baseline)

Country - region	GHG emission factor (excl. T&D)	T&D losses	GHG emission factor
	tCO2/MWh	%	tCO2/MWh
Uganda	All types	10.0%	0.000

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	74	0.000	0.0
Total	100.0%	74	0.000	0.0

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Coffee refuse	100.0%	263	0.007	1.9
Total	100.0%	263	0.007	1.9
Electricity exported to grid	MWh	74	T&D losses	0.0
				Total 1.9

Emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	0.0	1.9	-1.9		-1.9
Net annual GHG emission reduction	-1.9	tCO2	is equivalent to	-816.4	Litres of gasoline not consumed

Complete Financial Analysis sheet

RETScreen Financial Analysis - Power project

Financial parameters			Project costs and savings/income summary			Yearly cash flows				
General			Initial costs			Year	Pre-tax	After-tax	Cumulative	
Fuel cost escalation rate	%					#	\$	\$	\$	
Inflation rate	%	5.4%				0	-85,000	-85,000	-85,000	
Discount rate	%	12.0%				1	19,266	19,266	-65,734	
Project life	yr	10				2	18,894	18,894	-46,840	
			Power system	100.0%	\$	85,000	3	18,503	18,503	-28,337
						4	18,090	18,090	-10,247	
Finance						5	17,655	17,655	7,407	
Incentives and grants	\$					6	17,196	17,196	24,603	
Debt ratio	%					7	16,712	16,712	41,316	
			Balance of system & misc.	0.0%	\$	0	8	16,203	16,203	57,519
			Total initial costs	100.0%	\$	85,000	9	15,666	15,666	73,185
						10	15,100	15,100	88,284	

Appendix 6: Questionnaire

QUESTIONNAIRE

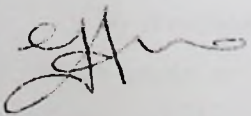
TECHNO-ECONOMIC VIABILITY OF HUSK POWER SYSTEMS APPLICATION IN UGANDA

Dear Sir/Madam,

This questionnaire is designed to gather data on viability of electricity generation from husks using a husk power system (HPS), a biomass gasification power project. The technology of HPS is based on the conversion of biomass such as rice husks into combustible gases that can run generators to produce electricity. Running on an environmentally friendly model, HPS ensures sustainable electricity to even the most remote parts of the country. The system consists of biomass preparation unit, biomass gasifier, gas cooling and cleaning system, internal combustion engine coupled with a generator and electricity distribution system.

The study is being undertaken in partial fulfillment of requirements for the award of Master's Degree in Renewable Energy of Makerere University. You have been selected as one of the participant in this study and I therefore seek your co-operation and honesty in responding to the questions in this questionnaire. There is no need to disclose your name. All information given will be treated with utmost confidentiality.

Yours Sincerely,



Turinayo Yonah K.

MSc. RENEWABLE ENERGY STUDENT (RESEARCHER)

Mob: 0782446704

0704939273

Email: t2rinayo@yahoo.com

QUESTIONNAIRE

AVAILABILITY OF HUSKS, WILLINGNESS TO ACCEPT, SUPPORT AND LOCAL INTEREST IN ADOPTION OF HUSK POWER SYSTEMS

A) Background

1. Address:

District

County

Sub-county

Parish

Village

Number of households in your village

2. Sex: Male ☐ Female ☐

3. Age: 15-20 years ☐ 20-30 years ☐ 30-40 years ☐
40-50 years ☐ above 50 years ☐

4. Highest completed level of education: Primary level ☐ O'level ☐ A'Level ☐
Diploma ☐ Bachelors ☐ Others (specify)

5. Duration you have been in this area: Less than one year ☐ 1-5 years ☐
5-10 years ☐ over 10 years ☐

6. Do you have electricity in your area? Yes ☐ No ☐

B) Availability of Husks

7. Which crop(s) do you receive for husk removal? (Please tick in a box)

Coffee ☐ Rice ☐ others, specify

8. How many crop growing seasons do you have? (Please tick in a box)

One ☐ two ☐ three ☐ throughout the year ☐

9. How many processing machines do you have in your village?

.....

10. Given reliable power supply and available crop for processing, how much crop do you process in kg/hour?
11. On average, how much crop(s) do you process considering all challenges faced in production
- Coffee:** kg/day;tones/day
 - Rice:** kg/day;tones/day
 - Others**kg/day;tones/day
12. On a scale that runs from 0 to 20, ie. 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, which means zero to 20hours of crop production by machines per day, using the above scale, by estimate, what is the daily average hour of crop production of your machines in a month throughout the year? Please indicate the daily average hours for each month bellow.
- January....., February....., Mach....., April....., May....., June....., July....., August....., September....., October....., November....., December.....
13. On average, how much husks do you generate
- Coffee:** kg/day;tones/day
 - Rice:** kg/day;tones/day
 - Others:**kg/day;tones/day
14. Where do you put your husks? (please tick in a box)
- Coffee:** dump ☐ sell ☐ burn in open air ☐
 - Rice:** dump ☐ sell ☐ burn in open air ☐
 - Others:** dump ☐ sell ☐ burn in open air ☐
- Others specify.
-
-
15. If selling, at what cost do you sell per unit mass/volume?
- Coffee husks..... Rice husks.....Others
16. Do you get any benefit from husks? Yes ☐ No ☐
17. What benefits do you get from husks?

.....

C) Willingness to support application of a Husk Power System (HPS) and current power demand

18. Supposing you had the capacity to support HPS in any way, would you be willing to do it?

Yes ☐ No ☐

If No, what hinders you from supporting HPS? Please explain

.....

If yes, what motivates you to support HPS? Please explain

.....

19. In your capacity to support Husk Power System, What are you willing to offer? Tick in a box or specify

i) Land for installation of power plant at a free cost (80x40ft) ☐

ii) husks at a free cost ☐

iii) Land and husks at a free cost ☐

iv) Land at a cost ☐

v) Husks at a cost ☐

vi) Land and husks at a cost ☐

vii) Nothing ☐

viii) Others specify.....

20. If land is offered at a cost, then how much money (Uganda shilling)?

21. If husks are supplied at a free cost, how much per day are you willing to supply?

.....

22. Supposing there is an opportunity to install and operate an HPS near your home of residence, would you be willing to accept? Yes ☐ No ☐
23. Basing on the information and understanding of importance of HPS, are you interested in adoption and operation of HPS in your area? Yes ☐ No ☐
24. What are your expectations from Husk Powered Systems application in your area?

25. What source of energy do you use to operate your milling machine(s)?
 Electricity ☐ Diesel ☐
 Others, specify.....
26. How much power do you consume per day? ElectricitykWh; Diesel
liters;
 Others, specify.....
27. What is the power rating (kW) of your milling machine(s)?
28. How much do you pay per kWh electricity?.....UGX/kWh

Appendix 7: Checklist

CHECKLIST

RESPONSE TOWARDS HPS DERIVED ELECTRICITY

A) Background

1. Address:

Name

District

County.....

Sub-county.....

Parish.....

Village.....

2. Sex: Male ☐ Female ☐

3. Age: 15-20 years ☐ 20-30 years ☐ 30-40 years ☐
40-50 years ☐ above 50 years ☐

4. Duration you have been in this area: Less than one year ☐ 1-5years ☐
5-10 years ☐ over 10 years ☐

5. What is your source of income? Tick in the box

i) Peasantry ☐

ii) Business ☐

iii) Teaching ☐

iv) Farming ☐

v) Private enterprise ☐

B) Power consumption

6. Are you connected to power generated by HPS? Yes ☐ No ☐

7. For how long have you been connected to power? Please tick in the box.

1month ☐ 2month ☐ 3month ☐ 4month ☐ 5month ☐ 6month ☐ 7month ☐

8month ☐ 9month ☐ 10month ☐ 11month ☐ 12month ☐

8. What does it take to have power connection?

.....
.....

9. How do you pay for the power consumed?

.....
.....

10. What do you use power for?

.....
.....
.....

11. How much money do you think you can afford to spend on power per month? Tick you choice.

i) 2,000 to 5,000/= ☐

ii) 5,000 to 10,000/= ☐

iii) 10,000 to 20,000/= ☐

iv) 20,000 to 30,000/= ☐

v) 30,000 to 50,000/= ☐

vi) 50,000 to 100,000 /= ☐

vii) Above 100,000/= ☐

12. What future plans do you have for electricity use?

.....
.....
.....
.....

13. Are you satisfied the way power is supplied to you? Yes ☐ No ☐

14. If No, what complaints do you have concerning power supply?

.....
.....

15. About how many households in your village have approached you requesting for power, in a radius of 1 km?

16. Have you experienced any problem (technical or social) that would require any attention? Yes ☐ No ☐

17. If yes, what problem could it be?

.....
.....

C) Significance of having power from HPS, and response from the community

18. How do you compare the current situation where you have electricity with the past situation without electricity?

.....
.....
.....

19. How would do you compare the current situation where you have electricity with the past situation without electricity?

.....
.....

20. How do you compare electricity from HPS with other energy sources which you have been using before?

.....

.....

21. Has electricity created any significant progress on your business? Yes ☐ No ☐

22. If yes, then how?

.....

.....

.....

23. Has anybody come to you showing interest in having power connection? Yes ☐

24. If yes, then how many? Please estimate the number

25. What advise do you give so as to improve on the services rendered by HPS?

.....

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