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A Study on Consumer Preferences to Adopt Domestic Biogas Digester Technology in Rwanda

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ABSTRACT

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Approximately 99.4% of households in Rwanda rely on traditional biomass energy for cooking in rural areas, particularly firewood, charcoal, and agricultural waste regardless of the negative implications on health, the environment, and the economy. To address these energy challenges, the government initiated multiple renewable programs to provide alternative clean and modern energy services for cooking. Biogas energy technology is a contender as a viable and affordable energy technology service that can meet rural energy demand for cooking because of its multiple benefits for health, the environment, and the economy, including the provision of a supply of slurry for agricultural production. Despite government efforts to underpin a biogas program by providing a flat subsidy of approximately 300,000RFW for the partial installation of a biogas digester to consumers, the penetration rate has remained extremely low at 1% since 2007. This raises the question whether the current biogas policies stimulate the adoption of biogas digester technology by consumers. To answer this question, the study investigated consumers' willingness to pay (WTP) for domestic biogas digester technology as a substitute for traditional biomass energy in rural areas using conjoint analysis and discrete choice models. The study conducted a conjoint survey on 250 rural households with 4,500 observations, and each household had at least three cows. The sample was selected from five districts with substantial cattle because cow dung is the main feedstock for biogas production. The study used a rank-ordered logit model to estimate consumer WTP for domestic biogas digester technology. The study used five attributes to develop 18 choice sets including the size of the biogas digester, cost, guarantee period, the service provider, and time saved after the application of the biogas digester.

The key findings show that household preference to adopt biogas digester technology increases with a sizeable biogas digester, with a low cost for the biogas digester, with an increase in household income, with a substantial guarantee period, and when the service provider is a private supplier. This study suggests that the government enhance awareness campaigns on the benefits of biogas digester technology. The study recommends the biogas financial subsidy reform to set up flexible funding policy based on consumer preference structure for biogas plant size, biogas standards, and a quality insurance framework with regular monitoring systems to formulate strong incentives such as tax subsidies, access to soft loans, and legal and regulatory frameworks that will motivate the private sector to invest in the biogas industry.

Keywords: Consumer preferences; Conjoint analysis; Discrete choice models; Domestic biogas technology; Willingness to pay; Rwanda.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

In most developing countries, traditional biomass energy (firewood, charcoal, agricultural waste) represents the prime source of energy for household cooking and lighting regardless of the health implications from the application of the energy source, particularly when used indoors (Karimu, 2015; WHO, 2009). Approximately 2.7 billion people, or 40% of the world's population, depend on biomass fuel for cooking, and approximately half of this number live in developing countries, particularly in Asia and Africa (IEA, 2014; Bonjeur et al., 2013).

The governments and relevant institutions set coherent policies to encourage households to shift to cleaner energy for cooking, such as biogas energy, liquefied petroleum gas (LPG), and electricity as sustainable solutions to the negative impact of traditional biogas energy use (Wisdom et al., 2011). Biogas energy is renewable, clean energy for cooking and lighting. Walekhwa et al. (2009) suggest that biogas technology is the most efficient tool and technology to diminish the combustion and degradation of fossil fuels and forest resources used for cooking and other purposes. Thus, biogas technology has been promoted by many developing countries including Africa, Asia, and South America as an instrument for climate change mitigation and to combat human health complications derived from the burning of biomass energy. In this context, there are several opportunities to promote the national domestic biogas programme (NDBP) in Rwanda. The most significant programme is the ‘One Cow per Poor Family programme. The government estimates that 315,000 households own substantial numbers of cattle, and at least 110,000 households meet the requirements to operate biogas plants (Dekelver et al., 2006) and to receive a 50% government subsidy for the initial costs of a biogas digester for households (UNEP, 2014).

Malik et al. (2014) define biogas production as the fermentation of organic wastes such as livestock manure, human waste, agricultural waste, and kitchen waste mixtures in a household anaerobic ferment digester. Brown et al. (2007) illustrate the significance of the decomposition of animal dung anaerobic process to household and entire populations citing the reduction of noxious fumes from animal dung, reduced health effects from indoor air pollution, greenhouse gas (GHGs) emissions reduction, and the provision of slurry as a form of fertiliser with rich P, N, and K nutrients that enrich soil fertility and boost agricultural productivity and food security.

The relationship between energy consumption and the environment, human health, and poverty requires that the factors that cause individuals to choose, adopt, or reject a particular energy source (Modi, 2005) are understood. Moreover, insights into the energy-related decision-making process at the household level are vital to build policies and technical interventions to effectively improve living standards, energy access, and energy security in developing countries (Micheal et al., 2015). Scholars have presented evidence of the factors that predominantly affect household willingness to adopt domestic biogas digesters as a substitute for biomass energy for cooking and lighting. For instance, Walekhwa et al., 2009) affirmed that socioeconomic factors such as household income, fuelwood and kerosene cost, land ownership, livestock practices, and land size have a significant effect on biogas technology adoption. Nkunzimana et al. (2013) found that, apart from socioeconomic factors, the availability of raw materials, financial and non-financial incentives, and awareness campaigns concerning the benefits of biogas technology, technical factors, political commitment, and institutional framework play a significant role in the sustainable development and adoption of biogas energy technology in rural areas.

1.2 Problem Statement

In Rwanda, as in many other developing countries, the energy balance is dominated by traditional biomass energy estimated at 85%. The remaining energy is provided by petroleum (11%), and electricity (4%) (MINIFRI, 2013). Approximately 99.4% of rural households in Rwanda use traditional biomass energy for cooking, which affects human health, depletes forests, causes a vicious circle of poverty, and augments GHG emissions (National Institute of Statistics of Rwanda (NISR), 2012). The total annual biomass energy consumption in Rwanda is estimated at 4,775 million tons, equivalent to 6,792,674 m^3, and the biomass energy supply is estimated at 2,905,520m^3, which indicates a deficit of biomass energy supply equivalent to 3,887,000 m^3 (Africa Energy Services Group, 2012). The increasing energy demand for cooking caused by population growth of 2.3% per annum puts substantial pressure on Rwanda's natural resource base resulting in a 7% rate of decline in forest area per year (Safari, 2010). The fuelwood use per household is estimated at 1.8 tons per annum; switching to charcoal would result in 3.5 tons of wood usage per household per annum, which indicates an increasing trend for wood energy demand (UNEP, 2015). According to UNDP and WHO (2009), approximately 1.94 million premature deaths in the world are reported every year as a result of indoor air pollution from solid fuel use, and a large portion of premature deaths are found in Southeast Asia and sub-Saharan Africa (SSA). Karima (2015) and UNEP (2015) also confirmed that women, children, and the elderly are the victims of indoor air pollution because household chores and cooking require exposure over long hours to smoke from biomass solid fuel leading to respiratory diseases. Traditionally, in Rwanda, women are responsible for cooking and other household activities including firewood and water collection. The household travels an average distance of 1.5 km per day to collect fuelwood for cooking (Huba & Paul, 2007), and survey results show that households travel an average of 8.4 hours per week to collect firewood for domestic cooking in rural areas of Rwanda (Table 5-2). Thus, women and children are the main victims of indoor air pollution leading to respiratory diseases, which are the second cause of death in Rwanda after malaria (Dekelver, 2005). The current trend of increasing energy demand and a decline in forest resources necessitates effective policies that provide alternative clean and renewable energy services to address these pressing energy problems.

The Rwandan government established a national domestic biogas program (NDBP) in 2007 that mandated the development of a policy and strategy for the implementation of a biogas energy sector and the distribution of biogas energy services. The program was particularly aimed at public institutions that consume large volumes of fuelwoods and charcoal for cooking such as prisons, boarding schools, military barracks, and rural households possessing livestock that can provide sufficient feedstocks for biogas generation. The implementation of the biogas program was executed by the Ministry of Infrastructure (MININFRA), assisted by SNV, the Netherlands Development Organization, and GIZ to disseminate domestic biogas digester technology and approximately 15,000 biogas plants in the whole country from 2007 to 2011 (SNV, 2006). Currently, over 4,600 households have been supplied with biogas digesters, and 76 institutional biogas digesters have been disseminated to boarding schools and prisons in the country by 41 domestic companies (MININFRA, 2015). Biogas energy technologies portray a limited penetration rate estimated at 1% since 2007, although the government provides a flat subsidy of 300,000RWF[1] for the initial cost of domestic biogas digesters regardless of the consumer preference structure for biogas plant size. This raises the question whether the current biogas energy policies stimulate biogas digester technology adoption in rural areas. To answer this question, this study investigated consumer willingness to pay (WTP) for domestic biogas digester technology as a substitute for traditional biomass energy (firewood, charcoal,

[1] Flat rate amount of 300,000RWF (US$417), based on the National Bank of Rwanda (BNR) exchange rate in October 2015, to supplement households in constructing a biogas digester.

and agricultural waste) in rural areas. Additionally, this study investigated socioeconomic factors that affect the adoption of biogas digester technology in rural areas. This study applied a conjoint analysis (CJ) and stated preferences method using a discrete choice model to study consumer preferences for the adoption of domestic biogas digester technology in Rwanda.

1.3 Purpose of the Dissertation

This study aims to investigate rural household WTP for domestic biogas digester technology as a substitute for traditional biomass energy (firewood, charcoal, and agricultural waste) for cooking. In this context, this study suggests policy recommendations to enhance the distribution and dissemination process for biogas digester technology and flexible funding policies that will attract new consumers and retain incumbent policies, particularly in developing countries, with a specific empirical study on Rwanda.

We use conjoint and discrete choice analysis to investigate the consumer's WTP for domestic biogas digester technology and identify appropriate pricing mechanisms with respect to the energy source's attributes, which include the size of the biogas digester, the installation cost, the period of guarantee in the purchase of a biogas digester, the supplier or service provider, and time saved as a result of the application of biogas digester technology for cooking and lighting.

The impact of demographic factors on consumer choice is also incorporated in this study to capture the influence of demographic variables on consumer utility and to identify groups categorised by income, education, age, marital status, and gender, which should be a priority for policy planning. Additionally, the impact of energy utilization behaviour on the adoption of domestic biogas digester technology is considered in this research. Implications from a combination of models provide appropriate policy suggestions considering consumer preferences for the adoption of domestic biogas digester technology in Rwanda.

No similar study, to the best of our knowledge, has been conducted to evaluate consumers' WTP for domestic biogas digester technology in developing countries using a conjoint survey and/or a discrete choice model, particularly for the case of Rwanda. Thus, this current study contributes significantly to the work of policy makers, academic scholars, the biogas industry, and donor agencies in designing a coherent framework for the dissemination of biogas energy technology and the promotion of renewable energy products for developing countries.

1.4 Outline of the Dissertation

This study is arranged as follows: Chapter 2 provides background information on Rwanda including an overview of the national energy sector, the electricity subsector, energy sector potential, current policies and legal framework, sustainable and efficient use of biomass energy, institutional and governance arrangements, and the transmission and distribution system. This chapter outlines the challenges that the energy sector faces, particularly with respect to the biogas subsector. The main research question is clarified and discussed.

Chapter 3 is composed of a review of previous literature that addresses biogas technology, its background, the factors influencing its adoption, and the benefits of biogas energy technology, such as its positive impact on health, the environment, and agricultural productivity. Chapter 4 discusses the methodology design of the study on consumer preferences for the adoption of domestic biogas digester technology in Rwanda. The consumers' behavioural model for the adoption of domestic biogas digester is defined and the methodological framework explained. This chapter presents the estimation procedure of the model setting and framework. WTP and the relative importance of the biogas technology attributes are also clarified. The CJ and stated preferences methods are also explained further in this chapter. Chapter 5 discusses the empirical study on consumer's WTP for rural domestic biogas digester technology. First, the chapter provides a general descriptive analysis and empirical results for CJ using discrete choice approaches to the adoption of biogas digester technology. The study reveals some findings and policy implications for the development of domestic biogas digester technology in Rwanda. The consistency of the model framework is discussed based on a combination of estimates from a rank-ordered logit and interacting demographics model. Based on these models, the main findings are clarified and discussed. Chapter 6, which is the final chapter, presents overall conclusions and policy implications resulting from the research findings. Appropriate policy options for the government of Rwanda are suggested to ensure increasing adoption of domestic biogas digester technology in rural areas and augment consumer satisfaction and confidence.

CHAPTER 2: COUNTRY CONTEXT

2.1 Introduction

Rwanda is a landlocked country situated in the heart of the African continent with borders to the north with Uganda, to the east with Tanzania, to the South with Burundi, and to the West with the Democratic Republic of Congo (DRC). According to the NISR (2012), the population density in Rwanda is 416 inhabitants per square kilometre, and the total population is 10.5 million based on the fourth population and housing census report. Additionally, approximately 73% of the population is engaged in agriculture, mainly subsistence farming, as their primary occupation. Rwanda's economy has been increasing annually at an average growth rate of 8.3% during the past 5 years (Ministry of Finance and Economic Planning (MINECOFIN), 2013). This economic growth has caused significant recent progress in the stabilization and reconstruction of the economy after the 1994 genocide against the Tutsi population in Rwanda. Currently, the government is targeting an annual economic growth rate of 11.5% for the second period of its economic development and poverty reduction strategy (EDPRSII) 2013 to 2017 (MINECOFIN, 2013). Moreover, this aspiration is defined based on the government's long-term economic development plan known as Vision 2020, which is aimed at uprooting extreme poverty and shifting Rwanda into middle-income country status with an estimated income per capita of US$1,200 by the year 2020. Progress has also been observed in access to education and health as well as gender equality, for which Rwanda tops the list as the country with the greatest number of women in parliament. Almost 64% of the seats were occupied by women in 2013, whereas women account for an average of only around 20% of parliamentary seats globally (Mukabera, 2015).

However, Rwanda, like many other SSA countries, confronts the major challenges of limited access to electricity and supply that results in constant load shedding. Kebede et al. (2010) state that the limited access to modern energy services hinders economic development. Rwanda has limited access to modern energy services with an equivalent of 16% of households connected to the national grid (NISR, 2012). Additionally, approximately 98% of households in Rwanda depend on traditional biomass energy, mainly for cooking, which depletes forests, causes environmental degradation, and creates health problems from indoor air pollution and economic stress. The per capita electricity consumption is one of the lowest in the world at approximately 26 kWh per person (CIA, 2014). Average per capita primary energy consumption in SSA is around 0.6 tonnes of oil equivalent. For Rwanda, it is only just over one-quarter of this level at approximately 0.17 toe per capita per annum, whereas industrialised country levels are 4.7 toe per capita per annum (Mpazimpaka, 2012).

2.2 Overview of the Energy Sector in Rwanda

The evolution of modern energy services began in the period of colonial rule by Belgium when the first Gisenyi micro hydropower plant was constructed in 1957 with a total installed generation capacity of 1.20MW. Another plant, Ntaruka, was constructed later in 1959 with an installed generation capacity of 11.25MW. Despite the contribution of energy use to the socioeconomic development of the country, modern energy services paved the way for a healthier investment climate and the enhanced wellbeing of the population. After the independence of Rwanda in 1961, there were limited efforts by subsequent governments to prioritise the energy sector as an engine for economic growth. Unfortunately, the first and second republic from 1961 to 1994 created additional installed generation capacity of 13.8MW from two hydropower plants (UNEP, 2015. The incumbent government, since the 1994 genocide against the Tutsi, has made considerable progress in prioritising the energy sector and lauding its contribution to socioeconomic development and foreign direct investment.

The current government has never achieved tangible results in addressing energy shortage, insecurity, unreliability, and unaffordability in Rwanda, which has represented a categorical key challenge for the investment and competitiveness of domestic infant industries in the global market. For instance, current electricity tariffs are relatively higher and heavily subsidised and cost estimates are $0.22 cents per kWh, which is higher in comparison to neighbouring countries and Africa in general (MININFRA, 2013). Such costs elicit higher production costs for businesses affecting trade competitiveness on a global scale. For example, the mining industry is constrained by a lack of access to affordable modern energy services, and other potential investment projects are never implemented because of higher energy costs that render projects economically unfeasible. Moreover, unstable power supply conditions and frequency load shedding also induce unexpected losses for manufacturing industries. For example, during industrial processing, power cuts lead to the unnecessary wastage of materials, such as dyes used in textile manufacturing and metals heated down in certain industries. This barrier is crucial in the manufacturing, mining, and agro-processing sectors, which is highly relevant for Rwanda.

The primary energy balance is dominated by biomass energy (85%) that is mainly used for cooking, electricity (4%), and petroleum (11%), mainly used for transport. Each energy source plays a significant role in socioeconomic development and poverty reduction (See Figure 2-1).

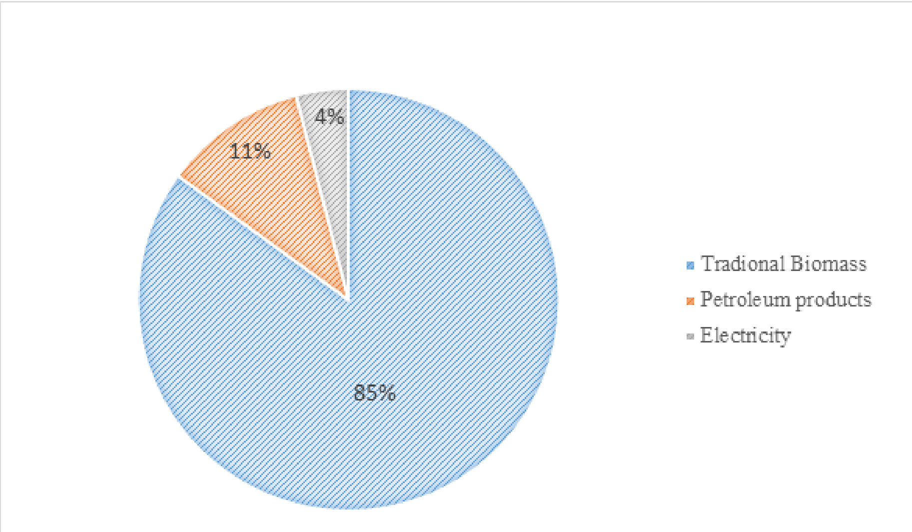

Figure 2-1: Primary energy balance in Rwanda

Source: MININFRA, 2013

Biomass energy consumption continues to lead as the primary source of energy for cooking in Rwanda. More than 98% of households use biomass energy for cooking; 82.2% is from firewood, 13.2% is from charcoal, and 2.7% is from agricultural waste (NISR, 2012). Biomass energy demand will continue to increase if no measures are undertaken because the annual population growth of 2.3% will bring additional energy demand for cooking. This demand will ultimately have negative implications for the environment and human health from indoor air pollution (Figure 2-2). Thus, forest depletion from charcoal harvesting and firewood collection will eventually pressure Rwandans to turn to renewable and modern energy services for domestic cooking and lighting. The government envisages reducing the reliance on traditional biomass energy use from 85% to 55% by 2018 by enriching the supply of LPG, modern peat briquetting, natural gas, and biogas energy, particularly for people with cattle who can provide sufficient feedstock for biogas production along with improved wood fuel cook stoves (MININFRA, 2013).

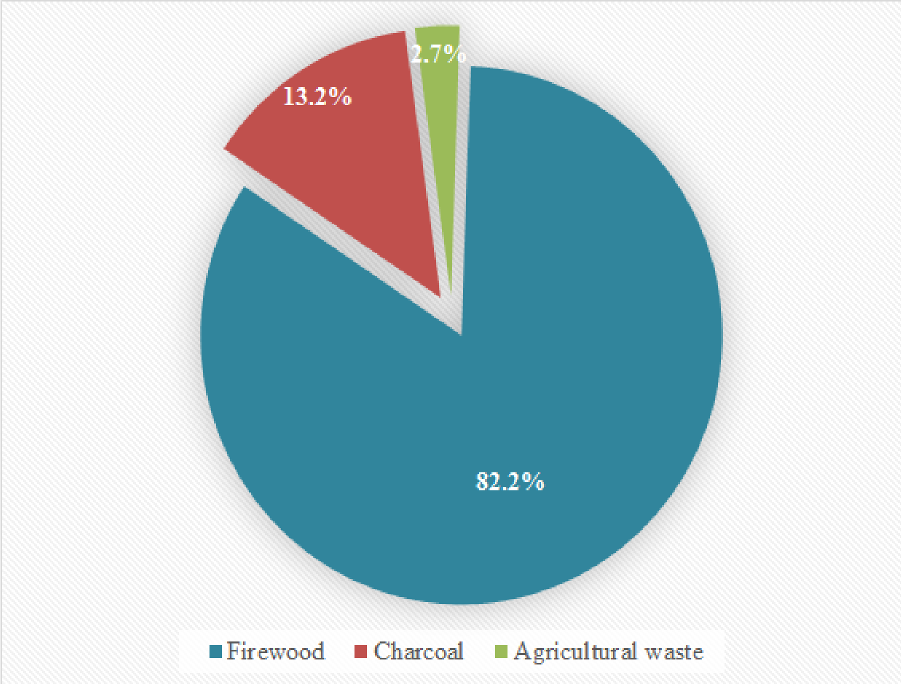

Figure 2-2: Traditional use of biomass energy for household cooking

Source: NISR, 2012

In Rwanda, the energy source for household cooking varies according to the area of residence. For instance, urban area households use more charcoal (63.2%) than rural areas (2.9%). In rural areas, a large number of households use firewood as a primary source of energy for cooking (93.3%) compared to urban households (31.7%) while agricultural waste and other grasses used for cooking in rural areas are 3.2% and 0.6%, respectively (See Figure 2-3).

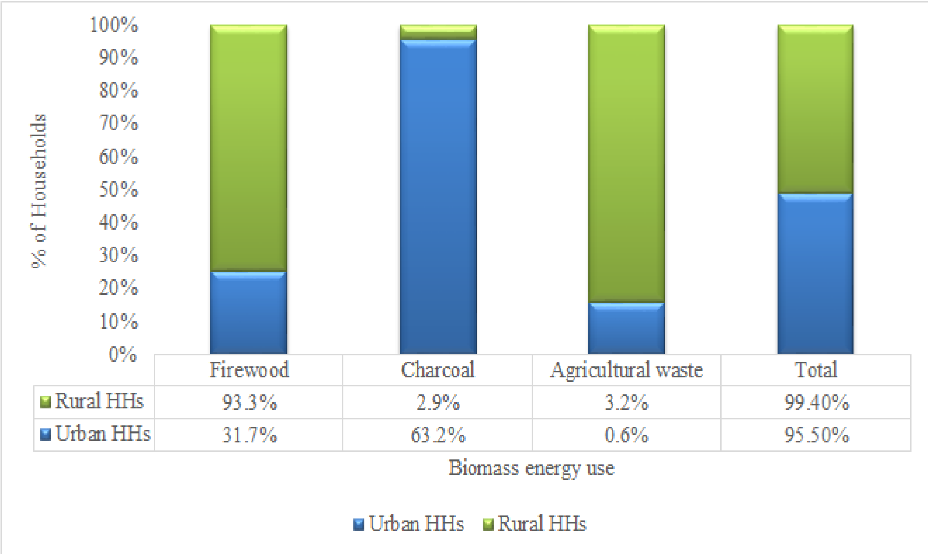

Figure 2-3: Household energy sources for cooking by residence

Source: NISR, 2012

Net energy consumption by sector in Rwanda is dominated by the residential sector, which represents approximately 91% of energy demand. The transportation sector represents around 4% of demand, the industrial sector 3%, and services 2% (Figure 2-4). The dominance of the residential sector mostly leads to high peak load that commonly occurs between 6:00 pm and 9:00 pm from the use of domestic electrical appliances such as TVs, radios, refrigerators, microwaves, freezers, electronic water cooking devices, computers, and irons.

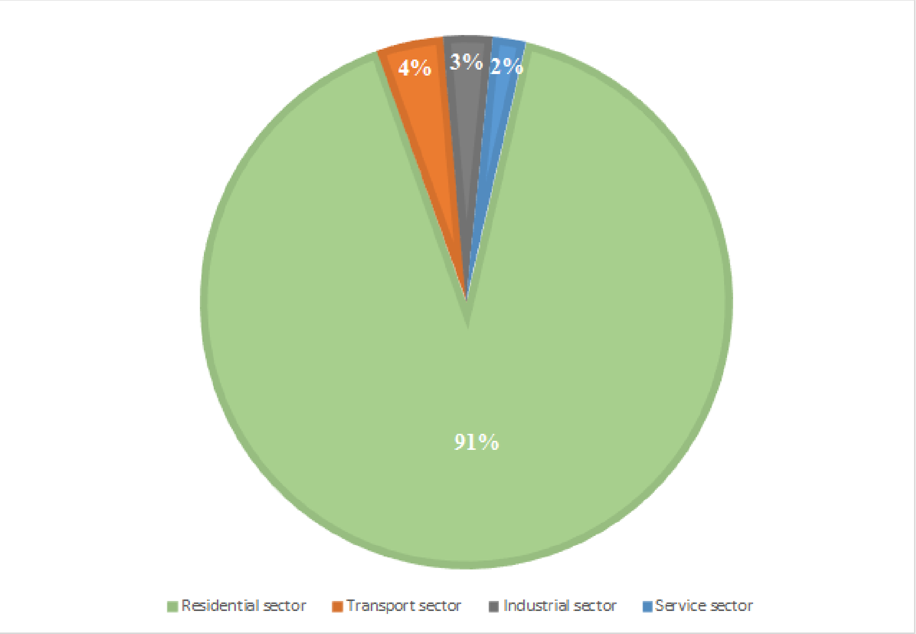

Figure 2-4: Net energy consumption by sector in Rwanda

Source: MININFRA, 2007

2.3 Electricity Subsector

Rwanda has strived to enrich electricity supply to confront increasing energy demand and national economic growth. Providing cost effective electricity is a mandate for the energy utility agency and MININFRA that collaborates with the energy sector to ensure affordable and reliable energy services to promote the business environment, economic development, and poverty reduction. The Rwanda energy mix has long been dominated by the hydropower energy source, which is fragile because of its dependence on climate change. For example, hydropower fragility was apparent in 2004 when the Ntaruka River was affected by a prolonged drought that hampered overall electricity supply by 50%. This severe shortage directly damaged industrial performance and entire macroeconomic variables because of frequency load shedding.

The power crisis stalled the diversification of energy sources and backup solutions were used such as power supply from diesel generators, which ultimately prompted high generation costs ranging between US$0.20 to US$0.30 per kWh. Emergency power supply is now a considerable percentage of GDP, but a better solution for the government than none at all. This measure was supported by the additional emergency of diesel generation from AGGRECO thermal power in 2004 (MININFRA, 2013). Hence, the power tariff in Rwanda remains the highest in the region and affects both domestic manufacturing industries, discouraging foreign direct investment and hampering economic development.

The average electricity tariff in SSA is approximately US$0.12 per kWh, which is considered expensive by international standards and is about twice the tariff in other parts of the developing world. The tariff is almost as high as that of high-income OECD countries and approximately half the power tariff in Rwanda (Briceño-Garmendia, 2010). The average electricity generation cost in Rwanda is expensive for several reasons including the landlocked nature of the nation that renders petroleum products expensive, a high dependence on diesel generation mix that accounts for over 40% of electricity generation, a lack of skilled personnel in the energy field, and high technology dependence. Diesel fuel imported from abroad is characterised by fragile, unstable, and unpredictable prices, which induce high end-user tariffs. For example, average electricity production is estimated at 210RFW/kWh, and it is purchased at 155.76RFW/kWh including value added tax while the remaining portion is subsidised by the government (Mpazimpaka, 2012)

Table 2-1: Electricity tariff from 1 July 2012 (excluding VAT 18%)

Service	**Period**	**Cost per KWH (RFW)**
Industry	Off-peak hours (23:00-07:00	96RFW/kWh
	Mid-peak hours (07:00-17:00)	126RFW/kWh
	Peak hours (17:00-23:00)	168RFW/kWh
Ordinary Consumption	Any time	134RFW/kWh

Source: RDB, 2015

The government envisages restructuring the electricity tariff and phasing out the subsidies and diesel generation in the overall energy mix. The government plans to diversify power with indigenous energy sources such as natural gas from Kivu Lake, geothermal energy, renewable energy, and peat to power by 2018 and to enhance regional interconnection to enable the import of cheap electricity from neighbouring countries. This strategy should maintain a regional competitive tariff to allow the local manufacturing industry to compete in the global market (See Figure 2-5).

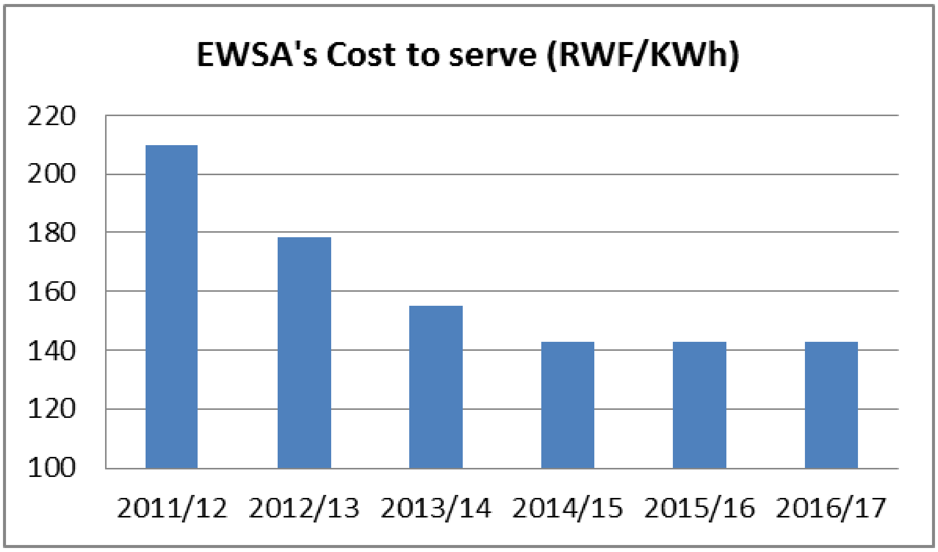

Figure 2-5: Rwanda utility plans to decrease generation cost

Source: MININFRA, 2013

The World Bank (2012) indicates that a lack of a reliable power supply in Rwanda will cause manufacturing enterprises to experience power outages that will result in significant losses to the total sales revenue of business operators estimated at more than 20%. An unstable power supply that damages manufacturing equipment or fire accidents that burn business assets particularly affect small businesses with no backup solution. For instance, during the years 2007 and 2008, Rwanda ranked tenth in a list of SSA countries with frequent power outages with an average of approximately 80 days per year (See Figure 2-6) compared to 56 days per year for other SSA countries. Thus, Rwanda's power outages suggest an unreliable power supply that constitutes a loss of more than 6% of GDP (World Bank, 2008).

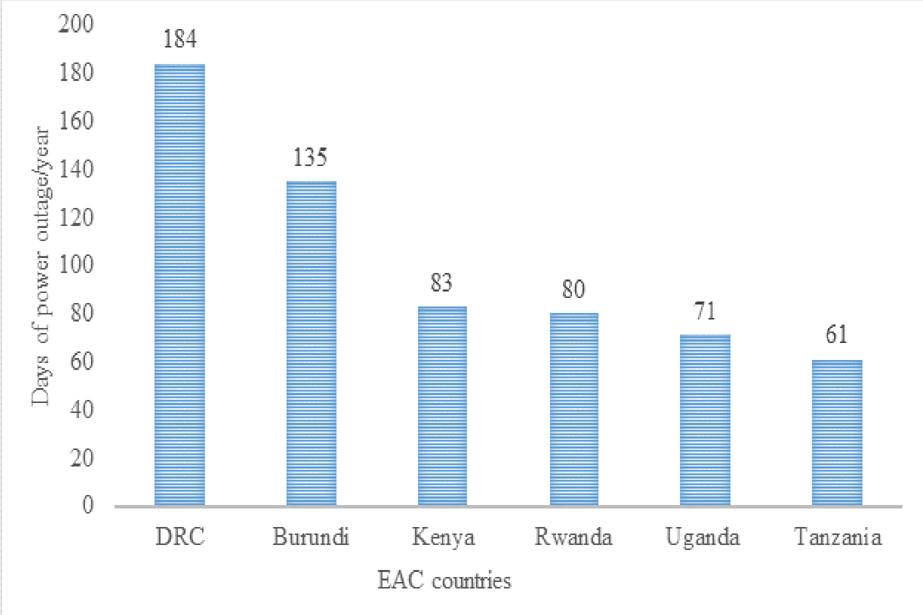

Figure 2-6: Days of power outage per year in EAC members and DRC

Source: World Bank, 2008

Rwanda's access to electricity is still low with 16% of households connected to the national grid (NISR, 2012). However, Rwanda has attained impressive progress over the last five years, and access to electricity increased from 110,000 to 497,346 households with grid connection (Figure 2-7). Great effort is required to obtain EDPRSII targets of 70% household access to electricity in both rural and urban areas. Grid connection to electricity supply is pledged to domestic industries and large commercial facilities that require stable and high voltage to run machinery at low cost. Connection to the national grid requires a significant amount of capital investment and payment. Based on MININFRA, 2013), computation of household consumption patterns estimates were 130kWh per month to fund financing costs verses current household electricity consumption estimated at 26kWh per month. In Africa, the average electrification level is estimated to be 40% and 31% in SSA (IEA, 2010). The electrification rate in Rwanda is still below the average for SSA countries, but the government envisages attaining 70% access to electricity through on-grid and off-grid solutions by 2018. At the same time, the government pledges additional generation capacity of 563MW from 110.8MW (EDPRSII, 2013). However, this ambitious target seems unrealistic considering the lack of funding sources and implementation framework.

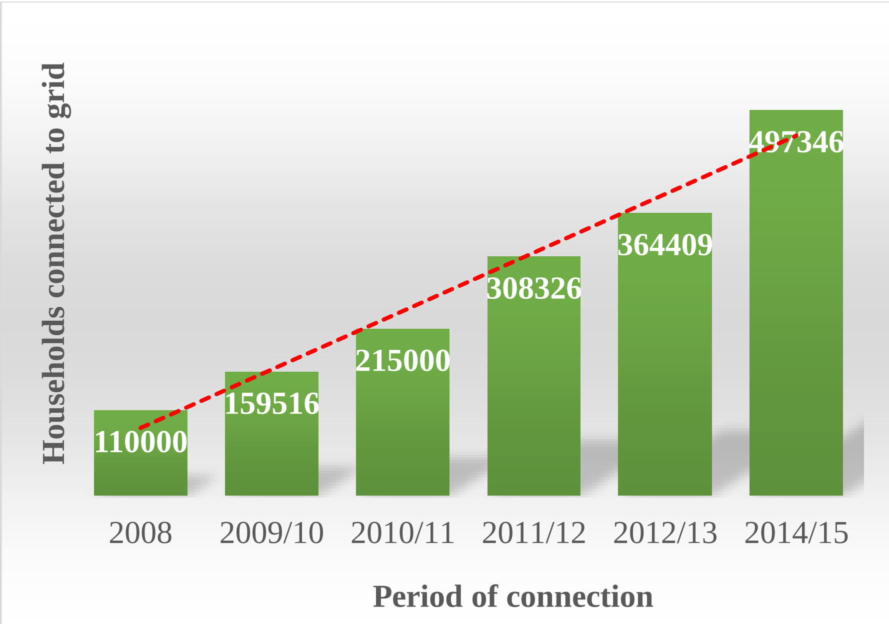

Figure 2-7: National electricity grid trends for connected households

Source: MININFRA, 2013

2.4 Energy Potential in Rwanda

Rwanda has a variety of natural resources including renewable and non-renewable sources of energy. A large portion of these resources is untapped because of the nation's limited financial and technological capacity. Currently, few resources are used for power generation on a small scale. For instance, the country has substantial hydro potential, natural gas in Kivu, geothermal potential in the northern and western regions, solar energy, biomass energy, and wind energy, but all remain untapped.

2.4.1 Hydropower Energy

Hydropower energy used to be the sole source of power generation from the 1950s to the 1990s, and it is still a dominant source of power supply accounting for more than 60% of power to date. However, it is affected by climate change (MININFRA, 2015). In 2004, the Ntaruka River and other associated rivers were affected by a prolonged drought that elicited under-capacity hydropower generation; hence, the country suffered a power crisis. Based on the hydropower Atlas project, 333 small hydro sites can generate enormous amounts of energy for the country to meet medium-term government aspirations and contribute an additional 563MW to the national grid (MINIFRA, 2013). Mini and micro hydropower operations are either developed or financed by government and private investors under the umbrella of an independent power producers' framework through on-grid and off-grid support of rural access to electricity. However, grid connection is costly because of geographical constraints and isolated rural settlements.

2.4.2 Geothermal Energy

Geothermal energy also has potential as a resource for power generation and is estimated to generate more than 720MW considering current prospective geothermal areas. These areas are located in the volcanic area of the Northern Province and the hot springs in the Western Province. The areas are associated with East African rift valley faults based on reconnaissance surface studies undertaken to explore Rwanda's resource potentials (Rancon, 1983; Chevron, 2006; BGR, 2009; KenGen, 2012). Apart from power generation from geothermal energy, geothermal energy also serves multiple purposes such as direct use of hot springs and spas for leisure, agriculture in greenhouses and soil warming, aquaculture, residential and district heating, and industrial application requiring heat as well as Combined heat and Power (CHP) applications (IPPC, 2012).

2.4.3 Solar Energy

Currently, Rwanda has a remarkable solar PV project in the East Africa community states with a total generation capacity of 8.5MW in the Eastern Province, Rwamagana district, and approximately 15,000 households benefit from this project (Rwanda Energy Group, 2015). Solar energy has an average potential of 5kWh/M^2/day. The application of solar energy technologies such as solar photovoltaic, solar thermal, and concentrating solar power (CSP) can significantly contribute to an increase in electricity supply and expedite access to electricity through off-grid solutions, particularly in remote areas where grid connection is economically unviable.

2.4.4 Natural Gas Energy

Rwanda has potential for natural gas from Lake Kivu, which is estimated to have generated over 700MW in 55 years shared equally with the DRC. The methane gas will be used to generate electricity, gas to liquid fuels, and possibly fertiliser production to boost agricultural productivity (MININFRA, 2007). Currently, pilot plants generate electricity, for example, Rwanda Energy Company KP1 has a pilot plant that generates 3.6MW, and another pilot plant commissioned in 2007 by the government has an installed generation capacity of 1.5MW (Rwanda Energy Group, 2015). There are several other energy projects underway for power generation such as Kivu Watt, envisaged to commission 25MW at the end of t2015.

2.4.5 Peat Energy

According to the Ministry of public works and energy (1993), peat reserves are estimated at 155 million dry tons spread over an area of 50,000 hectares. These reserves can generate power with energy peat content of around 10.5MJ/kg. Based on theoretical potential, peat energy potential for power generation is estimated to be 1,200MW, and Rwabusoro marshland around Akanyaru River can generate approximately 450MW of electricity for more than 25 years. The biggest energy project in Rwanda is under construction for a peat-to-power project in Southern Akanyaru with a generation capacity of 120MW to be delivered in segments. For phase I, 80MW is to be commissioned at the end of 2016; for phase II, 40MW is to be commissioned by 2020. Another EPC peat-to-power project is Gishoma, for which 15MW is envisaged to be commissioned by the end of 2015 in the Western Province, and a 100MW peat project in Northern Akanyaru is in the final negotiation phase and is anticipated to contribute to additional generation capacity of 563MW by 2017 (MININFRA, 2013). However, no detailed study provides an overall picture of peat resources in Rwanda; thus, detailed study is recommended to offer scientific evidence of the nation's peat resources. Additionally, peat resource areas are wetlands, and the negative environmental impact of peat extraction can outweigh the benefits of its energy use. Therefore, proper environmental impact assessment must be carefully conducted before extracting peat resources.

2.5 Sustainable and Efficient use of Biomass Energy

Biomass energy is a vast source of primary energy used for cooking, approximately 85% is in the form of firewood, charcoal, and agricultural waste in Rwanda (MININFRA, 2013). For instance, over 98% of households use traditional biomass energy as their prime source of energy for domestic cooking (NISR, 2012), and 99.5% of rural households use traditional biomass energy as the main source of energy for cooking (Africa Energy Services Group, 2012). In a survey by the Africa Energy Services Group, 2012 estimates of the annual biomass energy demand for Rwanda was around 4,775 million tons, equivalent to 6,792,674 m^3. The study suggests that there is a deficit of biomass energy supply estimated at 3,887,000 m^3 considering the available biomass supply estimated at 2,905,520m^3. The UNEP (2014) found that fuelwood use per household is estimated to be 1.8 tons per annum; switching to charcoal would result in 3.5 tons of wood usage per household per annum, which indicates an increasing trend for wood energy demand. Considering the current trends in population growth, socioeconomic development, and forest resource depletion, efficient and prudent policies and a regulatory framework to provide a sustainable solution to this pressing issue in the Rwandan energy sector are required.

The government envisages reducing the high dependence on biomass energy for cooking to 55% by 2018 (MINECOFIN, 2013) to mitigate the negative impact on human health from indoor air pollution and climate change. Consistent with the framework, the government established the National Domestic Biogas Program (NDBP) in 2007 to disseminate biogas energy and improve cook stove technologies with financial and technical support provided by SNV (a Netherlands development program) and GIZ. The program developed a commercial and sustainable domestic biogas sector substituting firewood with biogas for cooking and increasing agricultural production through the provision of bio slurry as a fertiliser (Dekelver et al., 2006).

Currently, over 4,600 households have domestic biogas digesters, and 76 institutional biogas digesters have been disseminated in boarding schools and prisons by 41 domestic companies (MININFRA, 2015). The institutional biogas programme has provided biogas fuel to schools and prisons with the result that 10 out of 14 prisons in Rwanda use biogas as a substitute for firewood for cooking. Overall firewood consumption and expenditure has been reduced by 50% as a result (Mpazimpaka, 2013).

The capital costs for domestic biogas digester installation varies according to the size and technology and are shared between the client and the government through a flat subsidy of 300,000RWF (MININFRA, 2013). The cost of each biogas technology varies primarily depending on the size and material inputs used in the construction of the domestic biogas digester. For example, fixed dome biogas technology is a common form of biogas technology used in Rwanda. The common size of the biogas digester used is 4 m^3, 6 m^3, 8 $m^{3,}$ and 10$m^{3,}$ and it is mainly used for domestic cooking and lighting. However, the biogas sector has not yielded practical tangible output based on expected results, and the pace of the technology adoption by households remains low at approximately 1% despite financial and non-financial incentives dedicated to the programme.

The government also promotes the use of improved cooking stoves (ICS) technology to enhance environmental management to reflect efficient and renewable energy use. The efficiency of ICS is estimated to range between18% to 37%, and an average of 73% of rural households use improved cooking stoves in Rwanda (Africa Energy Services Group, 2012). Moreover, ICS can reduce the quantity of firewood consumed to an estimated 60%, and CO2 emissions by 70% (Achim Steiner, cited in Africa Energy Services Group, 2012).

There is an exploitable opportunity for waste to generate electricity to enable proper management of landfill waste. However, the country suffers from an energy supply deficit although this field remains untapped with huge potential for development. According to a UNEP study (2014), the capital city Kigali supplies approximately 450 tons of solid waste each day, and 300 to 350 tons are collected from households by authorised companies. Kieron (2013) found that biomass potential in Rwanda can supply power estimated at 20MW using small-scale plant facilities. Figure 2-8 indicates the composition of waste disposal in the Nyanza landfill in 2012.

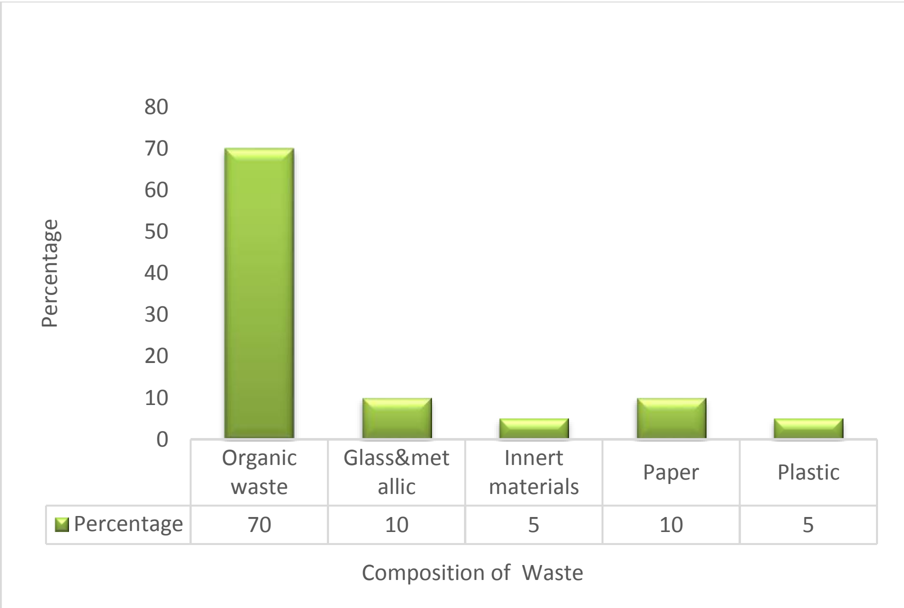

Figure 2-8: Composition of waste in Nyanza landfill in Kigali City

Source: UNEP, 2014

The population of Rwanda is projected to increase by 2.3% per annum, which will significantly increase energy demand, particularly the demand for traditional biomass energy (NISR, 2012). The inefficient use of traditional biomass energy for cooking in open stoves affects human health and causes respiratory disease from indoor air pollution. Each year, globally, over four million people die prematurely from diseases attributable to household air pollution from the use of traditional biomass energy for cooking, and the majority of victims reside in developing countries (WHO, 2014). The affordability of domestic biogas digesters by households remains a paramount obstacle to the technology's adoption, and a lack of a coherent funding policy and regulatory framework for biogas energy technology supply as a substitute for traditional biomass energy for cooking undermines biogas energy technology adoption in Rwanda.

2.6 Policy and Legal Framework of the Energy Sector

The policy framework presents the current policies in the energy sector and their main purpose in resolving the energy challenges and is outlined as follows.

2.6.1 National Energy Policy

Recently, the Cabinet approved the first national energy policy in March 2015 addressing the key energy challenges that are indicated in the energy policy such as integrated energy planning across economic sectors, the development of indigenous resources to ensure energy security, energy efficiency and conservation for energy demand management, energy pricing and subsidy policies to ensure a stable and affordable energy supply, a regulatory framework, energy sector governance, capacity building, private engagement in the energy sector, and a financing mechanism for the energy sector.

Additionally, an energy sector strategic plan was endorsed simultaneously with the national energy policy by the Cabinet in March 2015.

2.6.2 Electricity Law

The electricity law was enacted by Law No 21/2011 of 23/06/2011 governing electricity in Rwanda. The main objective of this law is to govern electric power production, transmission, distribution and trading activities within or outside the national territory of Rwanda (RURA, 2015).

2.6.3 Rwanda Renewable Energy Feed-in-tariff Regulation

The renewable energy feed-in tariff (FIT) regulation was initially issued in February 2012 and revised in 2015 by regulators. The tariff determines the applicable FIT for small and mini hydropower plants. This regulation is applied to any investor who wishes to construct and operate a hydropower plant with a minimum capacity of 50kW and a maximum range of 10MW. There is a plan to extend FIT to other energy technologies but, currently, the regulator sets the price range and concession agreements and power purchase agreements are negotiated with MININFRA, the Rwanda Development Board (RDB), and the Energy, Water, and Sanitation Authority (EWSA) respectively.

2.6.4 Biomass Energy Strategy

The biomass strategy was developed in 2008 with specific scope that mainly focuses on sustainable wood supply, particularly for charcoal consumption.

Although the biomass strategy was not sufficient to address the key energy challenges in the biomass sector including biomass consumption in rural areas, there are no specific policies or an updated biomass energy strategy. However, a substantial portion of the population depends on biomass energy for cooking in Rwanda.

2.7 Institutional and Governance Arrangements

The Rwanda energy sector is monopolised by a publicly owned single utility company responsible for the generation, transmission, and distribution of electricity to consumers known as EWSA. However, the government commenced the restructuring process of the energy sector by separating utility from electricity generation and development, water, and sanitation. This body is also responsible for the implementation of energy sector strategic plans and the operation and maintenance of energy infrastructures to ensure reliability, affordability, and a quality power supply to all residents. MININFRA is primarily responsible for formulating overall policy and strategy, monitoring and evaluating energy projects, setting the legal and regulatory framework, and coordinating the development of the energy sector. The RDB also coordinates investment activities in the energy sector and facilitates investment by showcasing investment opportunities including incentives, subsidies, and the tax exemption policy framework, whereas the Rwanda Utilities Regulatory Authority (RURA) is mandated to regulate electricity from renewable and non-renewable energy, industrial gases, pipeline and storage facilities among other public regulated utilities by law N° 09/2013 0f 01/03/2013 establishing RURA.

Following this mandate, the agency is responsible for promoting competition, advising the government during the formulation of energy policy, protecting consumers, educating stakeholders, approving contractual undertakings with regard to the distribution and transmission of electricity and gas, and assessing the tariff structure to protect consumers.

2.8 Transmission and Distribution System

In Rwanda, aged transmission lines are the main obstacle that provoke increasing technical losses estimated over 20% compared to the international target of 10% to 12%. A EWSA 2013 indicated that the pace of system loss is a result of the old transmission network. This study analyses electricity loss in the generation, transmission, and distribution systems and provides recommendations for medium to long-term loss reduction strategies. The strategies highlight the cost and benefits of different proposed loss reduction measures. However, it is pointless to increase electricity generation capacity without efficient transmission lines to supply power to end users. Doing so will perpetuate system losses that constrain electricity supply and affect the financial performance of power utility (Figures 2-9 and 2-10):

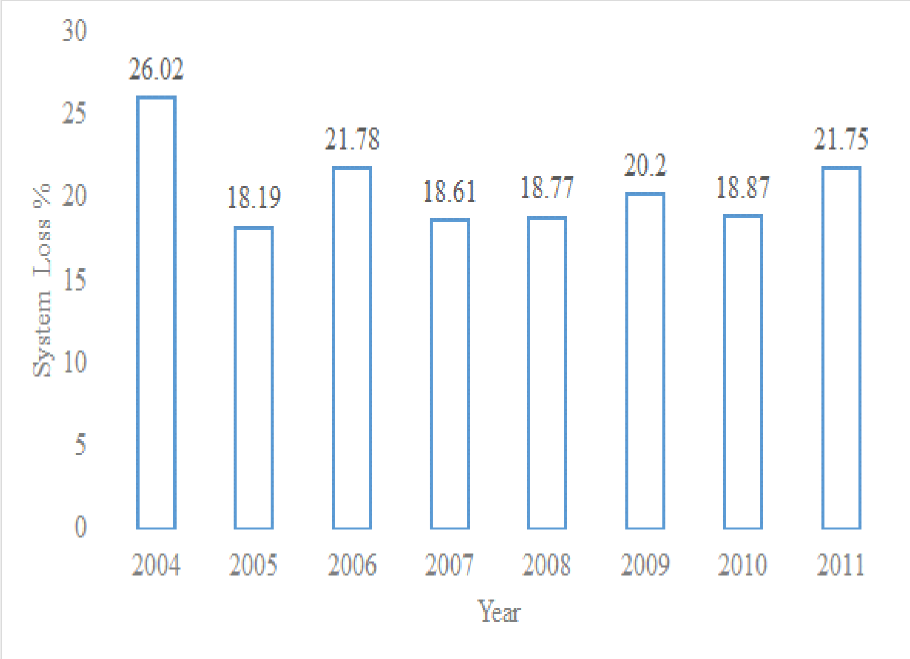

Figure 2-9: System losses 2004 to 2011

Source: EWSA, 2013

The EWSA Grid audit report (2013) found that enormous losses are observed in lower voltage commercial lines estimated at 33.5 GWh of losses. This is followed by lower voltage transmission lines at 27.9 GWh losses, and MVD estimated at 17.5GWh losses (Figure 2-10).

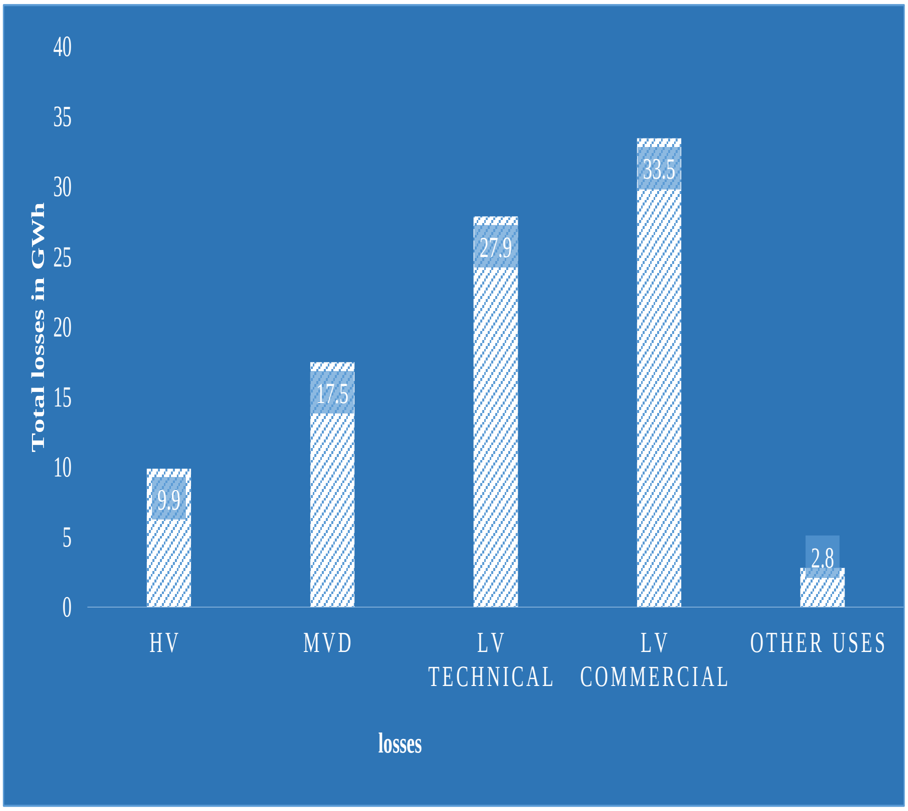

Figure 2-10: Total losses in GWh in 2013

Source: EWSA grid audit report, 2013

CHAPTER 3: PREVIOUS STUDIES AND LITERATURE REVIEW

3.1 Background of Biogas Technology

The first small-scale biogas plants for the digestion of animal manure were constructed in Germany in the mid-18th century. While the first biogas digester in China was constructed in 1920 and invented by Guorui Luo with the purpose of decreasing the use of imported oil for cooking and lighting. Biogas production is the result of the fermentation of different feed stocks including animal manure, human waste, agricultural waste, and industrial and municipal organic waste through a household anaerobic digester (Marlies et al., 2015). In the domestic biogas digester, organic input material (feed stock) is anaerobically decomposed in airtight digester tanks to produce biogas, a mixture formed composed of 50 to 70% methane (CH4), 30 to 40% carbon dioxide (CO2), and a small portion of other gases (SNV, 2011; Hessami et al., 1996). Moreover, the calorific value of biogas is 21 to 24 MJ/M^3 equivalent to around 6 kWh/m^3 (Bond & Michael, 2011), which corresponds to approximately half a litre of diesel oil, and a conventional biogas stove has an efficiency of 50% to 60%. Anaerobic (biogas) digesters are designed to operate in mesophilic (20 to 40 °C) temperature zones.

Biogas is one of the most renewable energy technologies attracting significant private and public support because of its benefits compared to other sources of energy, particularly addressing the issue of domestic energy demand for cooking (Walekhwa, 2009). Biogas digesters provide a clean, efficient, and renewable source of energy and can substitute for other forms of fuels for energy saving. Biogas digesters provide human health benefits and environmental protection in rural areas that predominantly use traditional biomass as the main source of energy for cooking and heating in developing countries. A domestic biogas digester can improve indoor air quality and reduce the need to collect firewood, agricultural waste, or purchase charcoal for domestic cooking. The technology provides organic slurry or bio slurry rich in nutrients that improves crop production and increases the organic matter content of the soil and reduces the need for chemical fertilisers (Smith, 2014). Therefore, investing in a small-scale biogas digester could reduce household expenditure on traditional forms of biomass energy, health, and fertilisers and augment the standards of living of rural households by providing additional time for income-generating activities that can send SSA children to school. Although biogas energy has been used for cooking and lighting in developing countries, the appliances used for cooking were tested in SSA and were considered low efficiency because the stoves were designed without adhering to basic gas stove theory (Tumwesige et al., 2014). The strong commitment of the government and state institutions to biogas promotion is vital for its success in developing countries. Some countries in Asia attained remarkable success in biogas energy supply, particularly in rural areas and in replacing traditional biomass energy for cooking and lighting as a medium-term strategy to address the urgency of energy deficit (Aggarwal 2003; GTZ, 1999; Silwal, 1999).

Intensive use of biogas energy will augment sanitation systems, provide clean energy, reduce GHG emissions, enhance the supply of organic fertilisers, and create employment in rural areas that suffer from energy imbalance, particularly for cooking

Daxiong et al. (1990) undertook a study on the microeconomic analysis of 58 biogas plants in Tongliang compared with 242 plants in Hubei. The results illustrate that there is a high rate of return on investment in biogas digester technology and a short payback period of fewer than four years. The study also suggested that in the subsequent period, the number of constructed new biogas digesters per year has declined tremendously as a result of the phasing out of subsidies. Chen et al. (2010) examined the opportunities and constraints for household biogas use in rural China and found that the opportunities include a reduction in rural energy deficits, sufficient feedstock for biogas production, national financial subsidies, and legal and international clean development mechanism support. However, some constraints exist such as limited awareness campaigns concerning the benefits of biogas in rural areas and insufficient monitoring frameworks and management of biogas plants.

3.2 Factors Influencing the Adoption of Biogas Digester Technology

There are various theoretical backgrounds concerning the adoption of biogas digester technology that are applied to many countries. The adoption of small-scale biogas digester technology has been constrained by various factors in SSA. Mwarigi et al. (2014) examined the socioeconomic constraints to the adoption of small-scale biogas digesters in SSA. The evidence shows that socioeconomic factors play a significant role in the failure to adopt biogas digester technology in SSA compared to Asian countries. The authors suggest remedies to these constraints that include high initial construction costs, limited internal and external funding mobilization, credit funding policies, a lack of standardization of proven technologies, and a lack of public awareness campaigns and the promotion of biogas digesters as an integrated system for both biogas and bio slurry production. Walekhwa. (2009) assessed in depth the factors affecting the adoption of biogas energy characterised by technical, economic, and socio-cultural obstacles in Uganda. The empirical evidence suggests that the likelihood of a household adopting biogas technology increases with the decreasing age of the head of household, increasing household income, increasing number of cattle owned, increasing household size, a male head of household, and increasing cost of traditional fuels. To overcome these constraints, the study recommends educational and awareness campaigns of the benefits of biogas, the provision of financial and non-financial incentives to households, and the establishment of an institutional framework.

Bettina et al. (2007) examined the impact of single versus multiple policy options on the economic feasibility of small-scale biogas (anaerobic) digestion from livestock manure using net present value (NPV), internal rate of return (IRR), and payback period (PP) economic decision approaches for Canadian farming. The combination of multiple policies that included cost share and green energy credit incentive schemes yielded sufficient financial feasibility of on-farm biogas energy production for both swine and dairy operations, and single policy schemes using green energy credit policy generated the highest financial returns compared to cost-share and low-interest loan schemes. The economic viability of small-scale biogas digester technology was evaluated based on the primary data from central and eastern Uganda (Walekhwa, 2014). The results show that biogas digesters with a volume size of $8m^3$, $12m^3$, and $16m^3$ are economically viable with a payback period of fewer than two years. The interest rate for borrowing money to construct biogas digester remains economically viable when it does not exceed 36%, 37%, and 39%. However, the economic viability of biogas is significantly dependent on discount rates, capital cost, and operating and maintenance costs. Landi et al. (2013) found that, in Rwanda, the biogas energy sector is constrained by unfamiliarity with biogas technology, limited institutional capacity, limited skilled manpower, limited financing, the bulk of biogas digester costs being shouldered by households, and inadequate marketing and awareness campaigns despite financial and technical support offered by government together with development partners such as SNV and GIZ. The study recommends that the government strengthen collaboration with all relevant stakeholders and develop private sector capacity to enable successful implementation of renewable energy technology. However, the study did not examine consumers' ability to contribute to construction costs and their WTP biogas digesters as an emerging technology.

Shane et al. (2014) identified the barriers to the adoption of biogas digester technology in Zambia although the technology commenced in the early 1980s. These constraints include a lack of funding policy, no legal and regulatory framework, inadequate expertise, limited awareness campaigns on the benefits of biogas, high capital costs, the lack of an institutional framework, and traditional beliefs and culture among household. However, apart from lagging behind SSA, no coherent framework or policy instruments have been proposed to uproot these challenges in Zambia. Bensah et al. (2011) analysed the chronology of biogas development in Ghana including the technological and market potential of household biogas plants, the strengths and weaknesses of main biogas service providers, human resource development, quality issues, and the risks involved in developing a large-scale household biogas programme. The study recommends the development of standardised digesters, enriching awareness programmes on the benefits of biogas systems, flexible payment schemes, and consistent monitoring services. The study recommends a coordinating body to engage all stakeholders in strengthening the implementation of a national action plan for biogas technology.

3.3 The Benefits of Biogas Energy Technology and the Diffusion Process

Biogas energy can provide multiple economic benefits such as providing time for women to participate in income-generating activities and social cohesion, crop production, and reducing medical expenses (Wang et al., 2007; Katuwal & Bohara, 2009).

Biogas can also provide rich slurry as a bio product that can provide fertiliser to enhance soil fertility and agricultural productivity to enhance food security (SNV, 2006). Studies confirm that biogas energy can reduce GHG emissions. For instance, Liu et al. (2008) found that the substitution of small-scale biogas digesters for conventional energy sources significantly reduce GHG emissions based on an analysis of energy consumed from 1991 to 2005 in China. The estimated emissions reductions after switching to biogas energy are 84243.94 Gg CO_2, 3560.01 Gg CO_2-eq of CH_4, and 260.08 Gg CO_2-eq of N_2O emission. Additionally, biogas energy use is significant in the reduction of GHG emissions (Pokharel, 2007). Subedi et al. (2014) investigated the application of biogas digester technology and found that it can reduce deforestation in Africa. The study results portray that biogas production has the ability to reduce deforestation mainly from firewood fuel collection by 10 to 40% in 2010 and has the ability to reduce deforestation by 9 to 35% of total deforestation in 2030. Norberg (1990) indicates that large-scale adoption of existing technologies can reduce energy use as well as carbon dioxide emissions. Katuwal & Bohara

(2009) found that biogas technology in Nepal contributed significantly to human health improvement, crop production, and time savings for women from firewood collection, and cooking hours. Consequently, biogas technology provides economic benefits to nations through carbon credits and the reduction of deforestation, which leads to a reduction in GHG emissions. Wang (2007) also found that biogas digester technology can contribute to a reduction in GHG emissions. Empirical results show that household per capita energy consumption decreased by more than 40% mainly instigated by biotic substance and, therefore, increased the environmental benefits. Moreover, the researchers noted that biogas digester application revealed economic benefits such as reducing medical expenses estimated at approximately 100 to 200 Yuan per year, but the amount varied by region in Lianshui and Guichi in China.

The diffusion of biogas technologies has been neglected for many years by researchers and policy makers, and there has been a lack of analysis of the rationale for the technology's low penetration in the population despite its benefits on health, the environment, and socioeconomic conditions. Jaffe & Stavins (1993) examined the energy paradox and the causes of the gradual diffusion of energy conservation technologies. The results showed that there are several reasons for low technology diffusion in a population such as private information costs, high discount rates, heterogeneity among potential adopters, and other reasons related to market failure. The controversy over technology diffusion, for instance, highlights that technologies that are minimally adopted are cost effective at the current price, and this has led to substantial discussion among scientists on the energy paradox concerning inadequate diffusion of cost-effective energy conserving technologies (Shama, 1983).

Malik et al. (2014) investigated the feasibility and consumer WTP for biogas plants in sub-urban areas of the Nankana district in Pakistan. The study found that only 13% of households sampled were WTP for installation costs estimated at 50,000 rupees while 53% of households were not willing to pay the costs, but they were willing to pay between 200 to 300 rupees per month for installation. However, the study does not provide the criteria for the selection of the type of biogas digester technology to encourage WTP because the price of a biogas digester varies depend upon factors such as size, technology, and construction materials. The conclusion concerning household WTP is based on an analysis of demographic factors as determinants for consumer preferences instead of product attributes that might be inaccurate estimates from which to design a comprehensive market framework for biogas technology.

Nkunzimana et al. (2013) assessed the consumer WTP for the development of biogas energy technologies by inhabitants of Gihanga district, Burundi. The results suggest that the amount that a household is willing to pay each month increases according to the size of the household, whether a household has extensive knowledge of climate change mitigation, whether consumers use candles for lighting, the level of household income, the level of education of the household head The study recommends that the government enhance awareness campaigns concerning the benefits of biogas and use financial and non-financial incentives, which are important policy instruments.

CHAPTER 4: MODELS AND METHODOLOGY

4.1 Introduction

This chapter justifies the methodology, underlying assumptions, and models applied to consumer preferences and the adoption of domestic biogas digester technology in Rwanda. The survey design, CJ, and stated preference method, discrete choice method, and WTP estimation are discussed in detail. The methodological framework is presented in Figure 4-1.

4.2 Survey Design

4.2.1 Sample Frame

The accurate design of the sample frame represents sample data that are representative of the entire population (Alreck & Settle, 1995). In this context, the sample frame is composed of three provinces (Eastern, Northern, Southern and Kigali city) and five districts. The selection of districts (Nyagatare, Rwamagana, Gicumbi, Kamonyi, and Gasabo) is based on a district ranking of the number of cattle in each province [2], descending order criteria were performed to select one district from each province plus Kigali city. However, in East Province, two districts were selected because of its vastness. Five

[2] The ranking of provinces and districts with a large number of cattle was based on data obtained from the fourth population and housing census for NISR (2012).

sectors with large numbers of cattle in each district were selected for a total of twenty-five sectors in the entire country. The lowest administrative organs called cell known as “Akagari” and Village known as “Umudugudu” used the same approach.

4.2.2 Sample Size and Selection

The selection criteria for the sample were identified based on households with at least three cows in rural areas. A total of 250 households were randomly selected for the interviews, 50 households from each district, and 10 households from each sector to represent the population and distribution of responses. All 250 households were interviewed, and each of them was requested to answer eighteen (18) choice sets divided into six choice sets where each choice set was composed of three choice alternatives plus the status quo, resulting in a total of 4,500 observations.

Additionally, face-to-face interviews were conducted for the whole choice experiment (CE) survey to encourage a high response rate and to provide the respondents with scope for detailed questions and answers. Thus, the interviews minimised the possibility of bias and distortion.

4.2.3 Sample Unit

It is paramount to present the sampling population whose values are studied. In most cases, the sample unit consists of individuals or households. In this study, the economic agent is the household because energy services as a utility are consumed at the household level. Moreover, the utility usage decisions are made at the household level and not at the individual level. According to Quiggin (1998), it is important to interview the main decision maker of the household to avoid biased WTP estimates.

In this study, a household with at least three cows was the sample unit of analysis for rural areas. The interviewee was the head of the household and was over 18 years of old. The gender balance was also considered because the decision of energy service typically involves both husband and wife. As in other African countries, in Rwanda, women are traditionally involved in food preparation and biomass energy use including firewood collection. Therefore, their views as decision makers provide insightful information concerning the choice of hypothetical energy services instead of the status quo.

4.3 Stated Preference and Conjoint Analysis Approach

This section presents the evidence for the choice of stated preferences and CJ. The advantages of stated preferences over revealed preferences are based on empirical evidence from relevant literature. The stated preferences method presents the advantages of CJ compared to contingent variation (CV) in the case of energy studies.

4.3.1 Stated Versus Revealed Preferences for the Analysis of Biogas Energy Technology

The data required for estimation of choice behaviour can be collected using two different approaches, namely, the revealed preferences (RP) and stated preferences (SP) methods. Train (2003) states that for revealed preferences data, decision makers are required to express their preferences or tastes directly through given choices they select in a practical situation thereby revealing their actual choice. For stated preferences data, individuals are asked to give their choice based on the attributes of the product or service that is presented by the researcher in the hypothetical situation thereby revealing their choice in an experimental situation (Louviere, 2000).

The advantages of a stated preference method are difficult to quantify in revealed preferences, but it can be measured in a form of intangible or psychological attribute factors that are easily reflected (Louviere, 2000).

Calfee (2001) found that the statistical advantages of stated preferences data verses revealed preferences data is that there is less variation in explanatory variables when analysing revealed preferences data. Therefore, revealed preferences data ground the predicted shares in reality, whereas stated preferences data provide the required variation in attributes. Additionally, stated preferences data can achieve success over the weak points of revealed preferences data because of spacious variation and independent characteristics. The revealed preferences approach can cause a high correlation as shown by Savage & Waldman (2005).

Moreover, stated preferences methods have been used in a number of studies in the absence of market information unlike revealed preferences methods that rely on the presence of market information. For instance, a previous study by Han (2008) in Korea failed to acquire the historical natural and social environmental impact of large dam construction information to conduct a study using stated preferences. China also resorted to the stated preferences method when it failed to obtain market information related to demand and demographic patterns of electricity use in the Panda reserve area, and researchers resorted to the application stated preferences (An et al., 2002).

This study is to estimate marginal WTP for domestic biogas digester technology. All approaches can be applied for this situation. However, limited information on the application of biogas digesters as an emerging technology in rural areas renders the use of the revealed preferences method difficult. Moreover, when estimating the demand for new products with new explanatory variables or attributes with limited variability in the market, the stated preferences data can be preferable (Louviere et al., 2000). Therefore, this study applies the stated preferences method with a choice experiment first developed by Louvier & Hensher (1982). This method has been applied in many energy-related studies that address renewable energy technologies (green electricity, wind farms, and biomass and new energy efficient technologies); for instance, (Beenstock,1998; Goett et al., 2000; Roe et al., 2001; An et al.,, 2002; Bergmannet al., 2006; Banfi et al., 2008; So-yoon et al., 2010).

4.3.2 Conjoint Analysis versus Contingent Valuation in Stated Preference Methods

Two methods are involved in evaluating consumer preferences from stated preferences data; CV and CJ. CJ simply means ‘decomposition into part-worth utility or values if a set of individual evaluation or discrete choice form in a designed set of multiple attribute alternatives (Louviere, 2000), whereas CV requires individuals for absolute valuation (Calfee, 2001).

Hanley et al. (2001) found that CJ that is CE is more beneficial in assessing the problem and assisting in the design of appropriate policies than CV because the latter does not estimate the attribute values that compose the total value. Additionally, the CJ method is more sensitive to scope compared to CV because the estimates are greater when more public goods are valued than public goods.

Based on the distinct literature suggests that a CJ approach has multiple merits over CV, Steven et al. (2000) portray that a CJ survey may discourage less protest behaviour from respondents, ultimately inducing greater response because individuals can directly express indifference. The CV method can provide biased estimations because of incorporated uncertainty (Elkstrand & Loomis, 1997). CV estimates vary widely in relevance with the respondent's uncertainty. Moreover, many studies present critical arguments undermining the contingent approach and revealing its weakness in estimations. For instance (Boxall, 1996; Steven et al., 2000). Additionally, CJ typically provides higher WTP estimates than CV estimates.

In this context, the CJ approach has been chosen for the current research because of its advantages over CV, and it has been applied in many other energy-related studies in the previous literature.

4.4 Discrete Choice Model

The discrete choice experiments in earlier studies have been described by the law of comparative judgement that argues that stimuli and its associated attributes are considered when a distinct level of stimuli are presented to respondents (Thurstone, 1927). These stimuli are interpreted as utilities that are random and can be maximised as results to propose random utility theory (Marschack, 1960). Random utility theory is consistent with Lancaster's economic theory of value (Lancaster, 1966), which assumes that consumers derive utility from a set of alternatives with varying attribute levels. Probabilistic choice theory assumes that it is hard to determine an individual's choice because of unobserved parameters, but applying consumer theory allows the assignment of probabilities.

4.4.1 Random Utility Model

The random utility model (RUM) is mainly used to analyse consumer preferences using discrete choice models (McFadden, 1973). The consumer will choose their product or service if it provides maximum utility that is, they choose their most preferred alternative on the basis that it maximises their utility (Train, 2003). The author argued that when the decision maker is faced with a choice among j alternatives for products or services, the decision maker chooses the most preferred alternative that offers the greatest utility from the available choices. However, utility maximization depends on the preference structure of the consumer and budget constraints. Thus, to predict the purchase behaviour of the consumer requires an understanding of the consumer's preference structure.

With respect to renewable energy service preferences, consumers have different characteristics, and consumers differ from one another based on their demographics and knowledge pertaining to renewable energy services, particularly biogas energy services. Therefore, we assume that each consumer perceives the utility associated with each attribute of biogas energy services and selects the service that provides the greatest possible utility.

The utility can be divided into two parts in the RUM deterministic, which can be observed by the researcher, and stochastic, which cannot be observed by the researcher at the time of the study. Based on this framework, the indirect utility function can be expressed as follows:

$$\mathrm{U_{nj}} = \mathrm{V_{nj}} + \varepsilon_{\mathrm{nj}} \quad (1)$$

where $\mathrm{U_{nj}}$ represents the utility obtained from choosing alternative j by the n^th^ consumer. $\mathrm{V_{nj}}$ represents the non-stochastic deterministic part of utility, whose determinants can be observed by the researcher, and $\varepsilon_{\mathrm{nj}}$ is the stochastic part of utility (determinants cannot be observed by the researcher). n stands for the n^{th} consumer and j for the j^{th} alternative of the choice situation.

According to Train (2003), the model is expressed in the following ways:

$$U_{nj} = \beta_{nx} X_{nj} + \varepsilon_{nj} = V(X_{nj}) + \varepsilon_{nj} \quad (2)$$

The deterministic part is composed of the utility obtained from biogas energy services and the characteristics of consumers as follows:

$$U_{nj} = V_{nj} + \varepsilon_{nj} = (x_{nj}, s_n) + \varepsilon_{nj} = \beta'_{nj} x_{nj} + \alpha'_{nj} s_{nt} + \varepsilon_{nj} \qquad (3)$$

where x_{nj} vector is composed of attributes of alternative j n^{th} for the consumer, and s_n is the vector composed of characteristics of the n^{th} consumer. β (Consumer preference) and α represent the degree of influence on the deterministic part of utility from the attributes of the biogas energy services and the characteristics of consumers.

According to Train (2003), the stochastic part, $\varepsilon = \{\varepsilon_{n1}, \varepsilon_{n2}, \dots \dots \varepsilon_{nJ}\}$, aligns with joint distribution that underpins the probabilistic decisions on individual consumers' choice. Thus, the probability that the n^{th} person will choose alternative i from the set of available alternatives J_n is equal to:

$$P_{ni} = P(U_{ni} \geq U_{nj}, \forall j \neq i) = P(V_{ni} + \varepsilon_{ni} \geq V_{nj} + \varepsilon_{nj}, \forall j \neq i)$$

(4)

By rearranging the terms:

$$P_{ni} = P(\varepsilon_{nj} - \varepsilon_{ni} \leq V_{ni} - V_{nj}, \forall j \neq i) \qquad (5)$$

this implies that the probability of an alternative is chosen depending on the joint distribution of the differences between the error terms. That is, the probability P_{ni} is the function of the integration over the distribution (ε_n). According to Train (2003), several different models have been developed from different specifications of this density depending to the distribution assumed for the stochastic part of the utility.

4.4.2 Rank-ordered Logit Model

The rank-ordered logit model (ROL) is an extension of usual discrete choice model specifications to capture additional information on the choice process by an individual. Unlike Multinomial logit model (MNL), ROL uses only the most preferred choice. The ROL uses ranked choices where the respondents are asked to rank their choice of alternatives from the most preferred to the least preferred choice to capture vast information on the respondents' preferences. Therefore, ROL provides more precise estimates of the unknown parameters that can be used to test the probability model specification. Beggs et al., (1981) and Banerjee & Ware (2003 have used ranked choices to estimate the characteristics of consumer choices from stated preferences experiments and argued that they provide more precise estimates of consumer preferences than data from a choice experiment.

According to the ranked stated preferences method, the behaviour model is based on the RUM, which is distinguished from a choice model. This current study selected the ROL model because of its benefits over the discrete choice models.

Based on Calfee et al., (2001), an individual n selects choice set C with J elements with each element indexed as j = 1,2,……, J. The vector of attributes for each element in the choice set available is denoted as x_{nj}, and s_n implies the demographic characteristics of each consumer. The utility of each element in the choice set for each person is represented in Equation 2:

$$U(r_{n1}) > U(r_{n2}) > \cdots > U(r_{nJ}) \text{ or } Pr(r_n) = Pr[U_n(r_{n1}) > U_n(r_{n2}) > \cdots > U_n(r_{nJ})]$$

In practice, a respondent n states that their ranking of alternative $r_n = \{r_{n1}, r_{n2}, \dots\dots, r_{nJ}\}$ as the descending order of preference. Then, facing the maximization problem, the order of choice is made if the probability is:

$$U(r_{n1}) > U(r_{n2}) > \cdots > U(r_{nJ}) \text{ or } Pr(r_n) = Pr[U_n(r_{n1}) > U_n(r_{n2}) > \cdots > U_n(r_{nJ})]$$

Then, this form can be decomposed as follows (Equation 6):

$$Pr(r_n) = Pr[U_n(r_{n1}) > U_n(r_{n2}) > \cdots > U_n(r_{nJ})] = Pr[U_n(r_{n1}) > U_n(r_{nJ}) \text{ for } j = 2, \dots, J] Pr[U_n(r_{n2}) > U_n(r_{nJ}) \text{ for } j = 3, \dots, J] \dots\dots Pr[U_n(r_{n,J-1}) > U_n(r_{n,J})] \quad (6)$$

Thus, the j-dimensional survey experiment can be transformed into (j-1) binary statements for which the alternative is preferred (Calfee, 2001).

Therefore, because the distribution of the random term follows Type-I extreme value distribution, Equation 6 can be transformed into a ‘closed-form’ solution following Train (2003):

$$\Pr[U(r_1) > U(r_2) > .... > U(r_J)] = \prod_{k=1}^{J-1} \frac{e^{Bx(r_k)}}{\sum_{m=k}^{J} e^{Bx(r_m)}} \qquad (7)$$

where k denotes the order of the alternative ranked at k-th by the respondent. Suppose there is an independent sample of N individuals facing independent and identically distributed ε_{nJ}, using the derivation by Calfee (2001), the log-likelihood function to be maximised is:

$$LL(B) = \sum_{n=1}^{I} \ln\left[\prod_{k=1}^{J-1} \frac{e^{Bx(r_{nk})}}{\sum_{m=k}^{J} e^{Bx(r_{nm})}}\right]$$

$$= \sum_{n=1}^{n}\sum_{k=1}^{J-1} Bx(r_{nk}) - \sum_{n=1}^{n}\sum_{k=1}^{J-1}[\ln \sum_{m=k}^{J} e^{Bx(r_{nm})}] \qquad (8)$$

In Equation 7, there is only one choice set. If it is assumed that there are T choice sets, the choice probability is formed as follows (Kim, 2005; Park, 2008):

$$\Pr[U_t(r_1) > U_t(r_2) > .... > U_t(r_J)] = \prod_{t=1}^{T} \prod_{k=1}^{J-1} \frac{e^{Bx_t(r_k)}}{\sum_{m=k}^{J} e^{Bx_t(r_m)}} \qquad (9)$$

Therefore, the rank-ordered logit model provides detailed information concerning consumer choice than the model that permits only the most preferred choice from the set of possible alternatives. As in Equation 7, a respondent generates multiple pseudo-observations (J-1 pseudo-observations for J alternatives), which are again multi-folded if the choice is repeated T times, as revealed in Equation 9, leading to the likelihood of decreasing estimation bias.

4.4.3 Demographics Incorporated Model

The random utility in case of interaction with biogas energy service attributes with individual demographic variables can be generalised based on the setting of Savage &Waldman (2009) as follows;

$$U_{nj} = V\left(d_k, x_{nj}\right) + \varepsilon_{nj} \qquad (10)$$

Following Equation 2, the setting of this equation incorporates the addition of the demographic and individual characteristic interaction terms d_k (k is the number of demographics interacted); specifically, V can be expressed as follows:

$$V(d_k, x_n) = \sum_n \left(\beta_{0n} + \eta_k d_k\right) x_n \qquad (11)$$

where β_{0n} is the mean of the parameters, η_k indicates the variation of part-worths following the demographics and characteristics of individuals.

The socioeconomic variables can be used to represent heterogeneous preferences among individuals. To make comparisons, we first estimate a logit specification excluding all demographics and assume identical taste parameters in the population. We later also include them during interactions.

4.5 Willingness to Pay

WTP for biogas energy services in the current study is linked to the set of underlying service characteristics that combine to generate a single, separable index service utility to consumer. WTP can be observed in the many ways, for instance, survey methods applying stated preference approach to collect consumer responses through asking them either directly or indirectly their WTP. In the indirect surveys such as CJ enables us to estimate WTP for a single respondent, segmenting or aggregating WTP for the entire population.

In the context of discrete choice methods the principle for WTP is measured in monitory form as dollar terms or local currency (RWF in our case) to ensure that the results are easily understandable. WTP is measured by computing the implicit value of the attribute levels divided by the linear price/cost parameter.

The consumers are utility maximises, and improvements to one attribute can be expressed as an equivalent deterioration in another along an indifference curve. A consumer's WTP is estimated by the consumers' surplus attached to the equivalent price change (McFadden, 1974).

When a utility function is linear in parameters and attributes, the WTP for a one-unit increase in that attribute is the ratio of its marginal utility to the marginal utility of the price (Bliemer, 2013), WTP is defined by equation 12 as follows:

$$w_k = \beta_k / \beta_c \quad (12)$$

where β_k represents the parameter for attribute k, and β_c is the cost parameter. In the general case of a nonlinear utility function, the WTP of attribute k is defined as:

$$w_k = \frac{\partial g_j / \partial X_{jk}}{\partial g_j / \partial X_{jc}} \quad (13)$$

Then, β_k and β_c are both known but, with uncertainty, uncertainty also exists with respect to w_k .

4.6 Relative Importance

The relative importance can be computed by examining the difference between the highest and the lowest utility for that attribute divided by the sum of the utility ranges across all levels of attributes (Seo, 2005; Hair et al, 1998). Relative importance is the percentage of that attribute's range in relation to the total variation. It is computed as the percentage from relative ranges, obtaining a set of attribute importance values that total 100%. Relative importance of the i^{th} attribute X_i can be defined as follows:

Importance of an attribute = $\left[\text{Max}\left(\alpha_{ij}\right) - \text{Min}\left(\alpha_{ij}\right)\right]$for each "i" (14)

To determine the relative importance of other attributes, normalise importance such as:

$$W_i = \frac{I_i}{\sum_{i=1}^{m} I_i} \text{ such that } \sum_{i=1}^{m} W_i = 1 \quad (15)$$

Let the attributes of the given set be defined by X_j where $j = (1,2,3, \dots \dots, J)$.

Then, we define the relative importance of the i^{th}attribute X_i as;

$$RI_i = \frac{|\beta_i|(X_{imax} - X_{imin})}{\sum_{j=1}^{J} |\beta_j|(X_{jmax} - X_{jmin})} \text{ x } 100\% \qquad (16)$$

Then, dummy variables $X_{imax} - X_{imin} = 1$. Therefore,

$$|\beta_i|(X_{imax} - X_{imin}) = \max\left(|\beta_1|, |\beta_2|, |\beta_3|, \ldots \ldots \ldots \ldots \ldots \ldots \left|\beta_j\right|\right) \text{ x } 1$$

With interaction terms, we have: $|\beta_i| = \left|\beta_j + \beta_k \overline{X}_k\right|$

If we assume that, $|\beta_i|(X_{imax} - X_{imin}) = Y_i$, then, we have:

$$RI_i = \frac{Y_i}{Y_1 + Y_2 + Y_3 + \ldots\ldots\ldots + Y_J} \text{ x } 100 \qquad (17)$$

such that if Y_1 = dummy, then, the equation becomes:

$$RI_1 = \frac{\max\left(|\beta_1|, |\beta_2|, |\beta_3|, \ldots\ldots\ldots \left|\beta_j\right|\right) \text{ x } 1}{\max\left(|\beta_1|, |\beta_2|, |\beta_3|, \ldots\ldots\ldots \left|\beta_j\right|\right) \text{ x } 1 + Y_2 + Y_3 + \ldots\ldots\ldots + Y_J} \text{ x } 100 \qquad (18)$$

and $RI_2 = \frac{Y_2}{\max\left(|\beta_1|, |\beta_2|, |\beta_3|, \ldots\ldots\ldots \left|\beta_j\right|\right) \text{ x } 1 + Y_2 + Y_3 + \ldots\ldots\ldots + Y_J} \text{ x } 100$.

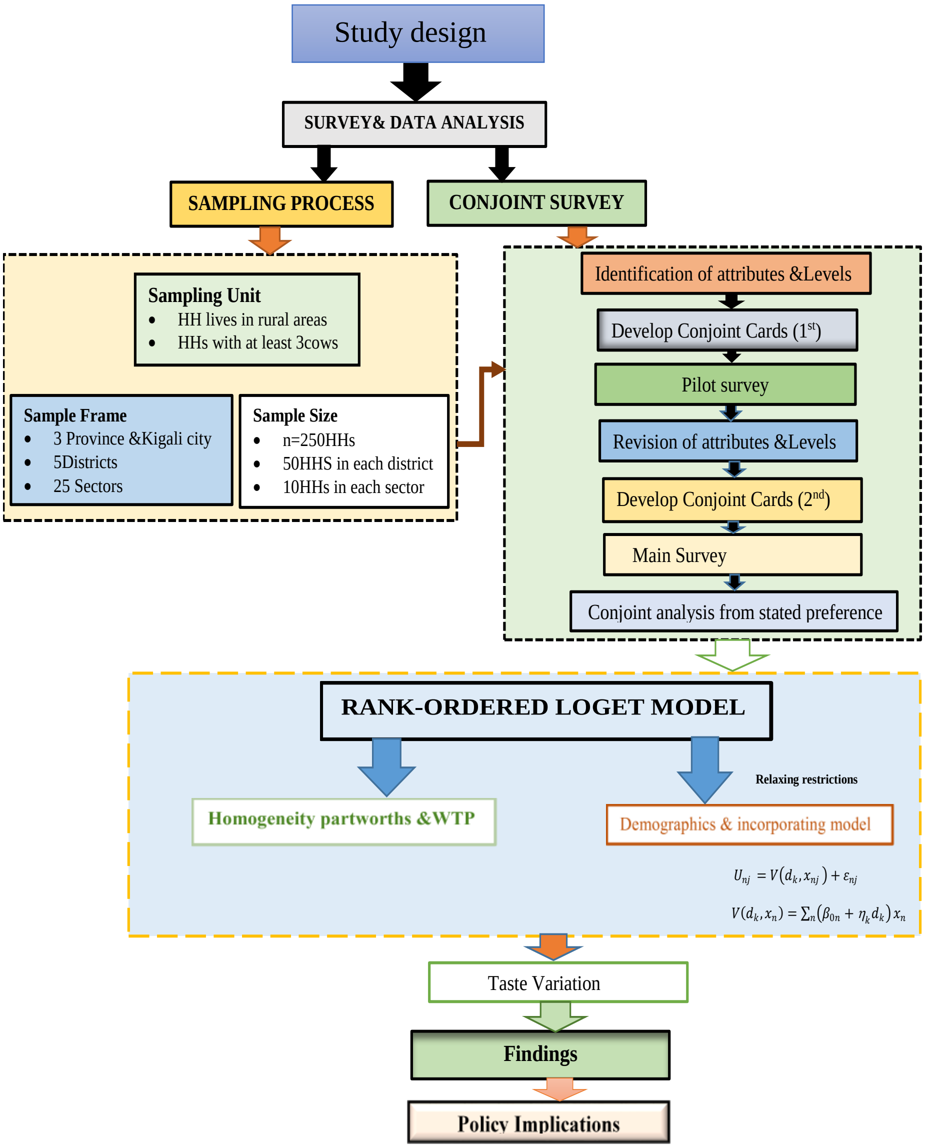

Figure 4-1: Methodological Framework of the Study

CHAPTER 5: THE RESULTS OF THE CURRENT STUDY

5.1 Descriptive Statistics

Table 5-1: General Descriptive Statistics of Respondents

	Frequency	Percent (%)
Gender		
Male	124	49.6
Female	126	50.4
Total	250	100
Marital status		
Married	181	72.4
Single	11	4.4
Divorced	4	1.6
Widowed	54	21.6
Total	250	100
Educational Level		
Primary	131	52.4
Secondary	22	8.8
TVET	8	3.2
University	8	3.2
None	81	32.4
Total	250	100
Primary Occupation		
Farming	214	85.6
Self-employed	15	6
Salaried employment	18	7.2
Casual labour	1	0.4
Others	2	0.8
Total	250	100

Source: Ngoboka, 2015

Table 5-1 shows the gender of respondents, which is considered an important element in the evaluation of WTP for domestic biogas digester technology. The study indicates that 49.6% of the respondents were male, and 50.4% were female, which implies gender representativeness. Thus, we acquire a well-balanced discrete choice model and insightful information because gender is balanced. According to the fourth Rwanda population and housing census (2012), females account for 52% and males account for 48% of the entire population of the country. The marital status of respondents in this survey is the following: approximately 72.4% are married, 21.6% are widows, 4.4% are single, and 1.6% are divorced or separated from their spouses.

The education level of respondents is composed of distinct categories. A large percentage of respondents have completed primary school and is estimated at 52.4%; 32.4% of respondents have not attended school, 8.8% possess a secondary education level, 3.2% have technical and vocational training (TVET), and 3.2% attended university. The rationale for less educated people in the area of study is that educated individuals dwell in urban areas and towns to target good jobs and favourable infrastructures that can enhance their standard of living rather than assuming a farming lifestyle in rural areas.

The primary occupation of respondents is dominated by farming at 85.6%, salaried employment at 7.2%, and self-employment at 6%. Casual labour is insignificant. We obtain a large number of agricultural occupants in this survey because the study mainly targets the households with cattle but that are located in rural areas where the majority survive on substance farming. NISR (2012) finds that the population depends on agriculture because the main occupation decreased significantly from 1978, 2002, and 2012 by 92.5%, 87.9% and 72.7%

respectively. Hence, in the CJ survey method, demographics and individual characteristics play a crucial role in estimating consumer's WTP for the products or services and test variation. In our case, the CJ survey will facilitate the capture of the influence of WTP on an individual's decision making for domestic biogas digester technology.

Table 5-2: General Statistics of Household Survey Data

	N	Mean	Std. dev	Min	Max
Payment for cooking fuels (RWF)	58	10,205	3,511	3,000	16,000
Time to collect firewood (Hours/week)	202	8.4	7.6	1	42
Expenditure on lighting fuel per month (RWF)	250	1,589	2,101	0	20,000
Distance from nearest source of water (meters)	248	1,200.70	1,596	0	13,000
How would you rate your knowledge about biogas energy	250	3.4	1.4	1	7
Age of respondent (years)	250	50.02	14.4	20	90
Household members	250	6.6	2.5	1	15
Size of land (M^2)	250	19,493	21,788	836	150,000
Number of cows	250	4.9	4.5	3	40
Number of pigs	32	2	2.3	1	14
Number of goats	88	3.31	3.2	1	25
Number of sheep	44	2.16	1.4	1	6
Monthly household expenditure (RWF)	250	45,387	31,039.60	3,000	200,000

Source: Ngoboka, 2015

The study analysis found that average rural household expenditure is approximately 10,205RWF ($14) per month for cooking fuel. There is little variation in the monthly payments among households for cooking fuels and a standard deviation of 3,511RWF ($5). The study results by Van Nes (2007) indicate that average expenditure for firewood is estimated to be from $8 to $20

(5,840RWF to 14,600RWF)[3] per month based on the current exchange rate. Based on estimation results, commercial fuelwood is estimated to comprise 23.6% of the fuelwood in rural areas, and the remaining portion is non-commercial fuelwood consumed used mainly for cooking. Drigo et al. (2013) found the cost of a bundle of 15 kg of fuelwood to be estimated at 1,500RWF in urban areas and 500RWF in rural areas. The Africa Energy Service Group (2012) found that a rural household on average uses 1,885 kg of fuelwood and 565 kg of charcoal per year in Rwanda. Thus, effective policies regarding energy consumption should encourage households in rural areas to switch to alternative modern energy services for cooking, such as domestic biogas digester technology, which can be an affordable and sustainable energy source considering the abundance of feedstocks from livestock in rural areas.

The average time a household travels to collect firewood is estimated to be 8.4 hours per week. In other words, a household spends more than one hour per day collecting firewood (Table 5-2). The variation of fuelwood collection hours among respondents is relatively high with a standard deviation of 7.6 hours. This implies that there are some households that travel long distances to fetch firewood because the maximum hours spent by the household fetching firewood is around 42 hours per week. According to the European Union Energy Initiative (EUEI) (2009), the average round-trip time for firewood collection is approximately 50 minutes in the Southern, Northern, and Western Provinces and 80 minutes in the Eastern Province. This suggests an average of

[3] Based on the current exchange rate of $1 = 730RWF by the BNR.

more than one hour per household spent collecting firewood for cooking in all provinces. The study also asserts that the distance travelled one-way to collect firewood for domestic cooking ranges from 1.5 to 2.5 km per day. Our results are almost the same as those of the EUEI study in Rwanda; therefore, appropriate policy is required to find alternative modern energy services, such as biogas energy services, to provide affordable and clean energy that can avoid the need for people to travel long distances to collect firewood. This issue affects the national economy because of the limited hours per day people can spend on income-generating activities because of the time required to collect firewood. This is a heavy burden, particularly for women, and affects the quality of education of their children.

The study shows that average expenditure on lighting fuel per month is approximately 1,589RWF per household with a standard deviation of 2,101RWF and a maximum range of 20,000RWF. There is substantial variation in the cost of household lighting fuel because of the energy form, which has a price that varies significantly. For example, some households use electricity, candles, dry cells connected to wires, or solar PV. The average distance from the nearest water source is estimated to be 1,200 meters from the household location with a standard deviation of 1,596 meters, which means that access to the nearest water source is difficult for rural households. In Rwanda, 72% of households have access to clean water, and there is limited access to water services in rural areas (NISR, 2012). WHO defines access to safe drinking water as when households can travel a distance of less than 1 kilometre away from its place of use, and when it's possible to obtain at least 20 litres of water per family member per day (WHO, 2015). These results affirm the true picture of water supply services because the area of study was rural areas and access to water services is predominantly poor. According to UNICEF and WHO (2014), in rural areas, 68% of residents have access to water service in Rwanda .The distance to safe water remains a significant burden for women and girls who shoulder primary responsibility for fetching water for their families. This hinders the quality of women's and girls' lives, their economic productivity, and their access to education.

This study analysis portrays the limited knowledge concerning domestic biogas energy services showing an average of 3.4 and a standard deviation of 1.4 based on the Likert scale (1 to 7), where the lowest level of knowledge concerning biogas energy services is represented by 1, and the highest level of knowledge is represented by 7. This indicates that households in rural areas have limited knowledge of biogas energy services and their benefits. However, this confirms the rationale for the low penetration of domestic biogas energy technology of targeted beneficiaries despite extensive government effort. Landi et al. (2013) assessed the barriers to biogas energy adoption in Rwanda and found that limited marketing and awareness campaigns are critical problems hindering the diffusion of biogas energy technology in Rwanda. Additionally, 52% of study respondents suggested that promotion strategies are necessary to enhance awareness and the benefits of domestic biogas digester technology to beneficiaries if the government is to achieve mass dissemination. Thus, policy makers should design policies that promote universal access to biogas energy services through awareness campaigns of the benefits of biogas energy technology to beneficiaries.

The mean age of respondents is approximately 50, with a standard deviation of 14 years. The study was designed for respondents aged over 18 years to ensure accurate household information. The average number of household members is approximately seven per household with a standard deviation of three members per household. This implies that rural families have many children and, like many other African countries, Rwandan families are characterised by extended families and large rural households.

The number of livestock per household is a significant element in this study considering the feedstock supplies required to generate biogas for cooking as a substitute for traditional biomass energy. The average number of cows per household in this study is approximately five cows and a standard deviation of 4.5 cows because the unit of analysis is a household with at least three cows. The minimum number of cows per household is three cows, and the maximum is 40 cows. Apart from cattle, households also own an estimated average of two pigs per household, three goats per household, and two sheep per household. The genesis of these statistics is the ‘One Cow per Poor Family Programme’ called the ‘Girinka programme’ that targets mostly poor households that depend heavily on biomass solid energy for cooking. The purpose of the programme is to support poor households in the acquisition of milk, manure, and feedstock for biogas production. These cows provide sufficient feedstocks because, in

Rwanda, cow dung is the main feedstock for biogas production because one well-fed cow can provide 15 kg to 20 kg of cow dung. According to Bui Van et al. (2013), in their handbook of quality guidelines for some types of small-scale biogas plants, the authors state that, in Vietnam, the size of a small-scale biogas digester with a volume of 4 m^3 requires approximately 15 kg to 20 kg of animal manure per day, which can be supplied by one well-fed cow assuming an average 40-day retention period based on the manure-to-water dilution ratio of up to 1:2, which is commonly used in Rwanda. Two to three cows are sufficient to supply feedstock to a biogas digester with capacity of 10 m^3.

Table 5-3: Descriptive Energy Use Statistics from Respondents

Energy use	Frequency	Percent (%)
Household cooking per day		
Once	1	0.4
Twice	105	42
Three times	142	56.8
Four times	2	0.8
Total	250	100
Forms of cooking fuel		
Firewood	214	85.6
Charcoal	22	8.8
Agricultural waste	13	5.2
LPG gas	1	0.4
Total	250	100
Cooking fuel purchases		
Yes	59	23.6
No	191	76.4
Total	250	100
Where do you purchase cooking fuels?		
Own farm	92	45.5
Forest	43	21.3
Woodlot	67	33.2
Total	202	100

Form of lighting used by households		
Candle	13	5.2
Paraffin	34	13.6
Electricity	101	40.4
Solar PV	9	3.6
Dry cells*	92	36.8
Others	1	0.4
Total	250	100
Have you heard of biogas digester technology		
Yes	151	60.4
No	99	39.6
Total	250	100

Small dry cells used in a torch to give light or directly connected to small wires and a lamp contact with a lamp filament.

(Source: Ngoboka, 2015).

The study results show that the majority, approximately 56.8%, of households cook three times a day, and 42% of households cook twice a day. Most households interviewed use traditional biomass energy for cooking regardless of its negative impact on their lives and environment. The study found that almost every rural household surveyed uses traditional biomass energy for cooking including firewood at approximately 99.6%. Approximately 85.6% of households use charcoal for cooking, 8.8% use agricultural waste, 5.2% use clean energy, and 0.4% use LPG gas. The fourth Rwanda population and housing census (2012) shows that 99.4% of rural households in Rwanda use traditional biomass energy for cooking including firewood (93.3%), charcoal (2.9%), and agricultural waste (3.2%) while, in the urban areas, biomass energy accounts for 95.5% of total energy use. Additionally, Africa Energy Services Group (2012) found that 99.5% of rural households use traditional biomass for domestic cooking. The current study confirms the real situation of biomass energy use in the country, which is similar to the situation portrayed in previous studies on biomass energy use in Rwanda. Therefore, policy makers should identify sustainable energy solutions that resolve the incumbent issues of energy for cooking considering health, environmental, and economic factors. Despite high energy demand in rural areas, a large portion of households do not purchase firewood for cooking (76.4%), and 23.6% of households purchase fuelwood for cooking. The only way for households to obtain free firewood for cooking is to collect it freely from the forest, woodlots, and farms. Households who collect firewood from their own farms account for 45.5%, those who collect from woodlots account for 33.2%, and those who collect from government forests account for 21.3%. Moreover, a large number of households, estimated at 40.4%, use electricity for lighting, 36.8% use dry cells as a torch, 13.6% use paraffin, 5.2% use candles, and 3.6% use solar PV in rural areas. The results from NISR (2012) found that the main sources of energy for household lighting in Rwanda are kerosene lamps (40%), electricity (17.4%), candles (10%), and firewood (8%). However, a high percentage of households (24%) use an unspecified energy source for their lighting (NISR, 2012). These figures represent the countrywide situation rather than that of specific areas. The electricity access roll-out programme (EARP) established by the government to increase access to electricity in both rural and urban areas achieved its five-year target in 2012 for which more than 350,000 households were electrified. This caused rural households to diversify and adopt modern energy services as their main source of energy for light rather than kerosene in 2012. This indicated clearly that households in Rwanda are dynamic and flexible concerning the adoption of modern energy services if coherent policies and strategies regarding the transformation from traditional biomass energy to modern energy services can be simply adopted on a large scale by the population.

In this study, approximately 60.4% of the households claimed that they had heard of biogas digester technology for cooking while 39.6% claimed to have never heard of biogas digester technology. This implies barriers hindering the technology's penetration because of limited awareness campaigns on its benefits. Therefore, policy that promotes universal adoption should be designed including awareness campaigns of the benefits of biogas technology to speed up its diffusion among the population.

Table 5-4: Household Perceptions on Biogas Energy Technology

	Frequency	**Percent (%)**
Willingness to use biogas digester technology		
Yes	241	96.4
No	9	3.6
Total	250	100
Willingness to obtain a loan for biogas technology		
Yes	220	88
No	30	12
Total	250	100
Household understands biogas digester technology as		
Easy to use	82	32.8
Expensive	88	35.2
Environmentally friendly	157	62.8
Convenient	189	75.6
Safe with respect to health	207	82.8
Reasons to promote biogas digester among households		

Awareness campaign	130	52
Access to soft loans	138	55.2
Subsidy	166	66.4
Reduce cost	176	70.4
Households use animal manure as fertilisers		
Yes	235	94
No	15	6
Total	250	100
Grazing practice by households		
Zero grazing	197	78.8
Open grazing	53	21.2
Total	250	100

Source: Ngoboka, 2015

In this study, households affirmed their willingness to use biogas digester technology for cooking and lighting after obtaining the description and benefits of biogas energy technology. Approximately 96.4% stated that they are willing to use the technology while 3.6% are not willing because of several reasons such as the initial capital cost of biogas energy technology (Table 5-4). Hence, policy makers should use this willingness opportunity to accept biogas digester technology and design flexible pricing policies and access to soft loans to boost low-income earner adoption and strengthen awareness campaigns through different channels such as media and local government meetings. This strategy is also indicated by the willingness of residents to acquire soft loans from micro financial institutions such as Umurenge SACCO, for which government and other stakeholders provide assistance. Approximately 88% of households in this study desired loans for the construction of biogas digesters, and only 12% did not. A policy can be designed to promote collaboration between micro financial institutions and households for access to soft loans for biogas digesters in collaboration with other different stakeholders, development partners, CDM projects, and carbon credit schemes as those in India, Nepal, and China that achieved substantial progress in biogas development (Sudhaka & Balachandra, 2006; CDM Nepal, 2005).

Perceptions of biogas digester technology imply that approximately 82.8% of households understand it to be a safe option with respect to health safety in terms of disease prevention associated with biomass solid energy use for cooking and indoor air pollution. A total of 75.6% of households consider the technology to be convenient, 62.8% consider it environmentally friendly, 35.2% consider it expensive, and 32.8% consider it easy to use (Table 5-4). This implies a positive attitude towards biogas digester technology from rural households. Hence, policies should be set based on these perceptions to augment the distribution of biogas digester technology among the population.

With respect to suggestions for biogas digester technology promotion, this study indicated that approximately 70.4% of households propose government assistance to reduce the cost of biogas digester technology cost, 66.4% propose a subsidy, 55.2% propose access to soft loans for the construction of biogas, and 52% propose enhancing awareness campaigns on the benefits of domestic biogas digester through media platforms and local administration meetings. The policies for the promotion of biogas digester technology should be set considering these important household recommendations to pave the way for dissemination of emerging biogas energy technology.

To increase soil fertility and agricultural productivity, approximately 94% of households in this study stated that they use animal manure as fertiliser while

6% do not. However, an integrated system between the energy and agriculture sector can be established to promote the use of biogas digester technology because it serves multiple purposes and can provide bio products such as bio slurry, which is a rich fertiliser to enhance soil fertility. This is a significant factor that can assist in policy setting for integrated planning and coordination of a biogas energy programme and state the role and responsibilities of each body involved. An evaluation performance scheme pertaining to biogas dissertation can diminish bureaucratic governance and poor performance.

The percentage of households that practice zero grazing is estimated at 78.8%, and 21.2% practice open grazing. Coherent policies and a regulatory framework should be designed to ensure that all cattle are grazed in the cattle shed to avoid manure loss for biogas production, slurry for fertilisers, and to simultaneously protect the environment.

5.2 Empirical Results and Discussion

5.2.1 Specific Models and Analysis of the Study Results

In this section, the individual model for biogas energy services preference structure is presented. The model is aligned with the methodological framework in which every specific model of the study is defined based on the framework in Figure 4-1. The first model to be considered is the RUM that is defined as follows:

$$U_{ijt} = \beta_{SIZE}\ \text{SIZE} + \beta_{COST}\ \text{COST} + \beta_{GUARA}\ \text{GUARA} + \beta_{SS}\ \text{SS} + \beta_{TIMSAV}\text{TIMSAV} + \varepsilon_{ijt} \quad (5.1)$$

The description of the variables ise indicated in Table 5-6. In summary, equation 5.1 is composed of the following variables, which include the following: SIZE is the size of the biogas digester, COST is the capital cost of the installation of the biogas digester, GUARA is the period of guarantee granted to the customer after the installation of the biogas digester by the service provider, SS is the supplier or service provider for biogas digester technology, TIMSAV is the time saved when the customer uses biogas digester technology as a substitute for biomass solid fuel. The rank-ordered logit model is described in Chapter 4.

The second model to be specified is the RUM. The model's part-worths that interact with demographics and individual characteristics include income, education, and land size (see Table 5-6). According to Savage & Waldman (2009), and as stated in Chapter 4, the interaction terms relax the restriction of fixed coefficients that are specified in the equation (5.1), and the model is defined as follows:

$$U_{ijt} = (\beta_{Size} + \beta_{SEDN}\,\text{EDN} + \beta_{SINCOME}\text{INCOME})\,\text{SIZE} + (\beta_{COST} + \beta_{CEDN}\,\text{EDN} + \beta_{CLAND}\,\text{LAND} + \beta_{CINCOME}\,\text{INCOME})\,\text{COST} + (\beta_{GUARA} + \beta_{GINCOME}\,\text{INCOME})\,\text{GUARA} + \beta_{SS}\text{SS} + \beta_{TIMSAV}\text{TIMSAV} + \varepsilon_{ijt} \qquad (5.2)$$

5.2.2 Model Estimate: Rank-ordered Logit Model

There are 250 valid interviews with completed information from the choice experiment survey. The respondents were requested to rank their order of preference from their most preferred choice to their least preferred choice plus the status quo in each choice set. Using orthogonal design technique with the assistance of the SPSS 17.0 version statistical package, the number of choices were reduced to 18 choice sets. The 18 choice sets were found to be burdensome and too large for each respondent. Therefore, the sets were divided into six choice sets to reduce the cognitive burden for respondents, and each choice set was composed of three choice alternatives plus the status quo or no choice in a choice card. Thus, this avoided the individual effect. As a result, the total observations for the rank-ordered logit estimation were 4,500. The current study uses the LIMDEP statistical package to estimate the rank-ordered logit model, and the results are presented in Table 5-5, which includes the parameter estimates, asymptotic t-statistics, WTP, and the relative importance for each attribute of biogas energy services.

Table 5-5: Rank-ordered logit model

Variable	Coefficient (β)	Standard error	t-value	P[|Z|>z]	WTP(RWF)	Relative importance
SIZE	0.13149716***	0.00976262	13.469	0.000	26,556	17.2%
COST	-0.000004952***	0.000000180063	-27.499	0.000	N/A	43.2%
GUARA	0.25119798***	0.01804498	13.921	0.000	50,730	21.9%
SS	-0.26562771***	0.05113743	-5.194	0.000	-53,645	5.8%
TIMSAV	0.13677616***	0.01558227	8.778	0.000	27,623	11.9%

*Note: WTP, star *** indicates a significance level of 99.9% (p-value < 0.001), ** indicates a significance level of 99% (p-value < 0.01) and * indicates a significance level of 95% (p-value < 0.05). Currency unit of WTP is RWF. At the time of the survey, the exchange rate was $1 = RWF730 according to the BNR.*

Generally, the estimation results fit the model properly. As indicated by the statistics in the above table, all attributes in the indirect utility function are statistically significant at the 1% level. The signs of the parameters are predicted by the RUM theory and current biogas energy service market.

Consequently, this study interprets the parameters as marginal utility as a partial derivative of the change in utility from one-unit increase in the variable (Savage & Waldman, 2005).

The coefficient of the size (internal volume) attribute presents marginal utility for the consumers with regard to the choice of the size of the biogas plant relevant to its production capacity. This parameter indicates a positive sign, which implies that consumers find more utility when the size (internal volume) of the domestic biogas digester increases. Consumers are willing to pay more costs estimated at 26,556RWF for one additional cubic meter volume of domestic biogas plant for cooking and lighting. This shows that people prefer a larger biogas digester because the survey results show that an average Rwandan household has approximately seven members, and more than 56% of households cook three times a day, and approximately 42% cook twice a day. Therefore, typically, large domestic biogas plants are preferred because household size and daily energy demand is substantial.

The coefficient of cost attributes reveals the marginal utility of the consumer to be the capital cost of the biogas digester installation. The cost attributes have a negative sign, which implies that an individual's marginal utility decreases with an increase in the cost of the domestic biogas digester. These results are aligned with economic and psychological theories suggesting that consumers prefer to purchase more products or services when prices are low to maximise their utility.

The price plays a significant role in new technology adoption and influences consumer decision making. Thus, preference structures have great impact on pricing and subsidy policies for biogas programs.

The coefficient of guarantee attribute (GUARA) presents the marginal utility of the consumer on guarantees given after the installation of the biogas plant for cooking. This attribute illustrates a positive sign, which implies that consumers have more utility when suppliers extend the period of guarantee to the installation of the biogas digesters. The average marginal WTP for one additional year of guarantee on a domestic biogas digester is estimated at 50,730RWF. This indicates the perceived fears and limited confidence concerning this emerging technology by biogas consumers. There is a need to design a policy that builds consumer confidence and trust to reduce the reluctance to adopt biogas technology.

The coefficient of supplier attribute (SS) reveals the marginal utility of consumers to service providers of biogas digester technology. The negative sign of the supplier attribute coefficient suggests that the consumer's marginal utility decreases when the government is the service provider and increases when the private sector is the service provider. This implies that consumers prefer private suppliers than government suppliers as service providers for domestic biogas digester technology. The average WTP when the private suppliers are the service providers of biogas digester technology is estimated to be 53,623RWF. It is surprising that consumers trust the private sector more than government agencies with respect to biogas services supply. The coefficient of the time-saving attribute (TIMSAV) indicates the marginal utility of time saved when diversifying to a biogas digester for cooking instead of charcoal and fuelwood. The attribute shows a positive sign, which implies that the relative utility increases when many hours are saved by cooking. The average WTP for an additional hour saved from cooking using biogas digester technology is estimated as 27,623RWF. The present study shows that a Rwandan household spends an average of more than eight hours per week collecting firewood in rural areas excluding cooking hours. The time that can be saved from the use of using biogas technology is precious because the time saved can be applied to income-generating activities. Women and children would be the main beneficiaries and would gain time to spend engaged in social cohesion activities such as participating in cooperative activities, council meetings, attending weddings, interacting with friends, and children can use the time to study and improve their education. Thus, policies to promote biogas digester technology can benefit both governments and households by empowering women and children and can increase household economic performance, secure time for productive activities, save on medical care expenses because of a decrease in diseases caused by indoor air pollution, improve health conditions, and protect the environment.

The analysis of the results of the relative importance (RI) of attributes in Table 5-5 is computed from the equation in chapter 4. The cost attribute is the most important attribute influencing consumers' decisions to adopt biogas digester technology estimated at 43.2%. The period of the attribute guarantee is the important (21.9%) followed by attribute size (17.2%), time saving (11.9%), and the least important attribute is supplier or service provider (5.8%). Table 5-5 shows the relative importance of the attributes as perceived by the households interviewed in this study. Thus, in setting policies for the promotion of biogas energy technology, it is paramount to consider the relative importance of these attributes.

However, all these suggestions are considered when we assume that the study population is homogeneous. In practice, people tend not to have similar demographics and individual characteristics. Thus, the proposed policies may not be effective for all individuals; therefore, we permit systematic test variation with interaction terms between the primary variables and socio-demographic variables to relax some restrictions and attain more detailed and efficient outcomes that benefit the whole population. The interaction model is explained in the next subsection.

5.2.3 Interaction with Demographics and Individual Characteristics

The interaction of demographics and socioeconomic variables permits a systematic test variation to be incorporated into the part-worth. Chapter 4 provides details. The demographics and individual characteristics in this study interact with five attributes, as shown in equation 5.2, while model estimate results are presented in Table 5-6, which includes the part-worth estimates.

After demographic interactions, the sign and magnitude of the mean values of the coefficients are almost similar compared to coefficients in Table 5-5 for the primary variables. Additionally, the order of importance of the attributes by households is the same, although the values were slightly changed in Table 5-5.

Table 5-6: Model with demographic interactions

Variable matching	Variable	Coefficient (β)	Standard error	t-value.	P[|Z|>z]	WTP(RWF)	R.I
Size	SIZE	0.12712034***	0.0232884	5.459	0.000	25,648	16.8%
Cost	COST	-0.0000051539***	0.000000446	-11.544	0.000	N/A	43.6%
Guarantee	GUARA	0.17615759***	0.03225672	5.461	0.000	49,839	21.7%
Supplier	SS	-0.27248601***	0.05184562	-5.256	0.000	-52,869	5.8%
Time saving	TIMSAV	0.14340074***	0.01581103	9.07	0.000	27,824	12.1%
Size*education	SEDN	-0.01454288***	0.00536403	-2.711	0.007		
Size*income	SINCOME	0.00000092548***	0.000000330	2.804	0.005		
Cost*education	CEDN	-0.00000022592**	0.0000001043	-2.166	0.03		
Cost*land	CLAND	-0.00000000004***	0.000000000010	-3.466	0.001		
Cost*income	CINCOME	0.00000000003***	0.000000000005	5.125	0.000		
Guarantee*income	GINCOME	0.00000177822***	0.000000598677	2.97	0.003		

*Note: The variables are defined in the table above. WTP, asterisk *** indicates a significance level of 99.9% (p-value < 0.001), ** indicates a significance level of 99% (p-value < 0.01) and * indicates a significance level of 95% (p-value < 0.05). The currency unit of WTP is RWF. At the time of the survey, the exchange rate was $1 = REF 730, according to the BNR.*

The following is the interaction model:

U_{ijt} = (β_{Size} + β_{SEDN} EDN + $\beta_{SINCOME}$INCOME) SIZE + (β_{COST} + β_{CEDN} EDN + β_{CLAND} LAND + $\beta_{CINCOME}$ INCOME) COST + (β_{GUARA} +$\beta_{GINCOME}$ INCOME) GUARA + β_{SS}SS + β_{TIMSAV}TIMSAV + ε_{ijt}

We consider that the variation in the marginal utility of households corresponds to the individual characteristics. The model causes the size attribute to interact with the number of individual characteristics such as education and income. The mean coefficient of the size (β_{Size} = 0.12712034) is positive, which implies that the individual's relative utility increases when the size of the biogas digester increases, increases more when the individual's income increases ($\beta_{SINCOME}$ = 0.00000092548), and decreases when the individual has a higher level of education (β_{SED} = -0.00000022592). The average WTP for one additional cubic meter volume of biogas digester is estimated as 25,648RWF (see Table 5-6).

The cost attribute's negative sign indicates that individual marginal utility increases when the price of biogas digester technology decreases increases more when the household's income increases ($\beta_{CINCOME}$ = 0.00000000003), marginal utility decreases when the individual has a higher level of education (β_{CEDN} =-0.00000022592), and decreases more when land size increases (β_{CLAND}= -0.00000000004). This indicates the practical situation where people prefer to purchase products or services at the lowest cost and buy more when their income increases based on economic theory. In other words, those with a higher education prefers to pay less money for a biogas plant, and household utility decreases as the land size increases.

The guarantee attribute presents a positive sign, which implies that individual relative utility increases as the period of guarantee increases (β_{GUARA} =

0.17615759) and increases more when the income increases ($\beta_{GINCOME}$ = 0.00000177822). The average WTP for one additional year of guarantee of the domestic biogas digester is estimated to be 49,839RWF. The supplier attribute's negative sign shows that individual marginal utility increases when the biogas digester technology is supplied by a private service provider and decreases when the government is the service provider. When biogas digester technology is supplied by a private company, the individual is willing to pay an additional amount estimated at 52,869RWF. The time-saving attribute has a positive sign, which implies that the marginal utility increases when more time is saved after the application of biogas digester technology as cook stoves replace traditional biomass stoves. The average WTP for one additional hour of saved time is estimated to be 27,824RWF.

The RI of attributes when combined with demographics and individual characteristics is calculated using equation 17 in Chapter 4. The most influential attributes of biogas digester technology adoption for respondents are cost (43.6%), guarantee period (21.7%), size (16.8%), time saved (12.1%), and the supplier (5.8%) is the least important attribute (see Table 6). Thus, policy makers should design policies considering the relative importance of the attributes to expedite consumer adoption of biogas digester technology in Rwanda.

In summary, the study analysis allows systematic test variation with interaction terms of the rank-ordered logit model of the interaction between the primary and socio-demographic variables of individual characteristics. This analysis captures consumer taste variations in the consumer choice. Therefore, using the study results, the government can set coherent policies that tackle the challenges indicated by the biogas sector that affect the entire population.

CHAPTER 6: CONCLUSION AND POLICY IMPLICATIONS

This chapter summarises the main findings of the research and provides implications of the current study of consumer preferences concerning the adoption of domestic biogas digester technology. The proposed policies are constructed based on the findings in Chapter 5 and case studies on previous literature on biogas energy services, renewable energy technology adoption, and consumer satisfaction in both developing and developed countries.

6.1 Conclusion

For developing countries to achieve universal access to modern energy services, particularly for cooking, the governments must promote available and affordable clean energy such as renewable energy services to meet the increasing energy demand and consumer satisfaction. Globally, there are several policy frameworks designed to realise this goal in each country depending on the magnitude of the challenge. Thus, it is relatively difficult, particularly for developing countries, to design a policy framework based on a practical understanding of consumers' perceptions, behaviours, preferences, and welfare. This difficulty has a significant impact on policy making and, in most cases, causes the failure of some implementation and practical policies.

In this context, the current study applied CJ, and the stated preferences approach using a discrete choice model to study consumer preferences for the adoption of domestic biogas digester technology in Rwanda. A discrete choice model was used to evaluate consumers' WTP for domestic biogas digester technology in rural areas. To provide a coherent policy framework, the study used a rank-ordered logit model to evaluate consumer WTP and interactions between the primary biogas energy services' attributes with demographics and individual characteristics. Based on the study results, the findings and policy implications were designed. For instance, the relative importance of the study attributes indicates the consumers' preference structure for biogas energy services. Thus, well-designed policies and recommendations can be drawn based on this preference structure to unlock the biogas industry in Rwanda. These findings have great impact and important implications for the biogas energy sector, market strategies, communication channels, and policies and strategies for the promotion of biogas energy in Rwanda.

The estimation results are consistent with previous studies and are efficient under the conditions of limited range of market penetration of emerging technology and new products or services that have not yet been introduced to the market. These results can also be used as theoretical background for policy formulation in other areas of the energy sector to enhance the level of penetration; for instance, the area of new and renewable energy, such as solar PV, solar water heaters, energy efficiency technologies, and appliances. Additionally, these estimation results can be used to simulate and identify the size of the biogas digester technology that will be most preferred and adopted by future households. Hence, an appropriate market strategy and incentives can be set to enhance the market penetration of biogas digester technology in Rwanda.

The results of this study are useful apart from their application to the sustainable development of a domestic biogas programme in the rural areas of Rwanda. The results are of interest to decision makers, policy makers, scholars, and contribute to the development of the biogas sector in other jurisdictions worldwide with similar characteristics as Rwanda's energy systems. Thus, the current study makes a paramount contribution to the limited literature on renewable energy using CJ and discrete choice modelling, particularly for SSA.

6.2 Main Findings and Policy Implications

The overall findings show that the low level of domestic biogas digester technology adoption is associated with limited knowledge of biogas technology, perceived high capital costs, limited access to soft loans, and a desire for support through subsidies. These results are aligned with the findings of Matthew et al., 2013) and assess the barriers that have limited successful biogas sector adoption in Rwanda since its establishment in 2007 to 2011. Almost all respondents indicated great passion for WTP for domestic biogas digesters for cooking (96.4%) as an alternative to traditional cook stoves that use charcoal and fuelwood. Approximately 88% of respondents were willing to acquire loans from micro financial institutions for the construction of biogas plants when the government assists in their access to financing. However, only 60.4% of respondents have heard of biogas energy services. Therefore, policy makers should formulate coherent and consistent policies that address the challenges to expedite the adoption of biogas digester technology in rural areas. The government should create pricing and subsidy policies to offset the perceived high cost, enhance awareness campaigns on the benefits of biogas digesters, create integrated system for both biogas and bio slurry production to enable proper coordination of the biogas program, provide easy access to soft loans for rural farmers to enable them to meet bank requirements, and engage other relevant stakeholders, such as the private sector and development partners, to bridge the supply gap in biogas energy services.

The empirical results of the conjoint survey and discrete choice modelling show that demographics, individual characteristics, and primary biogas energy services' attributes are important factors influencing the adoption of biogas energy technology. First, the coefficient of size is positive, which implies that the marginal utility of the consumer increases when the size of the biogas digester increases more with a higher household income, and decreases with a higher consumer's level of education. The findings indicate that the average WTP for a consumer is about 25,648RWF per one additional cubic meter of biogas plant volume. This implies that the majority of consumers prefer a large biogas digester to ensure sufficient gas production for their daily energy demand for cooking and to avoid using biomass solid energy. In contrast, the most educated people prefer a small biogas plant. This indicates that educated people are more sensitive to the size of the biogas plant because most educated people possess smaller households and their cooking habits are less; thus, their energy demand is relatively small, and there is no need for a large size biogas plant for cooking. This study suggests the biogas financial subsidy reform to set flexible funding policy based on consumer preference structure of biogas size contrary to the current flat subsidy policy. To secure universal and sustainable funding resources for renewable energies (REs), governments should engage specific stakeholders including the private sector, clean development mechanism (CDM) projects, development partners, and NGOs, to enrich the adoption of biogas digester technology. These funding mechanisms have been applied by many successful countries in biogas development programs such as China, India, and Nepal (Wang et al., 2007; Yu et al., 2010; Debadayita et al., 2014).

The second finding concerning biogas digester cost shows a negative sign, which implies that the marginal utility of consumers increases when the cost of the biogas digester decreases, increases more when income increases, and decreases when the consumer has a higher level of education and substantial land. Consumers prefer to purchase products at a lower price and purchase more when their income increases. This implies that consumers can adopt more biogas digesters if they are affordable and when their income is sufficient. In contrast, as household education levels increase, marginal utility decreases and decreases more as the household land size increases. These findings are similar to the empirical results in the study on adoption of biogas technology in Uganda by Walekhwa et al. (2009). The author found that the likelihood of household biogas digester adoption decreases when education levels are higher and decreases with an increase in land size. The rationale might be that educated households with substantial land prefer more advanced clean energy services such as LPG and electricity, which does not require the same level of efforts and time as biogas energy. Thus, the bottom-up approach of flexible financial and pricing policy, such as subsidies and access to soft loan to provide affordable biogas digesters for cooking for low-income people, should form a medium-term strategy to resolve the incumbent issues. The results show that educated households and those with substantial land have fewer preferences for biogas digester technology for cooking and are an indicator of their preferences for cleaner energy technologies for cooking such as LPG, natural gas, and electricity.

The empirical study reveals that consumer preferences for the adoption of domestic biogas digester increases when the period of guarantee increases and increases more when household income increases. This indicates that consumers have a strong desire for a significant guarantee period to reduce their perceived fears concerning the quality of the new cooking technology. Regulatory bodies should set standards and a quality insurance framework scheme to ensure high quality biogas digesters are supplied to reduce perceived fears and build consumer trust. The regulators and MININFRA should regularly monitor distributed biogas to maintain the required quality and functionality standards. The service provider and consumer should sign a contract that outlines the scope of the guarantee to settle technical disputes such as biogas malfunctions that may occur after installation. This policy will unlock and expedite the adoption of biogas digester technology to the majority early adopters.

According to the preferences for supplier attributes of biogas technology, the coefficient has a negative sign, which implies that the marginal utility of people increases when the service provider is a private supplier and decreases when the supplier is a government supplier. The average WTP is estimated to be 52,869RWF when the service provider is a private supplier. This implies that people prefer and trust private service providers more than government agencies. However, since the establishment of the biogas programme in 2007, the private sector has shown limited interest in biogas industry participation, which implies relatively low profits for investment. Therefore, the government should develop policies that attract investment through tax subsidies and other incentives to stimulate private sector investment in the biogas energy sector. Moreover, institutional arrangements can play a significant role in the distribution of biogas digester technology to beneficiaries to limit bureaucratic governance and enhance quality service delivery by government institutions.

The time saving attribute shows that the marginal utility of consumers increases when the time saved after the application of biogas energy increases. This indicates that the time people save from biogas digester technology as a substitute for biomass solid fuel is, at least, an average of three to seven hours per day. Katuwal & Bohara (2009) found that after the application of biogas digester technology, households saved substantial time, particularly women, from fuelwood collection and long cooking hours in Nepal. The time saved is used in other productive activities such as crop production, which increased food security in Nepal. Thus, a policy encouraging the universal adoption of biogas digester for cooking, such as promotional and awareness campaigns concerning the benefits of biogas digester technology, and local government meetings, such as “Umuganda”, to raise awareness of biogas technology should be instituted. The government should design a framework for a carbon trading scheme, for the engagement of CDM projects and other climate change mitigation international organizations, and for the involvement of the private sector as occurred in China, India, and Nepal to secure sustainable finance for the biogas program.

This study suggests that an integrated biogas and bio slurry production strategy will contribute multiple benefits and increase the use of biogas technology and its adoption as well as the use of slurry with high-value fertiliser that will increase agricultural productivity and food security.

Based on the multiple, long term, and economic benefits of biogas energy such as fewer health diseases from indoor air pollutions and climatic mitigation, it is paramount to set policy instruments that stimulate biogas energy adoption such as financial subsidies, access to soft loans, tax incentives to share the financial burden of household’s capital investment. This has been applied in the first stages of biogas development in many other developing countries that have attained substantial progress in the biogas industry, such as China, India, and Nepal.

6.3 Limitations of the Study and Future Research

The critical constraint encountered in this study occurred in the data collection period. For the conjoint survey and discrete choice model, the cognitive understanding of hypothetical options on choice card was challenging for respondents, but was tackled by training enumerators prior to the survey administration. This obstacle caused the overall survey to take more time than expected because the enumerators spent more time with respondents to understand the choice card.

The study was focused on households living in rural areas. Therefore, the study recommends future research to extend the survey on both rural and urban households to investigate WTP for domestic biogas digester in Rwanda using CJ and discrete choice models. A wider population study will provide profound information for the evaluation exercise and more generalised estimates.

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APPENDICES

Annex 1 - Generated choice cards

Card ID	Size	Costs	Period of Guarantee	Suppliers	Time Saving
1	$10m^3$	400,000 Rwf	1 Year	Private	3 Hours
2	4 m^3	600,000 Rwf	3 Years	Private	3 Hours
3	10 m^3	600,000 Rwf	5 Years	Government	5 Hours
4	4 m^3	400,000 Rwf	5 Years	Government	5 Hours
5	6 m^3	200,000 Rwf	1 Year	Government	7 hours
6	10 m^3	400,000 Rwf	3 Years	Government	7 hours
7	6 m^3	600,000 Rwf	3 Years	Government	3 Hours
8	6 m^3	200,000 Rwf	3 Years	Government	5 Hours
9	4 m^3	200,000 Rwf	5 Years	Private	7 hours
10	10 m^3	200,000 Rwf	3 Years	Private	5 Hours
11	4 m^3	400,000 Rwf	3 Years	Government	7 hours
12	4 m^3	600,000 Rwf	1 Year	Government	5 Hours
13	10 m^3	200,000 Rwf	5 Years	Government	3 Hours
14	4 m^3	200,000 Rwf	1 Year	Government	3 Hours
15	6 m^3	600,000 Rwf	5 Years	Private	7 hours
16	10 m^3	600,000 Rwf	1 Year	Government	7 hours
17	6 m^3	400,000 Rwf	5 Years	Government	3 Hours
18	6 m^3	400,000 Rwf	1 Year	Private	5 Hours

Annex 2- Survey Questionnaire (English & Kinyarwanda)

REQUEST TO COMPLETE QUESTIONNAIRE

Dear Respondent,

I am a Master's Student of Seoul National University, School of Engineering, South Korea carrying out a research work to "Examine consumer preference to adopt domestic biogas digester technology in Rwanda".

This survey has been designed to investigate the consumer's willingness to pay for domestic biogas digester as a substitute for fire wood and charcoal usage for cooking in the rural areas in Rwanda. The data collected by this survey might assist the government to design coherent policy for dissemination of domestic biogas digesters that benefits the customers.

The survey will be conducted anonymously and will be used solely for the research purposes. All the information recorded will be kept with utmost confidential.

There is no right or wrong answer in this research, so feel free to mark the answers that you think match your thoughts or behaviour.

You are free to ask Research Assistant to clarify any question or to repeat for you to understand it better any time.

Can we begin the interview now?

① ***YES*** *Very* good. ➡ ***START INTERVIEW.***
② ***NO*** Thank you for your time. ➡ **CLOSE THE INTERVIEW.**

SURVEY QUESTIONNAIRE/ BARURA		
Interviewer's Name:/ **Izina ry'umukarani w'ibarura:…………**	Supervisor's Name/**Izina ry'umuyobozi ……………**	Interviewee's Name/**Izina ry'ubazwa**: ……………………………..……
Completed Date: [____/____ /_______]	Checked Date: [____/____ /_______]	Tel Number: …………………… [*This part will be used for controlling RAs by Supervisor only and will be kept confidential]/* ***Ikigice kizakoreshwa n'umugenzuzi mukumenya ko mwabonanye n'umukarani w'ibarura.***

⊗ Please RA fill the location of the Respondent/ **Umukarani w'ibarura uzuza aho ubazwa atuye:**

Province: **District:** **Sector:** **Cell:**

CONJOINT SURVEY ON WILLINGNESS TO PAY FOR DOMESTIC BIOGAS DIGESTER TECHNOLOGY FOR COOKING AND LIGHTING IN THE RURAL AREAS IN RWANDA.

* DESCRIPTION OF ATTRIBUTES

Attributes		Attributes Levels
Size	**Description**	- The biogas plant varies from $4m^3$ to $10m^3$ internal volume of biogas plant based on common practice of small scale domestic biogas plants in Rwanda. - Each biogas plant has different internal volume and performance capacity, and required feed stocks for gas generation per day for household use.
	3 Levels	① The plant size of $4m^3$ plant capacity ② The plant size of $6m^3$ plant capacity ③The plant size of $10m^3$ plant capacity
Costs	**Description**	- The current costs for construction of biogas plant varies from plant size assuming constant technology. - The minimum capital cost for small scale biogas plant is 200,000frw and maximum cost is 600,000frw including government subsidies in Rwanda.
	3 Levels	① The cost for construction of domestic biogas plant is 200,000 Rwf ② The cost for construction of domestic biogas plant is 400,000 Rwf ③The cost for construction of domestic biogas plant is 600,000 Rwf
Guarantee Period	**Description**	- The guarantee period given to the consumer after the construction of the domestic biogas plant by the supplier to ensure quality and sustainability of the facility. - The guarantee ranges between 1 to 5 years of installed facility to a household up to its life time estimated to 20 – 30 years.
	3 Levels	① The guarantee period assumed to be 1 year ② The guarantee period is 3 years ③ The guarantee period is 5 years
Supplier	**Description**	- The most preferred and trusted service providers of household biogas digester for cooking - There are two service providers such as government and private providers.
	2 Levels	① Government service providers

		② Private service providers
Time savings	**Description**	- The time saved by household per day after using domestic biogas plant ranges between 3 to 7 hours. - Biogas plant can reduce time used for cooking and firewood collection.
	3 Levels	① The time household can save is 7hours after use of the biogas energy ② The time household can save is 5hours after use of the biogas energy ③The time household can save is 3hours after use of the biogas energy

PART I: CONJOINT SURVEY WITH CHOICE CARDS.

Assume that you want to purchase domestic biogas digester for cooking and lighting to replace the current cooking stove, what biogas plant would you prefer most to construct among others based on the list of hypothetical options given below. Please rank them from 1-3 (where **1= Most preferred option** and **3 = Least preferred option**) and **no choice** mark **(X)** for your choice as provided below;/**Uramutse ushatse kubaka Biyogazi murugo rwawe ukayisimbuza uburyo gakondo wakoreshaga mugucana no kumurika munzu, nubuhe bwoko wifuza cyane murubu bukurikira, butondeke uhereye kuri 1-3 (Aho 1 bisobanura ubwoko bukunyuze cyane, naho 3 bisobanura ubwoko bukunyuze gacye cyane). Kudahitamo gukoresha biyogaze andika (X).**

Card 1: Please rank your most preferred and least preferred biogas plant choice for your household as seen below**/ Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane (1-3):**

Attributes for domestic Biogas digester /Ibiyigize Biyogaze	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/ Ntayo Nyeneye**
Size/ **Ingano yayo**	4M3	6M3	10M3	
Costs/**Igiciro cyokuyubaka**	600,000Rwf	200,000 Rwf	600,000 Rwf	
Guarantee period/**Garanti wahabwa uyubatse**	3 Years	3 Years	1 Year	
Suppliers/ **Uwayikubakira**	Private	Government	Government	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	3 Hours	5 Hours	7 hours	
Ranking from 1-3 where, ***(1= Most preferred & 3 = Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 5 mentioned herein remains constant

Card 2: Please rank your most preferred and least preferred biogas plant choice for your household as seen below**/ Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane:**

Attributes for domestic Biogas digester /Ibiyigize Biyogaze	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/ Ntayo Nyeneye**
Size/ **Ingano yayo**	4M3	6M3	10M3	
Costs/**Igiciro cyokuyubaka**	400,000 Rwf	200,000 Rwf	400,000 Rwf	
Period of Guarantee/**Garanti wahabwa uyubatse**	5 Years	1 Year	1 Year	
Suppliers/ **Uwayikubakira**	Government	Government	Private	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	5 Hours	7 hours	3 Hours	
Ranking from 1-3 where, ***(1= Most preferred & 3= Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 5 mentioned herein remains constant

Card 3: Please rank your most preferred and least preferred biogas plant choice for your household as seen below/ **Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane:**

Attributes for domestic Biogas digester /Ibiyigize Biyogaze	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/ Ntayo Nyeneye**
Size/ **Ingano yayo**	6M3	4M3	10M3	
Costs/**Igiciro cyokuyubaka**	600,000 Rwf	200,000 Rwf	600,000 Rwf	
Period of Guarantee/**Garanti wahabwa uyubatse**	3 Years	5 Years	5 Years	
Suppliers/ **Uwayikubakira**	Government	Private	Government	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	3 Hours	7 hours	5 Hours	
Ranking from 1-3 where, ***(1= Most preferred & 3 = Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 5 mentioned herein remains constant

Card 4: Please rank your most preferred and least preferred biogas plant choice for your household as seen below/ **Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane:**

Attributes for domestic Biogas digester /Ibiyigize Biyogaze	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/ Ntayo Nyeneye**
Size/ **Ingano yayo**	10M3	6M3	4M3	
Costs/**Igiciro cyokuyubaka**	200,000 Rwf	400,000 Rwf	600,000 Rwf	
Period of Guarantee/**Garanti wahabwa uyubatse**	3 Years	5 Years	1 Year	
Suppliers/ **Uwayikubakira**	Private	Government	Government	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	5 Hours	3 Hours	5 Hours	
Ranking from 1-3 where, ***(1= Most preferred & 3 = Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 5 mentioned herein remains constant

Card 5: Please rank your most preferred and least preferred biogas plant choice for your household as seen below/ **Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane:**

Attributes for domestic Biogas digester /Ibiyigize Biyogaze	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/ Ntayo Nyeneye**
Size/ **Ingano yayo**	10M3	6M3	4M3	
Costs/**Igiciro cyokuyubaka**	200,000 Rwf	600,000 Rwf	400,000 Rwf	
Period of Guarantee/**Garanti wahabwa uyubatse**	5 Years	5 Years	3 Years	
Suppliers/ **Uwayikubakira**	Government	Private	Government	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	3 Hours	7 hours	7 hours	
Ranking from 1-3 where, ***(1= Most preferred & 3 = Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 6 mentioned herein remains constant

Card 6: Please rank your most preferred and least preferred biogas plant choice for your household as seen below/ **Tondeka ubwoko wahisemo uhereye kubukunyuze cyane usoreze kubukunyuze gacye cyane:**

Attributes for domestic Biogas digester /Ibiyigize	**Biogas Plant A**	**Biogas Plant B**	**Biogas Plant C**	**No choice/Ntayo Nyeneye**
Size/ **Ingano yayo**	10M3	6M3	4M3	
Costs/**Igiciro cyokuyubaka**	400,000 Rwf	400,000 Rwf	200,000 Rwf	
Period of Guarantee/**Garanti wahabwa uyubatse**	3 Years	1 Year	1 Year	
Suppliers/ **Uwayikubakira**	Government	Private	Government	
Time Saving/ **Igihe wabona cyo kuruhuka k'umunsi uyikoresheje**	7 hours	5 Hours	3 Hours	
Ranking from 1-3 where, ***(1= Most preferred & 3 = Least preferred option)***	( )	( )	( )	( )

Note: Assume that all other attributes besides 5 mentioned herein remains constant

Note: Please Research Assistant (RA) Tick the option(s) chosen by respondent from the list of alternative provided below/**Umukarani w'ibarura kosora igisubizo uhawe n'ubazwa mubisubizo binyuranye wahawe hasi:**

PART II: ENERGY UTILISATION OF HOUSEHOLD/ INGUFU ZIKORESHWA N'URUGO

1. What kind of cooking fuel mostly do you use in your household/ **Ni ubuhe bwoko bw'ibicanwa utecyesha cyane m'urugo rwawe?**

①Fire wood/**Inkwi** ②Charcoal/**Amakara** ③Agricultural waste/**Ibikomoka k'ubuhinzi** ④LPG gas/**Gaze** ⑤Paraffin/ **Mazutu** ⑥ Electricity/ **Amashanyarazi** ⑦ Biogas/ **Beyogaze** ⑧Others specify/**Ibindi bivuge** ……..

2. How often do you cook per day in your household/ **kumunsi muteka inshuro zingahe m'urugo rwanyu?**

①Once/**Rimwe** ②Twice/**Kabiri** ③Trice/**Gatatu** ④Fourth/**kane** ⑤More than four times/ **zirenze enye**

3. Do you purchase cooking fuel in your household/ **Mwaba mugura ibicanwa m'urugo rwanyu?**

①Yes ② No **(Skip to Qn 5)**

4. How much do you spend for cooking fuel per month**/ Mutanga amafaranga angahe ku kwezi mugura ibicanwa?** (________) R Rwf /Month **(Skip to Qn 8)**

5. If No, where do you get the main cooking fuel in your household? **/ Niba ntayo mutanga, mwaba mukurahe akenshi ibicanwa mutecyesha m'urugo rwanyu?**

①Own Farm/ **Isambu** ②Forest/ **Ishyamba** ③Woodlot/ **Aho batoragura inkwi kugasozi**
④Others specify/**Ahandi havuge…………….**

6. If you use firewood/agricultural wastes, how often do you collect them/**Niba utecyesha inkwi cg ibikomoka kubuhinzi, waba ujya gusenya kangahe mu icyumweru?** (________) Per Week

7. How long does it take to collect fire wood for cooking/**Byaba bigutwara amasaha angahe kujya gusenya mu icyumweru?** (_________________) hours/week

8. What is the main form of energy do you use for lighting/**Nubuhe bwoko bwingufu ukoresha mukubonesha munzu ninjoro?**

①Fire wood/I**nkwi** ②Candle/**Buje** ③Paraffin/**Petorori** ④ Electricity/**Amashanyarazi**
⑤ Solar PV/**Imirasire y'izuba** ⑥Batteries/ **Amabuye/ Itoroshi** ⑦Others specify/ **Ibindi bivuge** ……..

9. How much do you spend on fuel for lighting per month/ **Utanga amafaranga angahe ku kwezi ugura ingufu zo kubonesha munzu?** (_________________) Rwf/Month

10. Have you ever heard the domestic Biogas digester for cooking and lighting**/ Waba warigeze kumva biyogaze yogutekeraho nokubonesha munzu ninjoro?**

①Yes ②No

11. After hearing about its benefits, are you willing to use it as a substitute to firewood and charcoal for cooking fuel/ **Umaze kumva akamaro kayo waba wifuza kuba wayikoresha igasimbura inkwi cg amakara wakoreshaga muguteka?**

(*Please RA first explain briefly what is biogas digester and its importance on health, money savings, agricultural purpose and environmental benefits to the respondent/* ***Umukarani w'ibarura musobanurire ibyiza byayo mbereyuko umubaza***)

①Yes **(Skip to Qn 13)** ②No

12. What are the reasons for dislike to use Biogas digester for cooking and lighting in your household/ **Nizihe mpamvu zituma utayikoresha murugo rwawe?**

①Expensive/**Irahenze** ② Complex/**Iragoye kuyikoresha** ③Religion/**Idini** ④Lack of knowledge/ **Ntabumenyi** ⑤Culture factor/**Umuco** ⑥fire woods are free/ **Inkwi nubuntu** ⑦Risky/ **Yatera impanuka** ⑧ Others specify/ **Ibindi bivuge**……………

13. If government assists you to get soft loans for biogas plant construction from microfinance institutions such as SACCO will you accept to get loan**/Mugihe leta yagufasha kubona inguzanyo iciriritse mubigo by'imari na SACCO yokubaka biyogaze murugo rwawe wakwemera kuyifata?**

①Yes ② No

14. What is the distance from your nearest water source/ **Hangana gute kuva iwawe ugera kwivomo rikwegereye?**(_____) Meters

15. How do you understand the biogas digester technology for cooking and light/ **Ese waba wumva ute beyogaze icanwa kandi ikamurika munzu? (**Many answers are allowed**/ Ibisubizo byishi biremewe)**

①Easy to use/**Biroroshye kuyikoresha** ②Complex/ **Biragoye** ③Risk/ **Yatera impanuka** ④Expensive/**Irahenze** ⑤Cost effectiveness/ **Irahendutse** ⑥Health Safety/ **Ntangaruka yatera kubuzima** ⑦Environmental friendly/**Ntangaruka igira kubidukikije** ⑧Good for fertilizers/**Igira ifumbire nziza** ⑨Convenient/ **Ninsirimu** ⑩Others specify/ **Izindi zivuge**………….

16. What can be done by the government and other stakeholders to promote use of domestic biogas digester for cooking in your village**/Niki wumva leta n'abafatanyabikorwa bayo bakora muguteza imbere ikoreshwa rya biyogaze mumudugudu mutuyemo? (**Many answers are allowed**/ Ibisubizo byishi biremewe)**

①Awareness campaign/**Ubukangurambaga** ②Subsidy/**Ubufasha/ubwasisi** ③Access to soft loan/**Gutanga inguzanyo ziciriritse** ④Installment payment/**Kwishyura mubice** ⑤Decentralize biogas program/**Kuyegereza abaturage** ⑥Reduce costs/**Kugabanya ibiciro** ⑦Coherent policy/ **Gushyiraho ingamba zinoze** ⑧Increase skilled man powers/**Kongera umubare w'impugucye zayo** ⑨Others specify/**Ibindi bivuge ………**

17. How would you rate your knowledge about the domestic biogas digester for cooking and lighting? Choose the number that matches well your level of knowledge from the Likert scale of 1-7, where **1** is ***limited knowledge*** and **7** is ***the highest knowledge/ Nigute wagereranya ubumenyi ufite kuri biyogaze ikoreshwa muguteka no kumurika munzu, hitamo umubare ugaragaza urwego rw'ubumenyi ufite aho 1 bivuze ubumenyi bucye cyane naho 6 bivuze ubumenyi bwishi cyane.***.

1	2	3	4	5	6	7

PART III: IDENTIFICATION OF RESPONDENT/

UMWIRONDORO W'UBAZWA

18. Gender of the respondent**/ Igitsina cy'ubazwa?**

① Male/ **Gabo** ② Female/**Gore**

19. How old are you**/Waba ufite imyaka ingahe?** (_______________)Years

20. What education level do you have**/Warangije ikihe cyiciro cy'amashuri?**

① Primary/**Abanza** ②Secondary/**Ayisumbuye** ③TVET/**Imyuga** ④ University/**Kaminuza** ⑤None/ **Ntacyo**

21. What is your primary occupation**/Nuwuhe murimo wingezi ukora?**

①Farming/**Ubuhinzi-bworozi** ②Self-employed/ **Ndikorera** ③Salaried employment/**Mpembwa kukwezi** ④Casual Labor/**Nkorera abandi bubyizi** ⑤ Others (Specify/ **Ibindi bivuge** …………………………..)

22. If you practice farming, do you use fertilizers from your livestock to improve soil fertility**/Niba ukora umwuga w'ubuhinzi, waba ukoresha ifumbire ivuye mumatungo yawe murwego rwokongera umusaruro?**

① Yes ② No

23. What is your marital status**/Tubwire irangamimerere yawe?**

① Married/**Narashatse** ②Single/**Ingaragu** ③Divorced/separated/T**waratandukanye**

④Widow/**Umupfakazi**

24. How many members in your household**/Umuryango wawe ugizwe nabantu bangahe?**

(____________)

25. What is the size of your land**/Tubwire ingano yubutaka bwawe?** (______________) M^2

26. How many cows do you have in your household**/Waba ufite inka zingahe?** (__________)

27. How many other livestock do you have in your household**/Andi matungo ufite nangahe?**

①Pigs/**Ingurube**………… ②Goats/ **Ihene**…………. ③Sheep/ **Intama**……… …④Others specify/ **Andi yavuge**…………

28. What kind of grazing do you practice**/Nubuhe bwoko bwurwuri ukoresha?**

①Zero grazing/ **Nororera mukiraro** ②Open grazing/**Ndagira munzuri/ kugasozi**

29. How much money do you spend per month in your household**/ Waba ukoresha amafaranga angahe kukwezi mugutunga umuryango wawe?** (__________________) Rwf /Month

Thank you very much for your participation and time, we would like to notice you that information you have provided certainly will not be used for other purposes than for the objectives mentioned herein of this survey. /**Umukarani w'ibarura ashimira umuhaye amakuru kubwumwanya aguhaye.**

ABSTRACT IN KOREAN (국문 초록)

르완다의 가정용 바이오 가스 디제스터 기술 도입에 대한 소비자 선호 분석

갓프레이

기술 경영 경제 정책 전공

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장작, 숯, 농산 폐기물과 같은 전통적인 바이오 메스 에너지가 건강, 환경, 경제에 부정적인 영향을 미친다는 사실에도 불구하고, 현재 르완다 시골지방에서는 전체 가구의 약 99.4%가 요리에 전통적인 바이오 메스 에너지를 사용하고 있다. 이와 같은 에너지 문제를 해결하기 위해 르완다 정부는 여러 신재생 에너지 정책을 통해 요리에 사용될 수 있는 깨끗하고 현대적인 에너지 대안을 제공하기 시작하였다. 이 중 저렴하면서도 실행 가능하여 큰 주목을 받고 있는 것이 바이오 가스 기술이다. 바이오 가스 기술은 요리에 필요한 에너지 수요를 충족시킴과 동시에 건강, 환경, 경제에 여러 이점을 가지고 있는데, 특히 농산물

생산에 필요한 슬러리를 제공하기도 한다. 이에 따라 르완다 정부는 바이오 가스 디제스터를 부분적으로 설치하는 소비자에게 약 300,000RFW 를 보조금으로 제공하여 바이오 가스의 사용을 확대하고자 노력하였으나, 보급률은 2007 년 이래 여전히 1%에 머물고 있다. 정부의 노력에도 불구하고 보급이 확산되지 않는 이와 같은 모습은 현재의 바이오 가스 정책이 과연 소비자들의 바이오 가스 디제스터 도입을 촉진하고 있는가 하는 의문을 제기한다. 이 문제에 답하기 위해 본 연구에서는 컨조인트 분석과 이산선택모형을 이용하여 시골지역 주민을 대상으로 전통적인 바이오 메스 에너지의 대안으로서 바이오 가스 디제스터 사용에 대해 얼마를 지불할 것인지(Willingness-to-pay, WTP)를 분석하였다. 구체적으로, 시골지역의 250 개 가구를 대상으로 컨조인트 설문을 시행하여 4,500 개의 관측치를 수집하였다. 표본은 많은 양의 소가 살고 있는 5 개의 지역에서 추출되었는데 이는 소의 배설물이 바이오 가스 생산에 주 공급원료이기 때문이다. 따라서 설문 대상도 적어도 3 마리의 소를 보유한 가구로 한정하였다. 바이오 가스 디제스터 기술에 대한 소비자의 WTP 를 분석하기 위한 모형으로는 순위 로짓 모형(rank-ordered logit model)이 활용되었으며, 이에 적용하기 위해 바이오 가스의 속성을

크기, 비용, 보증 기간, 서비스 제공자, 적용 후 절약 시간 등의 5 가지로 가정하고 18 개의 대안 세트를 구성하였다.

분석 결과, 바이오 가스 디제스터의 크기가 크고 비용이 적을수록 바이오 가스 디제스터 도입에 대한 소비자의 효용이 높았으며, 보증 기간이 길고 민간 사업자가 서비스를 제공하는 경우 효용이 더 컸다. 또한 가구 소득이 높은 소비자가 바이오 가스 디제스터 도입으로부터 얻는 효용이 상대적으로 더 큰 것으로 나타났다. 본 연구의 결과는 정부가 바이오 가스 디제스터 기술의 이점을 국민들에게 홍보하려는 노력을 더욱 강화하여야 한다는 점을 시사한다. 또한 바이오 가스 디제스터의 크기, 표준에 대한 소비자의 선호에 기반하여 유연한 보조금 정책을 구성하여야 하며, 세금 보조, 소프트론과 같은 강력한 인센티브를 줄 수 있도록 규칙적인 모니터링 시스템을 활용한 품질 보증 프레임워크를 만들 것을 제안한다. 뿐만 아니라, 합법적이고 규제력을 지닌 프레임워크를 통해 민간 사업자가 바이오 가스 산업에 투자하도록 유도하여야 할 것이다.

키워드: 소비자 선호; 컨조인트 분석; 이산 선택 모형; 가정용 바이오 가스 기술; 지불용의(가격); 르완다.

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