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ASSESSMENT OF MAIZE AND RICE RESIDUES FOR RURAL ELECTRIFICATION IN GHANA: A CASE STUDY IN EJISU-JUABEN DISTRICT

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By

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Declaration

I, **Sarkodie Wilson Ofori**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Abstract

The study assesses the potential of maize and rice residues for rural electrification in Ghana using Ejisu-Juaben District as a case study. The focus of the thesis was based on agriculture residues pathways for rural electricity generation. More specifically, to assess crop residues potential for rural electrification in Ejisu Juaben District by gasification or combustion technology using the BEFS Rapid Appraisal tools and approach.

Structured interview of farmers and local authorities and detailed study of the available literature and scientific reports on the production, collection, disposal and other uses of residues was carried out to collect additional data and information from some selected communities (Besease, Nobewam and Donaso) within the Ejisu Juaben District. A Bioenergy and Food Security Rapid Appraisal (BEFS RA) Assessment was carried out using collected data from questionnaires, FAOSTAT, World Development Indicators (WDI) and Data from National Statistical Agencies in Ghana such as Ghana Statistical Service, National Energy Statistics, Ghana Living Standard Survey and Fact and Figures from Ministry of Food and Agriculture (MoFA).

The total amount of residues (maize stover, maize husk, maize cob and rice husk) generated on the field was 13, 043 tonne per year. Out of this amount, 12, 565 tonne per year is available for bioenergy. Maize stover generates the largest quantity of residues, contributing about 88% by weight of the total available residues. The findings show that, combustion pathway is the most preferable choice since it recorded the least unit price of electricity, 1.36 USD per kWh as compared to gasification of 1.37 USD per kWh. The combustion pathway can create 14 potential plants, 74 potential jobs and 184 household electricity connections. In addition, maize stover and maize cob are the most feasible options for power generation at all plant capacities since they provided a positive NPV, thus 104,000 and 102,000 USD respectively. Therefore, combustion pathway is the most feasible option over gasification.

Keywords: Renewable Energy, Biomass and Bioenergy and Food Security Rapid Appraisal (BEFS RA)

Résumé

L'étude évalue le potentiel des résidus de maïs et de riz pour l'électrification rurale au Ghana à l'aide du district d'Ejisu-Juaben comme étude de cas. L'objectif de la thèse était basé sur les voies de résidus agricoles pour la production d'électricité en milieu rural. Plus précisément, pour évaluer le potentiel des résidus de cultures pour l'électrification rurale dans le district d'Ejisu Juaben par la technologie de la gazéification ou de la combustion à l'aide des outils et de l'approche d'évaluation rapide BEFS.

Une entrevue structurée auprès des agriculteurs et des autorités locales et une étude détaillée de la littérature disponible et des rapports scientifiques sur la production, la collecte, l'élimination et autres utilisations des résidus a été effectuée pour recueillir des données et des informations supplémentaires auprès de certaines communautés sélectionnées (Besease, Nobewam et Donaso) Le district d'Ejisu Juaben. Une évaluation rapide de la bioénergie et de la sécurité alimentaire (BEFS RA) a été effectuée à l'aide des données collectées provenant de questionnaires, FAOSTAT, Indicateurs du développement mondial (WDI) et des données des agences statistiques nationales au Ghana, telles que le Service statistique du Ghana, les Statistiques énergétiques nationales, le Ghana Living Standard Survey Enquête et faits et chiffres du ministère de l'Alimentation et de l'Agriculture (MoFA).

La quantité totale de résidus (farine de maïs, coquille de maïs, cochenille de maïs et coquille de riz) générée sur le terrain était de 13 043 tonnes par an. Sur ce montant, 12,55 tonnes par année sont disponibles pour la bioénergie. Maize Stover génère la plus grande quantité de résidus, contribuant à environ 88% en poids du total des résidus disponibles. Les résultats montrent que la voie de combustion est le choix le plus préférable puisqu'il enregistre le prix unitaire le moins élevé d'électricité, 1,36 USD par kWh par rapport à la gazéification de 1,37 USD par kWh. La voie de combustion peut créer 14 plantes potentielles, 74 emplois potentiels et 184 connexions d'électricité domestique. En outre, le grille de maïs et l'arachide de maïs sont les options les plus réalisables pour la production d'électricité à toutes les capacités de l'installation, car elles ont fourni une VPN positive, donc 104 000 et 102 000 USD, respectivement. Par conséquent, la voie de combustion est l'option la plus réalisable par rapport à la gazéification.

Acknowledgement

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LIST OF ABBREVIATION

BEFS	Bioenergy and Food Security
BEFS AF	Bioenergy and Food Security Analytical Framework
BEFS RA	Bioenergy and Food Security Rapid Appraisal
CHP	Combine Heat and Power
CRI	Crop Residue Index
EIA	US Energy Information and Administration
FAO	Food and Agriculture Organization
GLSS	Ghana Living Standard Survey
GWEC	Global Wind and Energy Council
IRR	Internal Rate of Return
IRENA	International Renewable Energy Agency
MoFA	Ministry of Food and Agriculture
NPV	Net Present Value
RE	Renewable Energy
RPR	Residue-to-Product Ratio
OECD	Organization for Economic Co-operation and Development
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER ONE

1 Introduction

1.1 Background to the study

The combustion of fossil fuels has created a global concern for the environment and world economy. Also, overuse of fossil fuel is increasing the carbon dioxide level in the atmosphere and significantly contributes to global warming (Silva Lora et al., 2011; Abdel-Fattah and Abdel-Naby, 2012). Fossil fuel resources such as coal, oil and natural gas are expected to peak in 46, 57 and 22 years respectively (Greene at al., 2006; Maggio and Cacciola, 2015).

The aforementioned reasons have directed national and regional policies toward the utilization of biomass for meeting their future energy demands to meet carbon dioxide reduction targets as specified in the Kyoto Protocol as well as to decrease the dependence on the supply of fossil fuels (Sarkar et al., 2012). There is a pressing need to adapt the use of biomass as a renewable and clean energy source. However, the use of food crops as biomass for bioenergy has sparked debate about its sustainability. The focus of the debate include food price increases, land competition and greenhouse effects. Recent research studies have focused on the use of non-edible raw material to produce biofuels from lignocelluloses and marine algae rather than first-generation biomass such as wheat, corn, sugar beet, barley, potato, sugar cane, sunflower, rapeseed, palm, soybeans, and coconut (Demirbas, 2010; Ganguly et al., 2012). Biomass residues usage contributes to the share of renewable energy sources for energy production, decreasing fossil fuel imports, simultaneously decreasing the risk of forest fires and reducing atmospheric carbon dioxide concentration to reduce greenhouse effect (Fernandes and Costa, 2010). There are different end use options of biomass which include electricity generation, heating homes, fueling vehicles and providing process heat for industrial facilities (Fernandes and Costa, 2010).

Ghana, which was formerly known as Gold Coast, is on the west coast of Africa. In 2015, the population stood at about 27 million with relatively high growth rate of 2.4% per annum (Ghana

Statistical Service, 2016). Ghana's gross domestic product growth since 2001-2009 averaged around 5.5% and this has risen to 8% since the production of crude oil in 2010 (IRENA, 2015). The country's GDP per capita is 1.5 billion (Energy Commission, 2015). The country's total land area of 23,884,245 ha is divided into ten administrative regions. Agricultural land area is approximately 13,600,000 ha representing 56.94% of the total land area of which total cultivated land is 6,421,450 ha, which represent 47.22%. The area under inland waters, forest reserves, savanna and woodland cover an area of 8,856,021 ha representing 41.2% (Agriculture Facts and Figures, 2016). Modern energy access has not kept up with electricity access in Ghana as electricity accounted for 64.2% of households lighting fuels in 2010. The situation is far worse in rural communities where close to 90% of households depend on either firewood, charcoal and agricultural residues for cooking (IRENA, 2015). (See Figure 1.1)

The Energy sector in Ghana is faced with two principal challenges which are: (1) the inability to provide adequate electricity generation capacity to ensure reliable power supply and (2) the increased use of wood-fuels as main cooking fuel for close to 80% of households who do not have access to modern cooking fuels (Kemausuor et al., 2015). Electricity generation, which in the past depended mainly on hydropower is increasingly shifting towards a more expensive thermal generation. This has resulted in erratic electricity supply because of low water inflow in the hydropower dams and increasing price cost of crude oil as government struggle to purchase fuel to run the thermal plants. In addition, population growth and urbanization have increased energy demand in recent time.

According to Hensley et al. (2011), the increased energy demand is however pronounced in the use of wood fuel more particularly charcoal. The task facing technology developers and policy makers is to move beyond the use of biomass in traditional forms and to introduce technologies that utilize biomass to produce modern fuel such as electricity and heat at both small and large-scale levels. The modern use of biomass can contribute significant share of renewable energy and decrease dependence on oil.

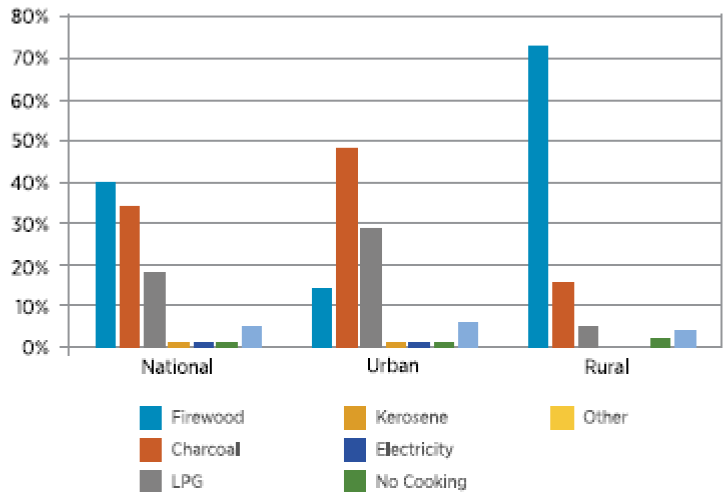


Figure 1.1: Access to fuels in Ghana (IRENA, 2015)

Ghana's renewable Energy Act (RE Act) which was enacted in 2011 has as one of its aims to promote biomass use for electricity generation. In accordance with this, a number of scientific research work have been conducted which indicate potential of modern biomass fuels in Ghana. Some of these studies include those by Bellot et al. (2016), Arranz-Piera et al. (2017), Kemausuor et al. (2014) and Duku et al. (2011). However, these studies have focused on aggregated biomass at the national level. There is limited study at the district level regarding the use of crop residues such as maize and rice for rural electrification using mini-grids for example. In addition, there is no published work done in Ghana that uses the FAO Bioenergy and Food Security (BEFS) Rapid Appraisal approach for crop residues assessment.

1.2 Research hypothesis

- Maize and rice residues have the potential to produce electricity for rural communities in Ejisu Juaben District.
- Gasification of maize and rice residues for rural electrification is feasible and profitable.
- In terms of labour and energy access, gasification has the highest potential for rural electrification.

1.3 Aim and objectives

1.3.1 Aims

The focus of the thesis will be on agricultural residue pathways for rural electricity generation. More specifically, to assess crop residues potential for rural electrification in Ejisu-Juaben District by gasification or combustion technology using the BEFS Rapid Appraisal tools and approach.

1.3.2 Specific Objectives

- To provide an indication of the amount of rice and maize residues based on both aggregated and site-specific data.
- To estimate the available potential of rice and maize residues.
- To perform a techno-economic analysis of related combustion and gasification pathways, including:
    - Defining which electricity generation capacities will be more profitable.
    - Considering current uses, is there enough biomass available to supply 10kW, 40kW or 100kW plant capacity?
    - Would it be economically feasible to collect and mobilize the biomass required?
    - How many jobs will be created? How many households can be supplied?

1.4 Research question

- What is the potentially available amount of maize and rice residues that could be available for energy production?
- Which rural electrification technology pathway is feasible and profitable?
- In terms of labour and energy access, what potential do the selected electrification pathways have?

The outcome of the study will inform decision makers to facilitate investment into clean energy technologies using crop residues as feedstock. The outcome of this study will also enhance food security, as successful implementation will reduce the use of edible crops for energy generation and mitigate climate change. Researchers and students can make inference for their scientific research.

CHAPTER TWO

2 Literature review

2.1 Current worldwide energy scenario

The total primary energy consumption will rise from 549 quadrillion Btu in 2012 to 815 quadrillion Btu in 2040 which account for 48% increase (EIA, 2016). This confirms that the world still relies heavily on fossil fuel to meet international energy demands. However, the negative consequences related to consumption of fossil fuels include the depletion of the reserves, impact of CO_2 emissions as well as economic dependence on countries where political instability is prevalent (Schabort, 2014).

The energy consumption projections are divided according to Organization for Economic Cooperation and Development members (OECD) and non-members (non-OECD). The OECD members are divided into three basic country grouping thus OECD Americas (United States, Canada and Mexico/Chile), OECD Europe and OECD Asia (Japan, South Korea and Australia/ New Zealand). Non-OECD countries are divided into five separate regional subgroups: non-OECD Europe; Africa; and Non-OECD Americas (which include Brazil) (EIA, 2016). (See Figure 2.1)

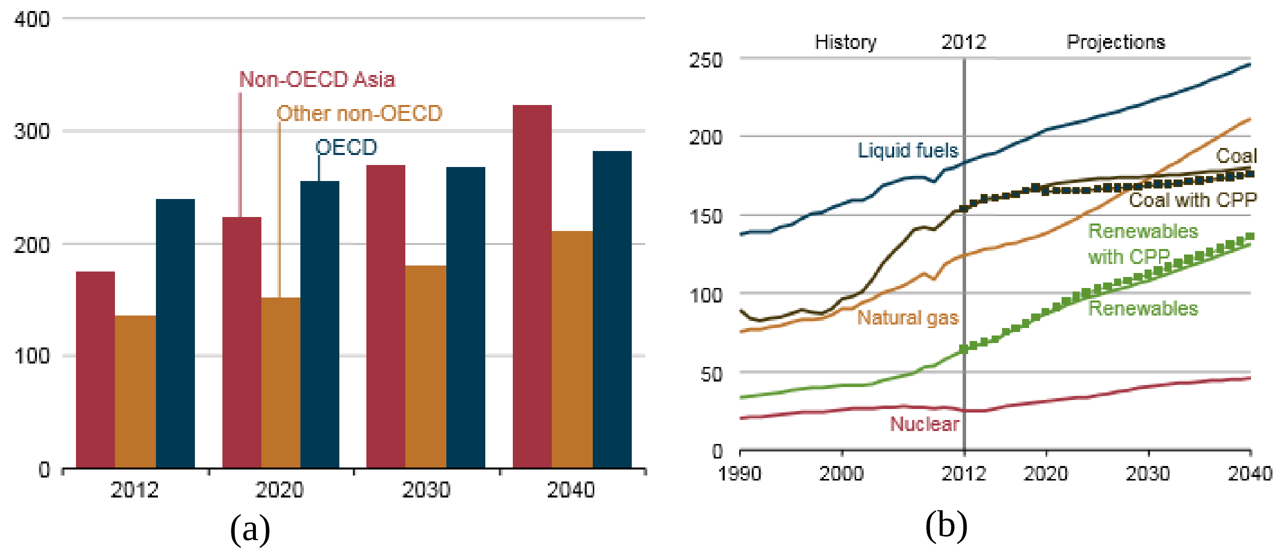


Figure 2.1: (a) World energy consumption by country grouping, 2012-2040 and (b) Total world energy consumption by energy source, 1990-2040 (EIA, 2016)

2.1.1 Fossil fuel

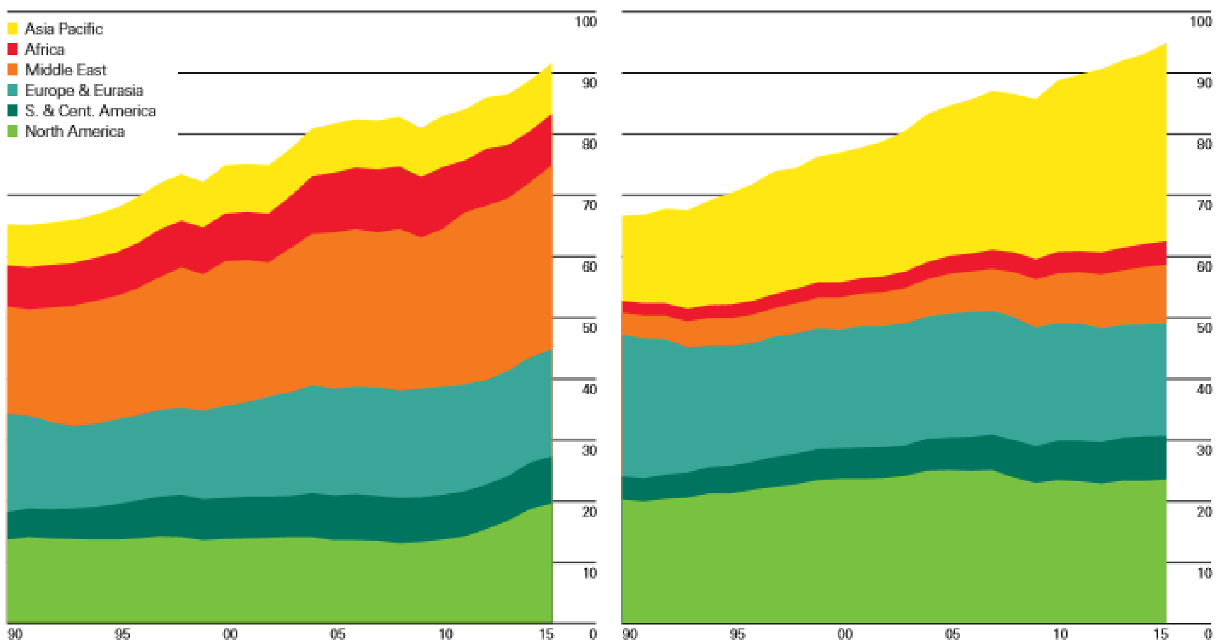
The world's largest energy source still remain fossil fuel in the form of oil, natural gas and coal (EIA, 2016). These fuels play an important role in generation of electricity and in the production of transportation fuels. The worldwide energy needs are met by about 87% of fossil fuels of which 97% are used in the transportation sector (Schabort, 2014; EIA, 2013; BP Statistical Review of World Energy, 2013).

2.1.1.1 Oil

Oil is the biggest contributor to energy in the world with a market share of 33.1% (Schabort, 2014). The world use of petroleum and other liquid fuels are expected to grow from 90 million barrels per day in 2012 to 100 million barrel per day in 2020 and to 121 million barrel per day in 2040 (EIA, 2016). According to BP Statistical Review of World Energy (2016), 43.3% of oil is being produced by the four biggest oil producing countries that is United States of America

(13%), Saudi Arabia (13%), Russia (12.4%) and China (4.9%). The two kinds of oil are conventional and unconventional. Conventional oils are light hydrocarbons with a light to medium viscosity and extracted from porous and permeable reservoirs as well as natural gas liquids whilst unconventional oils are heavy oil, oil sands and oil shale.

The total proven oil reserves of both conventional and unconventional as the end of 2015 were calculated to be 1697.6 billion barrels with Middle East recording the highest (47.3%) followed by South and Central America (19.4%), North America (14%), Europe and Eurasia (9.1%), Africa (7.6%) and Asia Pacific (2.4%) recording the lowest (BP Statistical Review of World Energy, 2016). The global proved oil reserves in 2015 fell by 2.4 billion barrels which is 0.1% of 1697.6 billion barrel total proven reserves.

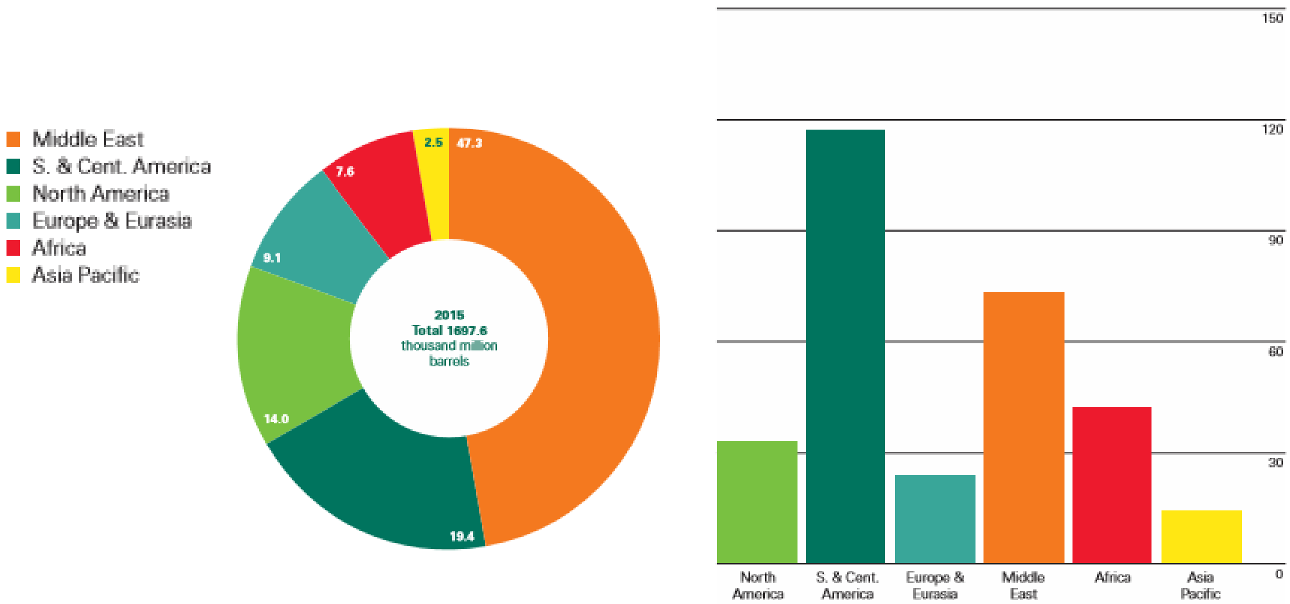


(a) (b)

Figure 2.2:(a) Oil production by region million barrels daily and (b) Oil consumption by region million barrels daily (BP Statistical Review of World Energy, 2016)

Many studies have projected when peak oil production will occur. Peak oil production will occur somewhere from 2009 to 2021 (Maggio and Cacciola, 2015). Greene at al. (2006) also anticipate that there will be a severe contraints on oil production by 2023. In addition, Valero and Valero (2010) conservative resource study showed that the point of oil peak production has already been reached since 2008.

According to the trend in oil consumption, all conventional oil reserves will be depleted within 46 years (Schabort, 2014). In order meet the growing energy demand, a mojor change over of conventional to uncoventional is required. According to Greene at al. (2006) the switch from conventional to unconventional oil should occur at rate of 7-9% per annum before 2030.



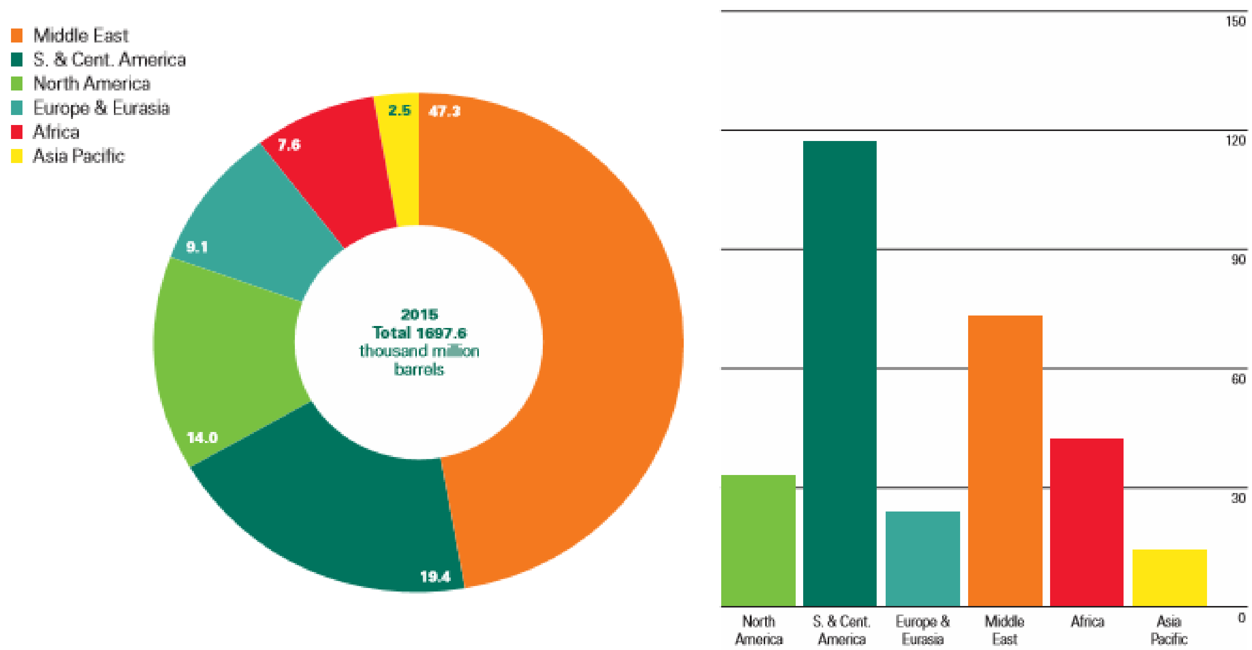
(a) (b)

Figure 2.3: (a)Distribution of proven reserve in 2015 and (b) Reserves-to-production ratio by region in 2015 (BP Statistical Review of World Energy, 2016)

2.1.1.2 Coal

The worldwide consumption of coal increased at the end of 2012 by 2.5% (BP Statistical Review of world Energy , 2013). However, the production and consumption of coal declined by 4% and 1.8% respectively at the end of 2015 (BP Statistical Review of World Energy, 2016). The worldwide proven reserves in 2015 were enough to meet 114 years of global production and by far the largest reserve-to-production ratio for any fossil fuel (BP Statistical Review of World Energy, 2016). According to Maggio and Cacciola (2015), coal account for 23.9% of the world's primary energy demand making the second largest fossil fuel contributor. Coal is the most abundant fossil fuel even though is not the largest fossil fuel energy contributor. By region, Europe and Eurasia hold the largest proved reserves while North America has the largest reserve-to-production ratio of 276 years. Asia Pacific holds the second largest proved reserves but higher rates of production accounting for 70.6% of global output and leave it with the lowest region of reserve-to-production ratio of 53 years (BP Statistical Review of World Energy, 2016). However, the present challenges of the coal sector are the demand by climate change mitigation and transition to cleaner energy forms.

Prediction of coal peak production is expected to occur between 2042 to 2062 according to Maggio and Cacciola (2015) which is in line with a 2060 prediction of Valero and Valero (2010). These predictions also support Rutledge (2011) findings, who predicted that 90% of total coal production would have taken place by 2070.

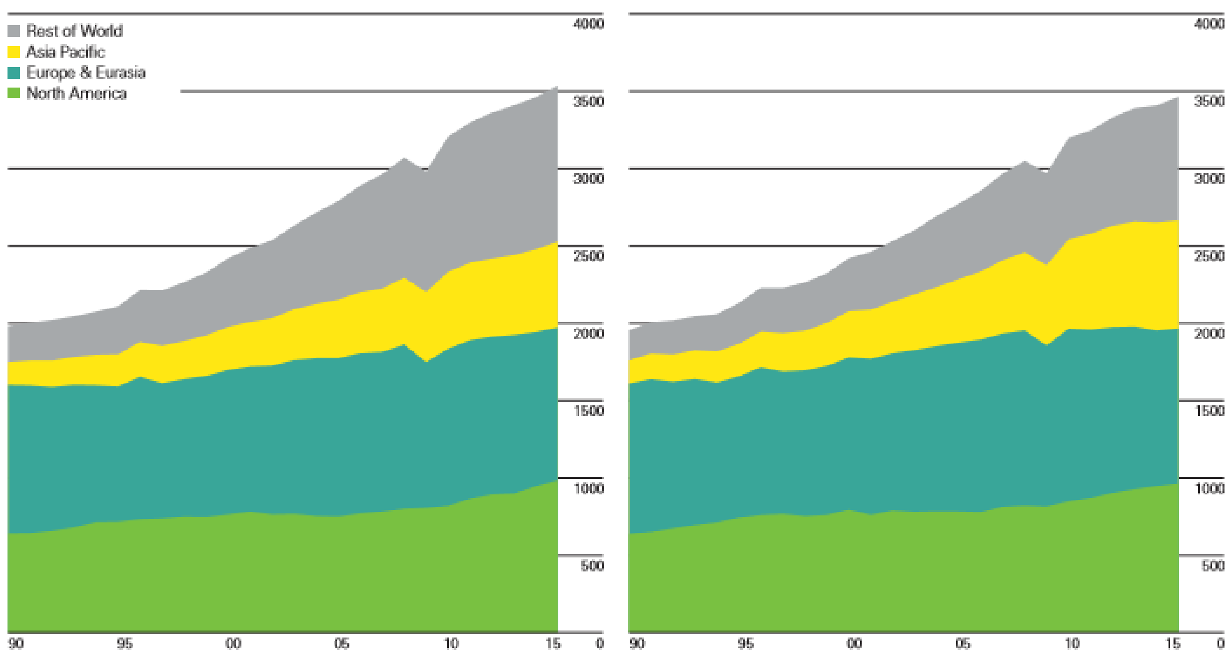


(a) (b)

Figure 2.4: (a) Distribution of proved reserved in 2015 by region and (b) Reserved-to-production ration by region (BP Statistical Review of world energy, 2016)

2.1.1.3 Natural gas

Natural gas is the only fossil fuel whose share of the primary energy mix is expected to grow and has the potential to play an important role in the world transition to cleaner energy (World Energy Resources, 2016). According to BP Statistical Review of World Energy (2016), the world natural consumption grew by 1.7% in 2015, indicating a significant increase from the very weak growth in 2014 (+0.6%). The total amount of proved reserve of natural gas in 2015 amounted to 186.9 trillion cubic metres. The largest share being Middle East (42.8%) followed by Europe and Eurasia (30.4%), Asia Pacific (8.4%), Africa (7.5%), North America (6.8%) and South and Central America (4.1%). Research studies by Maggio and Cacciola (2015) predicts that natural gas production will peak in 2035 while Valero and Valero (2010) also predicts earlier peak production of natural gas by 2023.



(a) (b)

Figure 2.5: (a) Natural gas production in billion cubic by region and (b) natural gas consumption in billion cubic by region (BP Statistical Review of World Energy, 2016)

2.1.1.4 Conclusion

Fossil fuel is being depleted at a rapid rate. Oil is predicted to peak between 2008 and 2030 while coal production is expected to peak between 2020 and 2060. Also, natural gas peak production will occur between 2023 and 2035. The overall peak production of fossil fuel was predicted by an integrated study by Valero and Valero (2010) to occur in 2029. Therefore, an alternative source of energy, which is renewable, is significant.

2.1.2 Nuclear energy

World nuclear power generation increased by 1.3% in 2015 which was above the 10 year average of 0.7% and Asian Pacific accounted for all of the net increase which is driven by growth in China (28.9%) which overtook South Korea to become the world's fourth-largest producer of nuclear power (BP Statistical Review of World Energy, 2016). (See Figure 2.6). According to Dittmar (2012), the contribution of world energy supply by nuclear energy is only 4.49% and usually in the form of electrical energy. The total amount of nuclear energy supply is expected to increase by 73% to 4800TWh by 2030 (Kahouli, 2011). However, this is a negligible amount considering the growing worldwide energy demand.

In addition, nuclear power has been dealt with a blow with regards to public acceptance, following the Fukushima catastrophe Japan (Maggio and Cacciola, 2015). Furthermore, as the result of this incidence, many countries are re-evaluating the role of nuclear energy as a source of low carbon electricity (REN21, 2011).

Nuclear power is a clean energy; however, it is not fossil based fuel and cannot be considered as renewable since uranium is limited and non-renewable. Dittmar (2012) predicts peak uranium production of between 98000 and 141000 tons is expected to occur in 2020 and steep reduction to between 68000 and 109000 tons per annum in 2035. Uranium is being depleted at a fast rate similarly to fossil fuel.

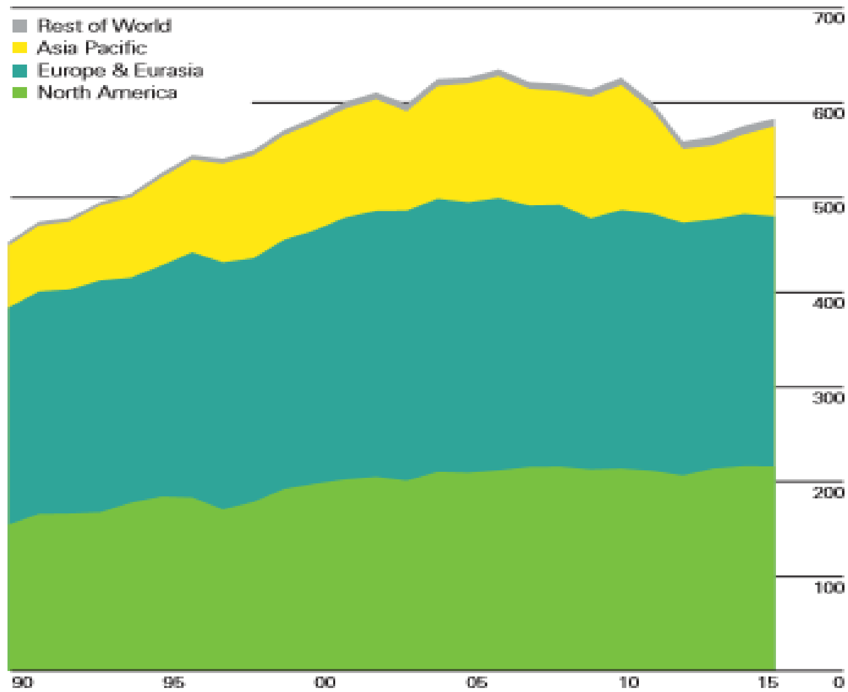
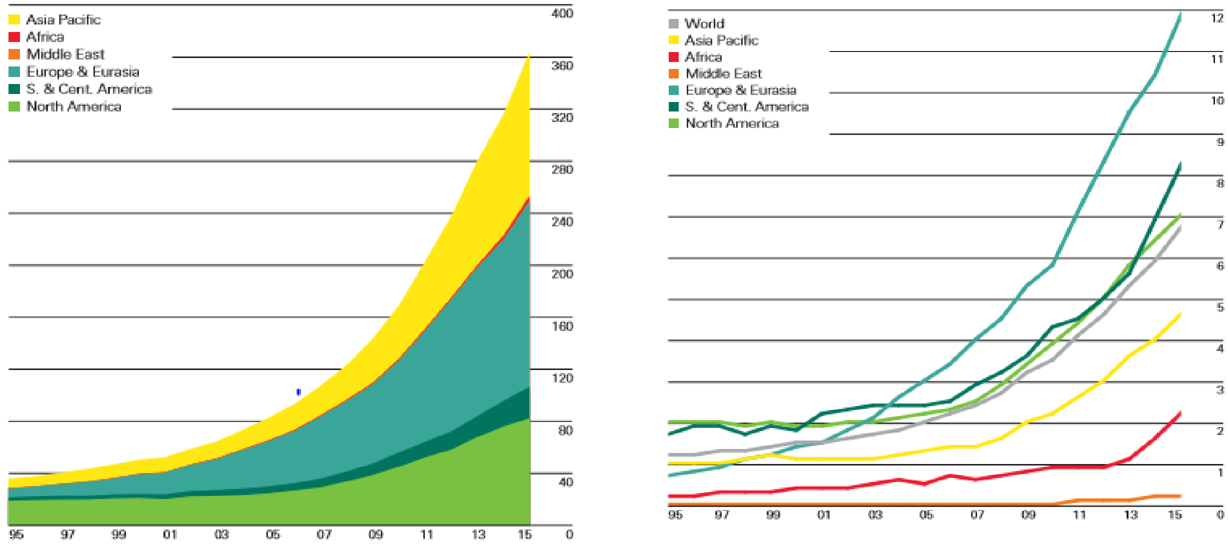


Figure 2.6: Nuclear energy consumption by region in milion tonnes oil equivalent (BP Statistical Review of World Energy, 2016)

2.1.3 Renewable energy

Renewable energy is an alternative source of energy for fossil based fuel which is inexhaustible and clean. Renewable energy is gaining attention globally in recent time as security measure to counteract fossil based fuel depletion and climate change effects. Renewable energy in power generation increased by 15.2% in 2015 with wind having the largest increment of 17.5 mtoe (BP Statistical Review of World Energy, 2016). Regionally, Europe & Eurasia and Asia Pacific recorded the largest increment thus over 18.8 mtoe and 17.5 mtoe respectively (BP Statistical Review of World Energy, 2016). (See Figure 2.7)



(a) (b)

Figure 2.7: (a) Renewable energy consumption in million tonnes oil equivalent by region and (b) Renewable share of power generation in percentage by region (BP Statistical Review of World Energy, 2016)

2.1.3.1 Solar energy

Solar energy is an energy obtained from the sun's radiation or energy created by light and heat emitted by the sun in form of electromagnetic radiation. The global annual energy consumption is less than the total energy of solar radiation reaching the earth per year. This means that solar is the most abundant source of renewable energy. Solar energy is still costly despite the decline in cost compared to conventional energy technologies. In order to make successful implementation, various fiscal and incentives are prerequisite.

There are two forms of solar energy: active solar energy and passive solar energy. Active solar energy involves equipment or action to covert solar energy into useful energy. One key example is the use of solar cell to convert the energy from the son into electrical energy. Passive solar energy does not require any specific action or equipment for example heat provided by windows when sunlight enter. Solar energy focuses on two main application technologies, which are solar photovoltaic and solar thermal technologies.

The solar PV industry has doubled its production and market in 2010 with estimated capacity of 17GW bringing global capacity to 40GW (REN21, 2011). This is quite remarkable if taken into account that the PV global capacity was 0.7GW in 1996 (REN21, 2011).

In the case of concentrated solar thermal power (CSP), advancement in the technology have been much slower than in field of solar PV. According to REN21 (2011), the global installed capacity in 2010 was 1.1GW of which parabolic trough accounted for 90%.

Solar water heating capacity had a remarkable increased in 2010 by estimated of 25GW_{th} to reach 185GW_{th}, excluding unglazed swimming pool heating (REN21, 2011).

2.1.3.2 Wind energy

Wind power is considered as abundant renewable energy source, which has drawn considerable attention worldwide in recent times. According to Global Wind Energy Council (2017), the total installed capacity of wind worldwide reached 486.8 GW with 54 GW installed capacity in 2016. This is in line with Sun et al. (2012) prediction on global wind installed capacity reaching over 400 GW by 2014. Wind energy is another promising source of energy.

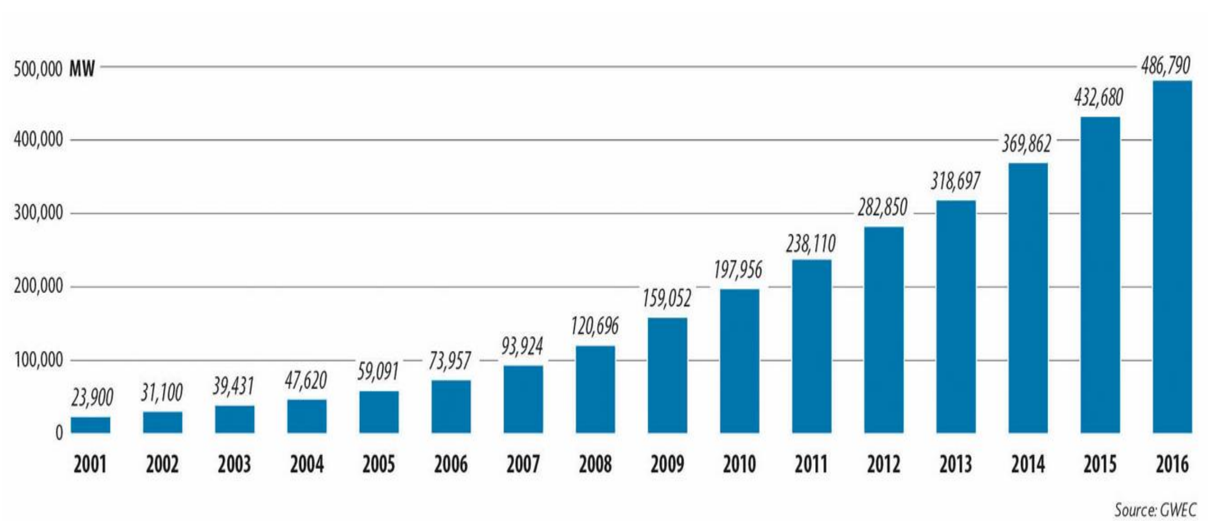


Figure 2.8: Global cumulative installed wind capacity from 2001-2016 (Global Wind Energy Council, 2017)

2.1.3.3 Hydropower

Hydropower production reached 16% of the world electricity production in 2010 representing 35 GW with total global capacity reaching an estimated 1010 GW (REN21, 2011). There has been tremendous growth in hydroelectric global supply since 2003 bringing it to 890 million tonnes of oil equivalent in 2015 (BP Statistical Energy Review, 2016).

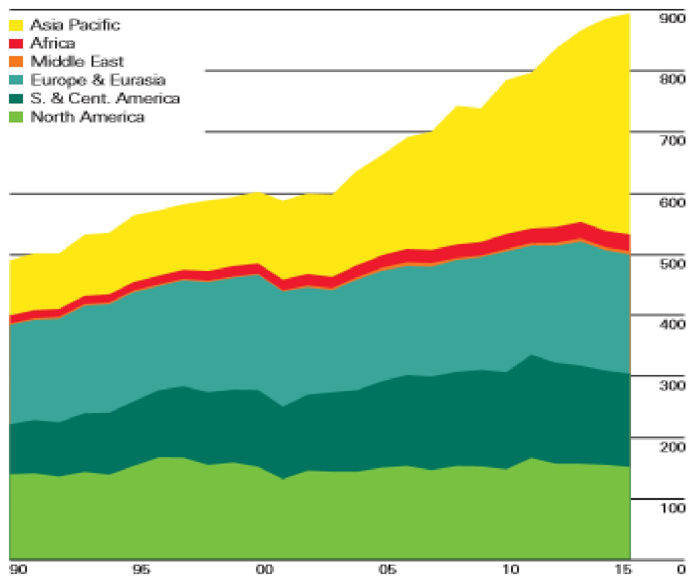


Figure 2.9: Hydroelectricity consumption in million tonnes by region (BP Statistical Review of World Energy, 2016)

2.1.3.4 Geothermal energy

Geothermal power plant operated in at least 24 countries in 2010 and 78 countries directly use geothermal energy as heat. The power development of geothermal slowed in 2010 with global capacity reaching over 11 GW (REN21, 2011). The annual heat from geothermal increased by an average rate of 9% over the past decade (REN21, 2011). Advancement in the geothermal technology will increase the deployment of geothermal in other countries that have the potential.

2.1.3.5 Biomass

Biomass is a universal energy source that can used for production of heat, power, transport fuels and biomaterials aside making a significant contribution to climate change mitigation. The current uses of biomass include combined heat and power, co-firing and combustion plants provide reliable, efficient and clean power and heat. Feedstock for biomass energy plants can include residues from agriculture, forestry, wood processing and food processing industries, municipal solid wastes, industrial wastes and biomass produced from degraded and marginal lands (Zafar, 2015).

2.1.3.5.1 Definition of biomass

Biomass is a renewable energy resource obtained from living or recently living organism (Kemausuor et al., 2014). The United Nations Framework Convention on Climate Change also defined biomass as a non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms (UNFCCC, 2016).

2.1.3.5.2 Classification of biomass feedstock

Biomass can also be classified into two main groups (He and Zhang, 2011). They are:

First generation: Feedstock harvested from sugar crops such maize, millet, rice, sugarcane, sugar beets, molasses, sorghum and oil crops such as soybean, palm oil, coconut oil etc.

Second generation: Lignocellulosic feedstock harvested for their total biomass, which include energy crops such as switchgrass, agricultural and forest residues.

According to Duku et al. (2011), agricultural crop residues are classified as crop residues and agricultural industrial by-products. They stated that, crop residues are what is left or burnt on the farm after harvesting the target crops. In addition, they stated that crop residues in Ghana include straw and stalk of cereals such as maize, rice, sorghum and millet and cocoa pods.

According to Anabire (2014), forest residues include wood residues or wastes from logging and wood processing activities.

2.1.3.5.3 Biomass energy potential

Biomass is the best option and has the largest potential, which could ensure fuel supply in the future. Several studies available tried to quantify biomass potential. The theoretical potential of bioenergy at the total terrestrial surface is about 3500 EJ/year (Demirbas et al.,2009). In Ghana, biomass contribute about 64% of the primary energy supply (Duku et al., 2011) and the bulk of this potential is found in South America and Caribbean (47-221 EJ/year) and sub-Saharan Africa (31-317 EJ/year).

In farming communities in Ghana and the West African region, crop residues are often unused and remain available for valorisation. A study to assess clustered agricultural residues for trigeneration plant in terms of plant capacity, biomass yield, energy output and economic analysis indicate good prospects for the deployment of trigeneration as an energy solution in rural areas of sub-Saharan (Arranz-Piera et al., 2016).

A study conducted by Arranz-Piera et al. (2017) on prospects of electricity generation from small holder farmers crop residues in most districts in Ghana reported that, a minimum of 22-54 larger (10 ha) farms would need to be clustered to enable an economically viable biomass supply to a 1000 kWe plant whilst a 600 kWe plant would require 13 to 30 farms. According to Arranz-Piera et al. (2017), a financial investment on 1000 kWe CHP plant may be viable in Ghana if current feed-in-tariff rate increased by 25% or subsidies from a minimum 30% of investment cost. Rahman and Teknologi (2017) also reported that, prospects and potential of agricultural residues in the rural areas of Bangladesh, India, Nepal, Pakistan, and Sri Lanka are bright.

BEFS Rapid Appraisal approach was used to assess the options for rural electricity generation based on biomass availability in Malawi. They found out that the best option for Malawi was sunflower- SVO based electricity generation, followed by maize cob and sorghum stalk and straw gasification (Felix et al., 2015).

2.1.3.5.4 Estimation of agricultural residue potential

To estimate crop residues availability accurately, it requires good data on crop production by region or district. A survey is necessary if these data are not available. Information on all the uses for crop residues besides fuel thus burning in situ, mulching, animal feed, housing, etc. should be included in the survey in order to calculate the available amount as fuel. Exception include groundnut and sometimes part of cotton crop residues (Rosillo-Calle, 2007).

To obtain accurate estimates of residues production, it is important to have good estimates of crop production by country, region or district. A survey especially in the subsistence sector to determine production of both crops and plants residues is significant and should include all possible uses of the residues in addition to fuel. Total crop production can then be calculated using existing data on the yields of the various crops. The quantity of residues can then be calculated through estimates of the ratio of by-product to main crop yields for each crop type and by multiplying the crop production of a particular year by the residue ratio. Lal (2012), define residue production estimates by this equation.

Equation: $$grain\ production \times \frac{Straw}{grain} = Residue\ production \quad (1)$$

Another method for estimating crop residues is to use the crop residue index (CRI). This is defined as the ratio of the dry weight of the residue produced to the total primary crop produced for a particular species or cultivar. The CRI is determined in the field for each crop and crop variety, and for each agro-ecological region under consideration. It is very important to state clearly whether the crop is in the processed or unprocessed state (Anabire, 2014).

2.1.3.5.5 Residue to product ratio (RPR) of agricultural crops

Crops yield has a definite relationship with the residue left after harvesting the produce. The RPR is defined as the gravimetric ratio of the residue to the actual produce of the crop. According to Murali et al. (2008), the near value of the RPR value of a particular crop leads to the realistic estimates of the total residue generated. According to Esteban et al. (2010) , RPR can be obtained in the following ways:

- Sampling a crop before harvest: this consists of weighing the total crop biomass in sample plots just before harvesting. Samples are collected in each plot and carried to the laboratory where grain is separated from straw and weighed. The fractions are oven dried to estimate moisture content.
- Sampling residue after grain harvest: this procedure consists of weighing and sampling the residue that lies on the floor, usually in rows, after harvest. A portion of each residue row is weighed. Average row length and the distances between row axes is recorded. Samples are taken for oven drying.
- Evaluating straw production in a parcel: this procedure is similar to procedure 2, but in this case the residue is harvested completely and the whole parcel is weighed.

CHAPTER THREE

3 Methodology

3.1 Location of study

The location of the study is Ejisu-Juaben District of the Ashanti region of Ghana. The Ejisu-Juaben municipality lies within latitudes 1°15' N and 1° 45' N and longitude 6° 15' W and 7° 00" W. The population of the municipality is 143,762 representing 3% of the region's total population. The employed population of 36.1 percent are engaged as skilled agricultural, fishery and forestry workers, 24.3% in service and sales, 17.1% in craft and related trade and 10.6 % are engaged as managers, professionals and technicians (Ghana Statistical Service, 2014). The municipality is made up of about 23.9% of household who are engaged in agriculture.

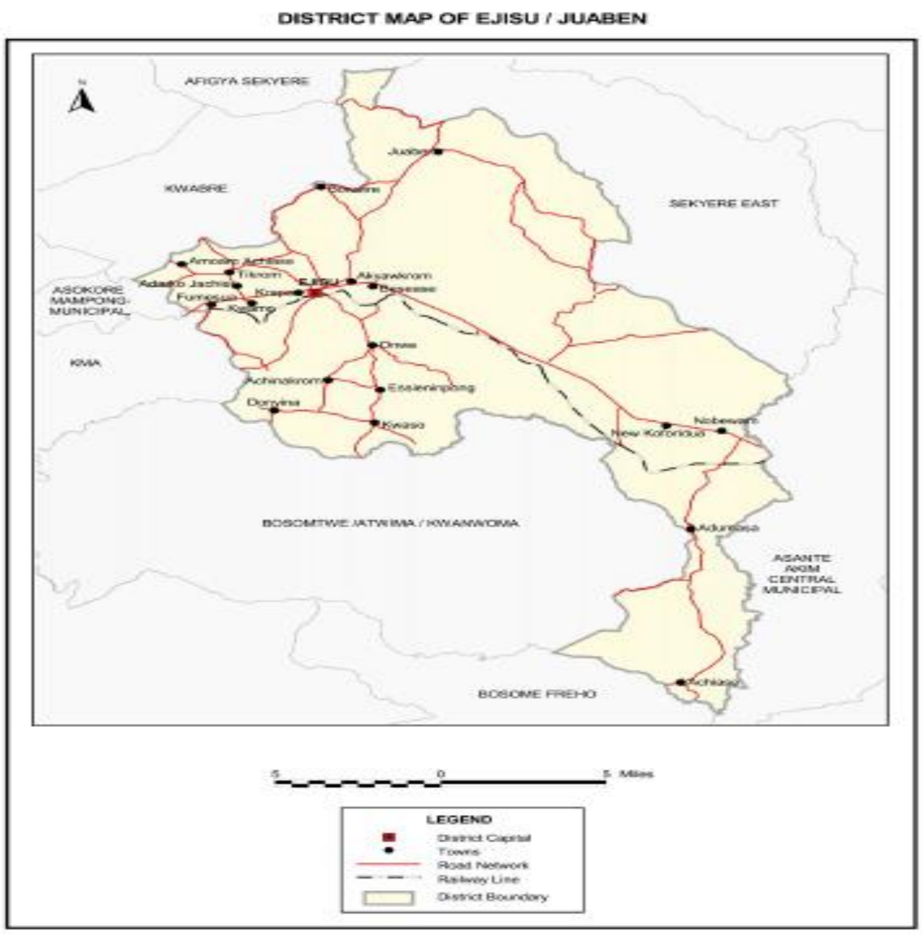


Figure 3.1: Ejisu-Juaben District Map (Ghana Statistical Service, 2014)

3.2 Research design

3.2.1 Questionnaires administration and Literature

Structured interview of 200 farmers and local authorities and detailed study of the available literature and scientific reports on the production, collection, disposal and other uses of residues were carried out to collect data and information from some selected communities in the Ejisu Juaben District: Nobewam, Besease and Donaso.

Additional data was obtained from FAOSTAT, World Development Indicators (WDI), National Statistical Agencies in Ghana such as Ghana Statistical Service (Ghana Living Standard Survey), Ghana Energy Commission (National Energy Statistics), and Ministry of Food and Agriculture (Agricultural Fact and Figures).

3.2.2 BEFS Rapid Appraisal Assessment

The techno-economic assessment for electricity generation from crop residue was carried out using the FAO's Bioenergy and Food Security Rapid Appraisal (BEFS RA) assessment tool. The analysis that is undertaken within the BEFS RA follows the BEFS Analytical Framework (BEFS AF) as illustrated in the Figure 3.2.

The analysis undertaken within the BEFS RA is divided into three modules namely Country Status, Natural Resources and Energy End Use Options. The modules are run in sequence to obtain a set of results covering the bioenergy pathways identified within the BEFS RA. The BEFS RA comprises of as set of tools. The tools used for this study are Country Status Tool, Agricultural Residues Tool, Gasification Tool and Combustion Tool.

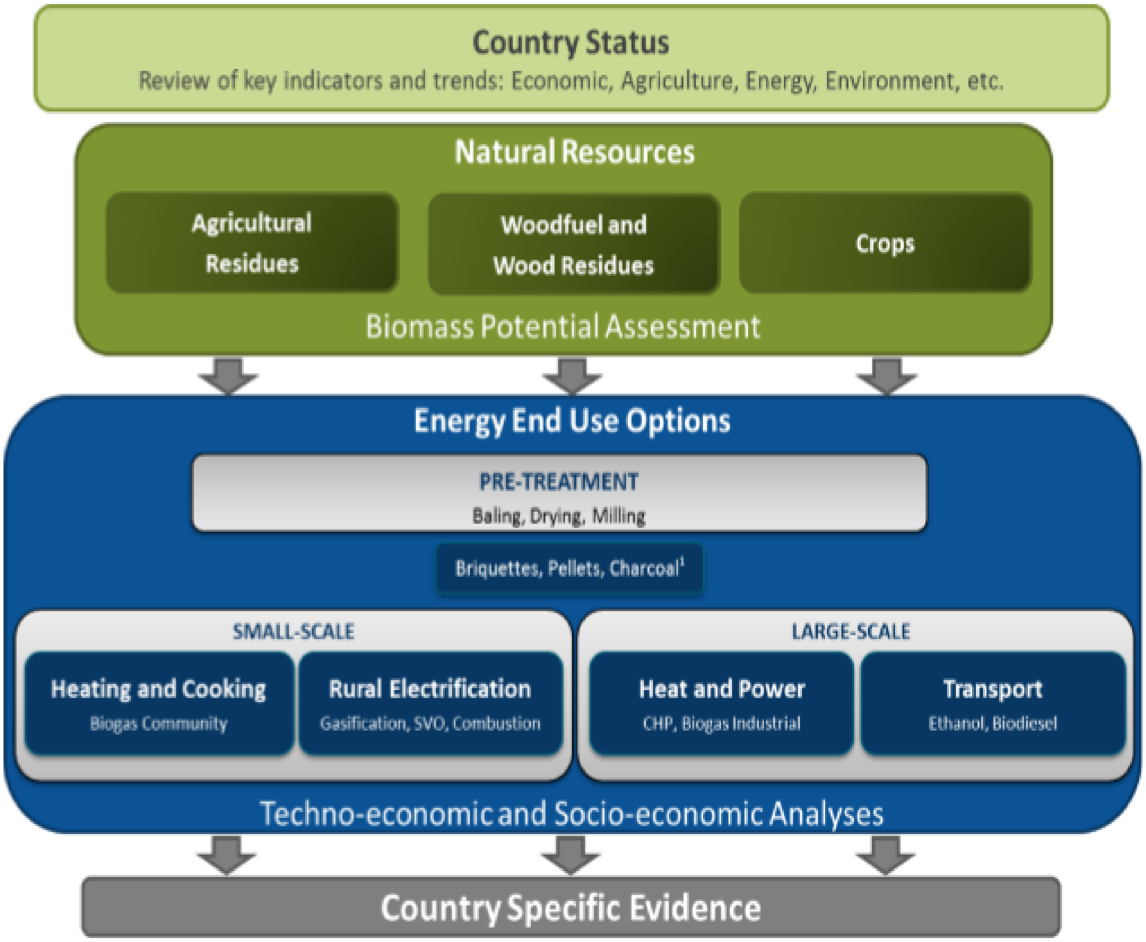


Figure 3.2: BEFS Analytical Framework

3.2.2.1 Country status

The country status module collects information on Ghana status and defines the context, needs and constraints in the key sectors, such as Agriculture and Energy. The country status tool was used to input the data required for the analysis. The country status tool gives an overview of the population, socio-economic indicators, land cover/land use, food security and energy use, food supply and key food stuffs in the country. In addition, the net trade position for some key food crops, energy balance and current energy demand was assessed with the tool.

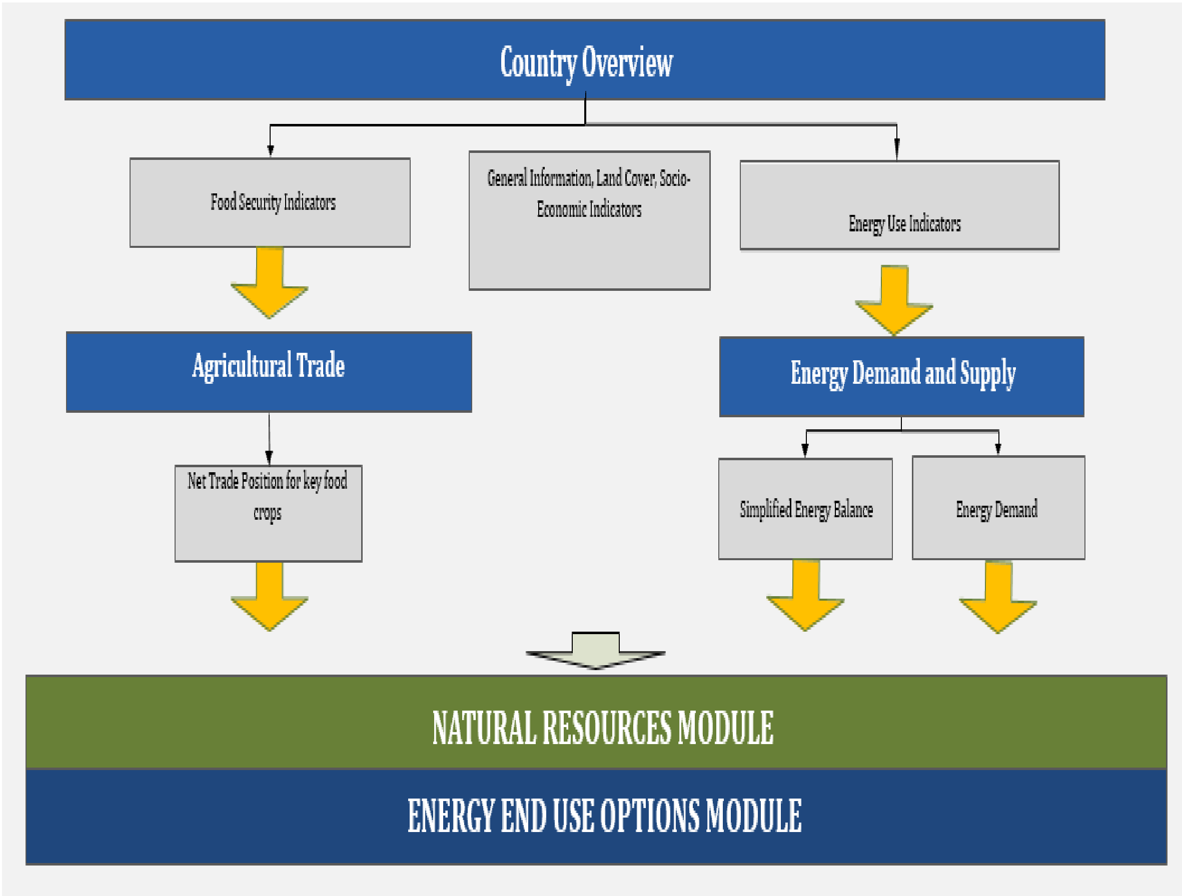


Figure 3.3: Country Status Module (FAO:BEFS RA)

3.2.2.2 Natural Resources: Biomass Assessment

The natural resources tool comprise of three main components, thus agricultural residues, wood fuel and wood residues, and crops. The natural resources module estimates feedstock availability, considering competing uses and needs. The competing uses are assessed to the level possible and then excluded. In this study, crop residues assessment was done using Agricultural residues tool of the BEFS RA for maize and rice (See Figure 3.4).

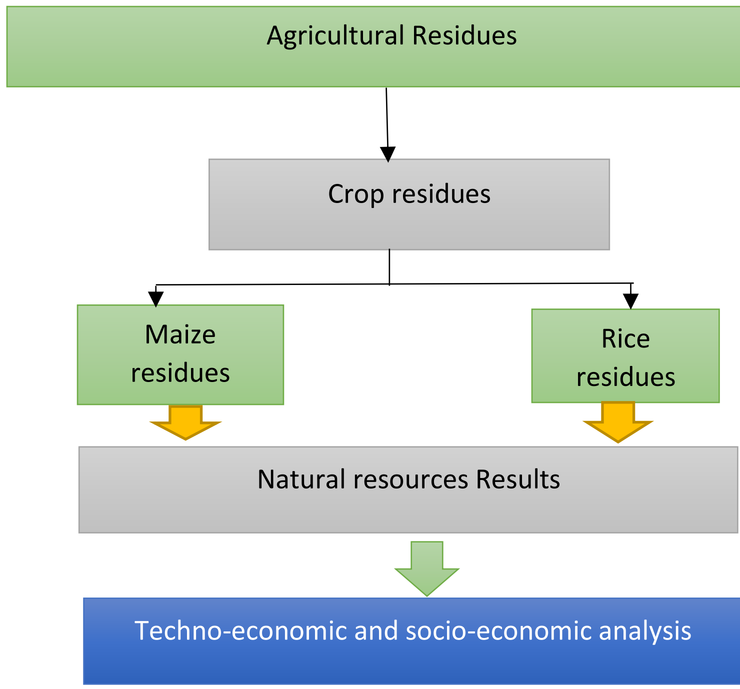


Figure 3.4: Natural resource module (FAO: BEFS RA)

3.2.2.3 Energy End Use Options: Techno-economic and Socio-economic Analysis

The energy end use options module evaluates Rural Electrification considering two pathways: Gasification and Combustion options, based on the district context. The Gasification and Combustion Tools were used for the evaluation.

3.2.2.3.1 Gasification component

The gasification component was designed to assist in evaluating the potential to develop biomass gasification technology to supply electricity in rural areas. Gasification refers to a process in which combustible materials such as biomass are partially oxidized or partially combusted with a change of the chemical structure at 500-900 °C in the presence of a gasifying agent, for instance air, oxygen, steam, CO_2 or mixtures of these synthesis gas or syngas (He and Zhang, 2011) .

3.2.2.3.1.1 Principle of operation of a gasification plant

Biomass is pretreated thus drying to remove moisture and reducing the size of the feedstock before going into a downdraught gasifier. Down draught gasifier is fixed bed gasifier where the feedstock and the air moves in the same direction. The biomass residues is converted into syngas. The syngas goes through the cooling and cleaning process before been fed into a gas engine for power generation. (See figure 3.5)

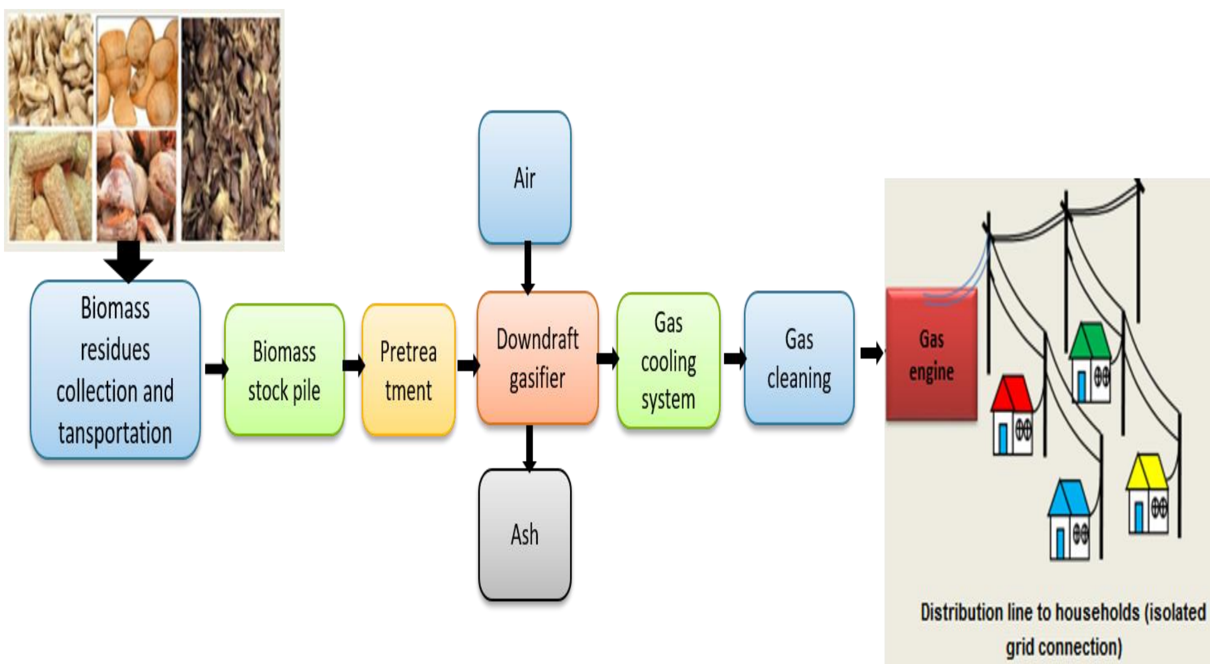


Figure 3.5: Biomass Gasification System for rural electrification (FAO: BEFS RA)

3.2.2.3.2 Combustion component

Combustion is a thermochemistry process where a fuel and an oxidant agent (air or oxygen) react exothermally, generating heat and series of converted products named combustion gases. Different types of substances or materials can be employed as combustion fuels, including fossil fuels, residues or biomass. The combustion component assist in evaluating the potential to develop biomass combustion to supply electricity in rural areas without current access to electricity and where extension of the grid is not feasible.

3.2.2.3.2.1 Principle of operation of a combustion plant

The feedstock is first pretreated (reduce moisture content, reduce size etc.) and combusted in a boiler. The boiler generate steam, which is in turn used to drive a steam turbine for power generation as shown in the Figure 3.6.

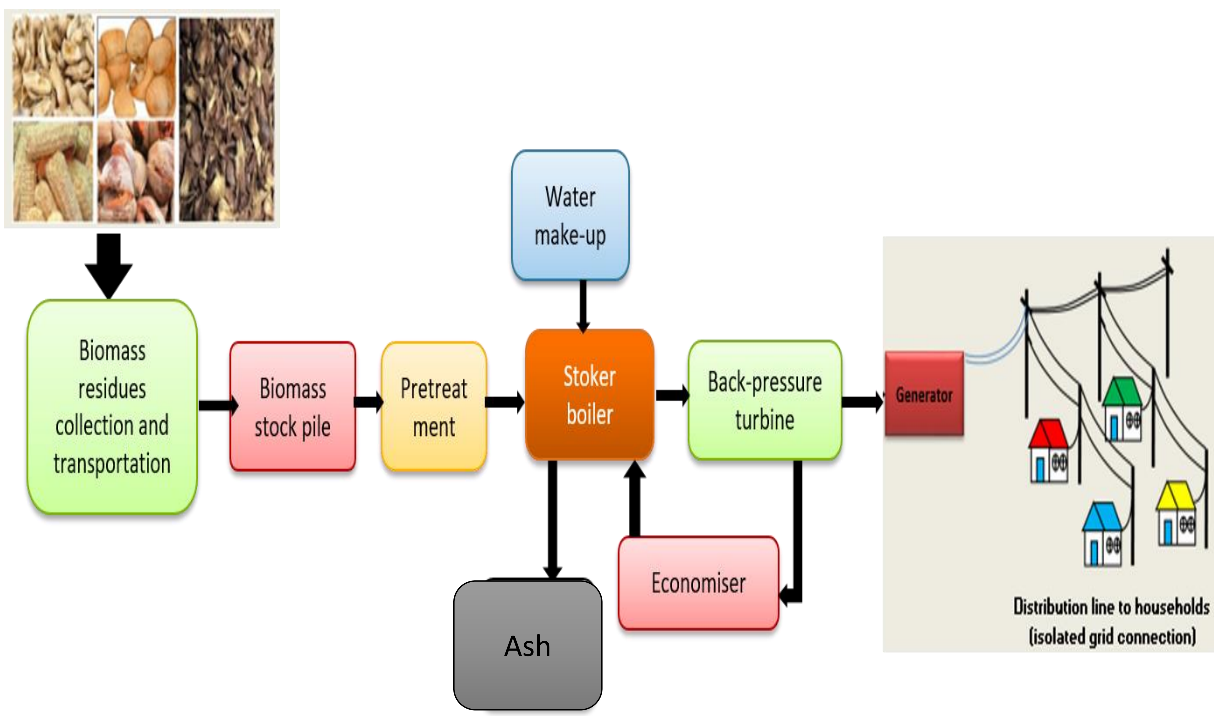


Figure 3.6: Biomass combustion system for rural electrification

3.2.2.3.3 Gasification and combustion analysis

The following steps were used for the gasification and combustion analysis:

1. Energy demand.

   The energy demand of the district was estimated based on the consumption per household in kWh/month. This was defined in the country status module. A total electricity consumption of 129.72 kWh/month was estimated. The feedstock for the analysis were defined.
2. Defining the price of electricity

   The default values provided by the tool were used to estimate the price of electricity.
3. Production cost and financial parameters

   Data on labour cost, utilities cost, feedstock collection and transportation cost of feedstock were provided to do the analysis.

Equation: Transportation cost =

$$\frac{Hourly\ wages\left(\frac{\frac{USD}{hour}}{person}\right) \times workingtime(hours)}{Transportation\ distance\ (km) \times feedstocktransport\ (\frac{tonne}{person})} \quad (2)$$

CHAPTER FOUR

4 Results and discussion

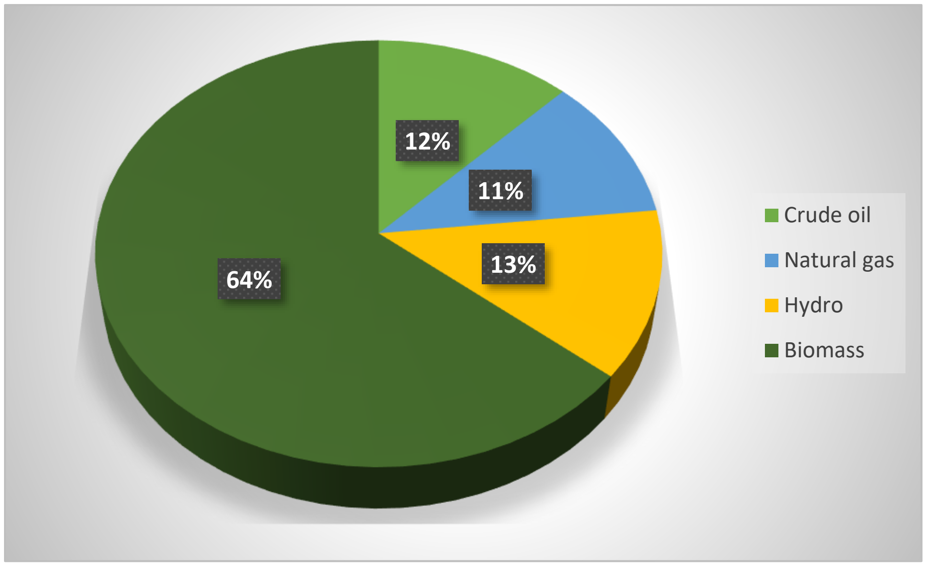
4.1 Country status

4.1.1 Country Overview and Net Trade Position

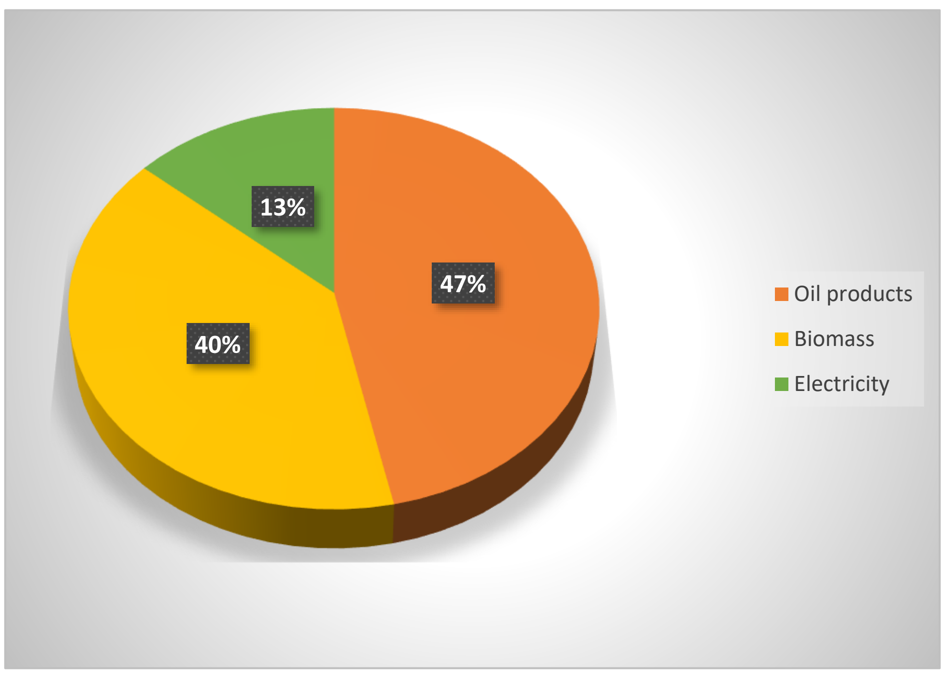
According to the WDI (2017) 5% of Ghana's total population are undernourished and the poverty headcount ratio is 24%. About 45% of the total population live in rural areas and are mostly farmers. Agriculture contributed 21% to GDP in 2015, with cassava being the most important food crop. The net trade position of Maize and products, rice products, yam and cassava and products and plantain over 10 years indicate that Ghana is self-sufficient with these crops.

4.1.2 Energy Balance

Primary energy supply in Ghana is dominated by oil products. Biomass contribute over 64% of the primary energy supply in the country. This is followed by hydro, crude oil and natural gas with 13%, 12%, and 11% respectively as shown in Figure 4.1. The country's over dependence on fossil-based fuel is not sustainable and should consider more of renewables in its energy mix.



(a)



(b)

Figure 4.1: (a) Total Primary Energy Supply and (b) final energy consumption (Energy Commission, 2015)

The residential sector consumed the highest amount of energy, recording about 300 ktoe in 2014, of which biomass was the most consumed energy resources followed by electricity and oil products as shown in Figure 4.2. The transport sector is the next energy consumer, consuming about 2550 ktoe of oil products.

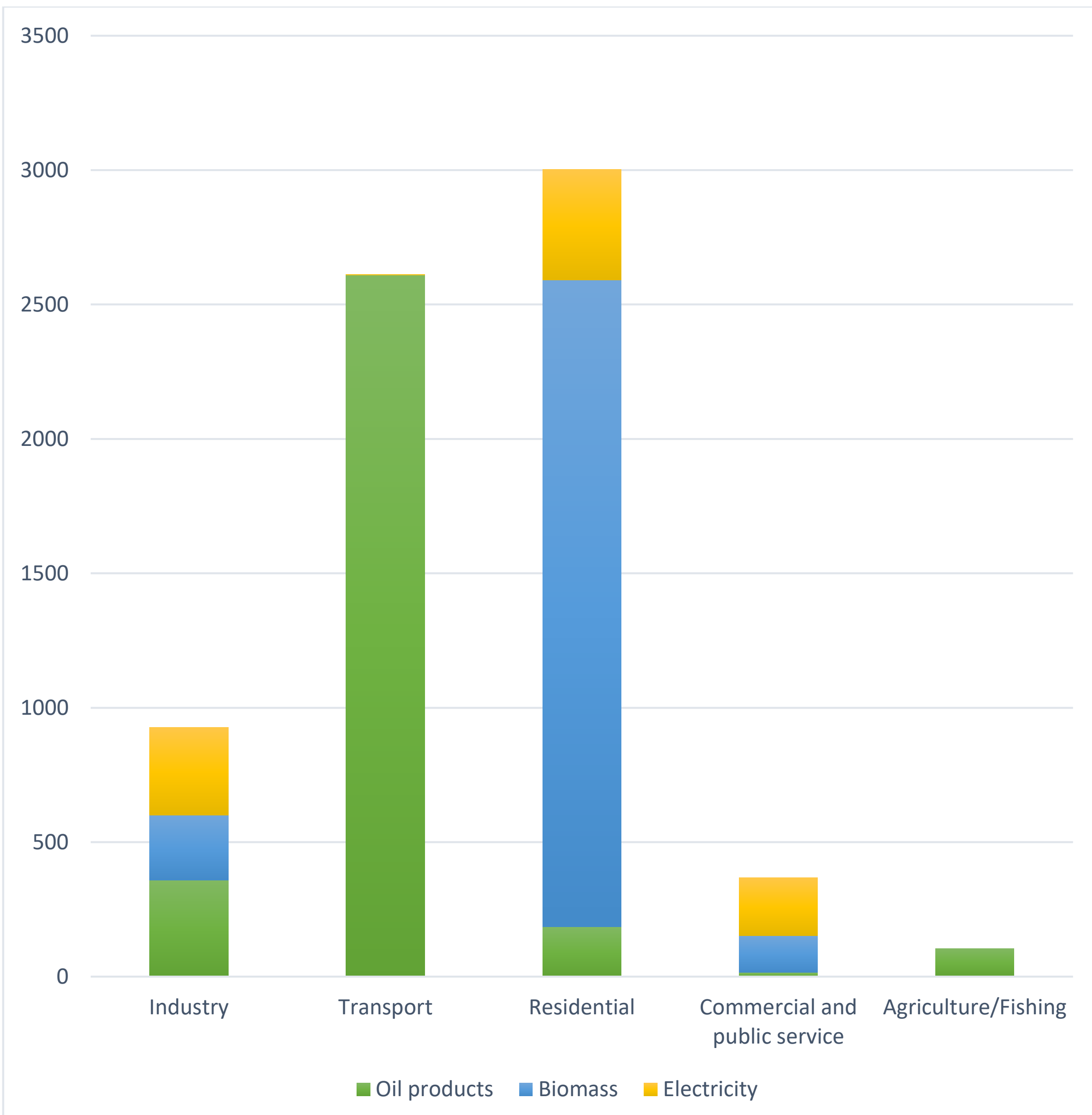


Figure 4.2: Final Energy Consumption by sector (Energy Commission, 2015)

4.2 Agricultural residues

4.2.1 Crop residues

The total amount of residues generated on the field was 13, 043 tonne per year. Out of this amount, 12, 565 tonne per year will be available for bioenergy. In order to make fair comparison 50% of the available residues was allocated to each technology pathway, thus combustion and gasification. The remainder amount of 478 tonne per year is used as animal feed and industrial purposes. The amount of residues available by the respective crop residues as shown in Figure 4.3. Maize stover is the highest, followed by maize cob, maize husk and rice husk with 6603, 5053, 463 and 446 tonne per year respectively. (See Figure 4.3)

The average farm size cultivated was one acre since farmers could not afford renting of farm machineries. Most of the cost incurred by farmers include labour cost, cost of land and transportation cost. This according to the farmers take about 50% of their total income.

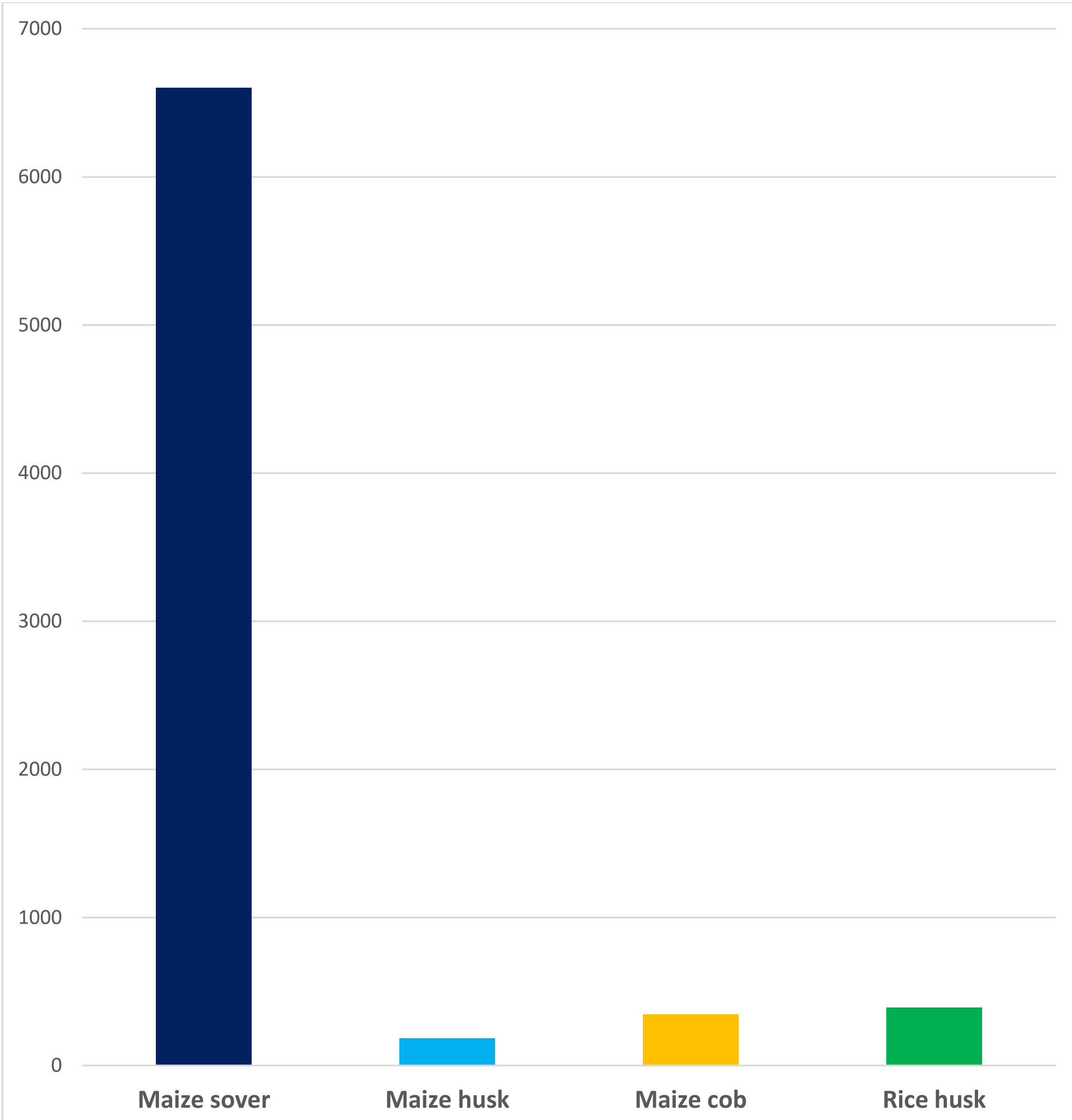


Figure 4.3: Crop residues available for bioenergy

CHAPTER FOUR

4.3 Energy end use option

4.3.1 Gasification

4.3.1.1 Maize stover

Maize stover was found to be the most abundant feedstock for power generation. The production cost and distribution cost of electricity of 10 kW ranged between 0.81-1 USD per kWh. These unit costs are lower than the electricity price of 1.37 USD/kWh. Therefore, this plant is feasible and attractive for investment. The total investment cost of 10 kW is 59,883 USD.

The feedstock availability is 6603 tonne per year, which is sufficient to supply the feedstock needed for the three production capacities. Considering the feedstock availability, 24 potential plants of 10 kW capacity, which requires 142 hectares feedstock area, can be developed. A maximum of 13 households can be supplied with electricity from the 10 kW power plant. In addition, the collection of feedstock and plant processing could create five jobs.

The net present value and internal rate of return for all plant capacities are positive. It can therefore be concluded, maize stover is feasible for power generation at all plant capacities. (See Figure 4.4 for other pre-defined capacities).

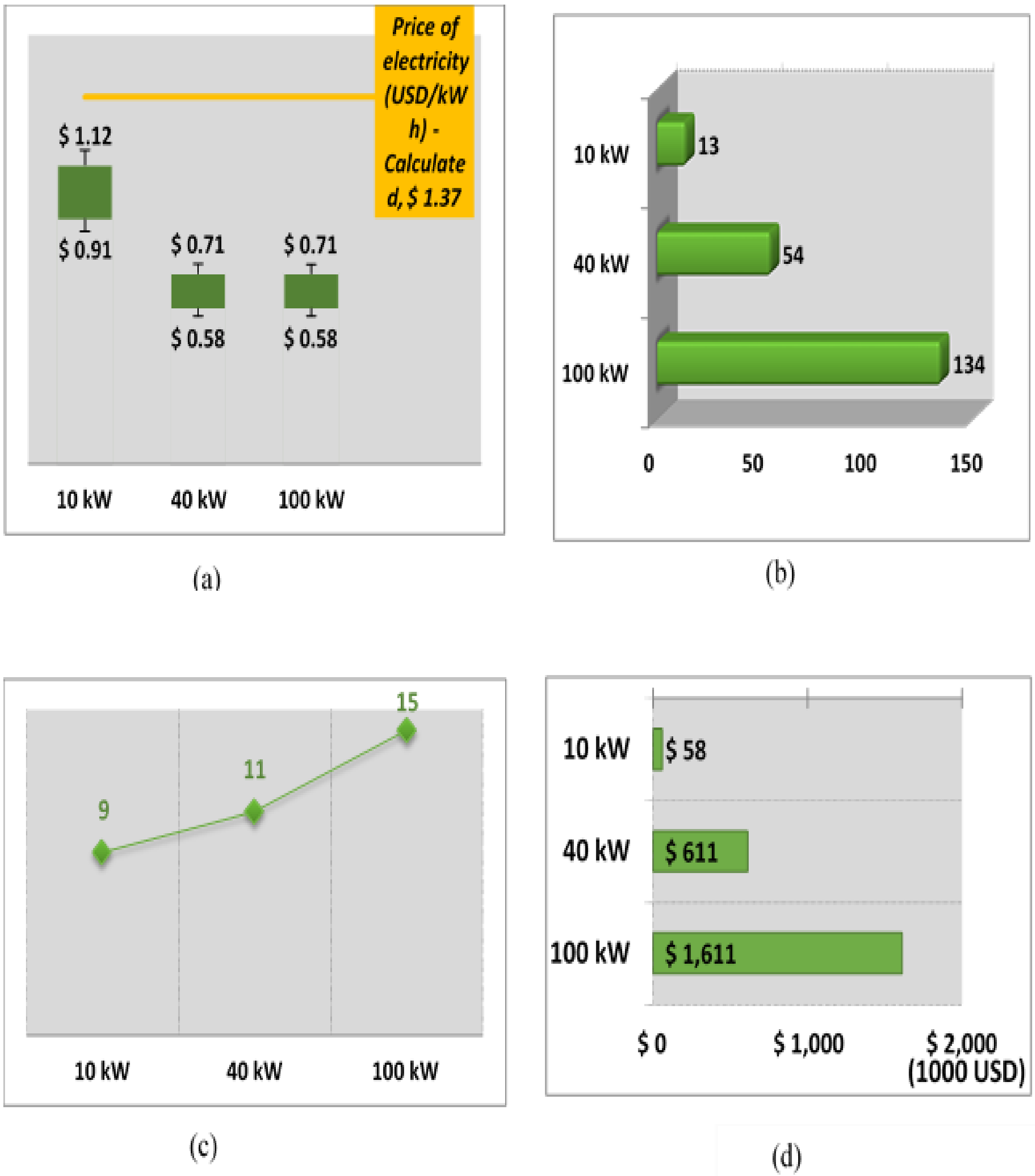


Figure 4.4: Summary results of rural electrification-gasification from maize stover; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.1.2 Maize husk

The production cost and distribution cost of 10 kW plant ranges from 0.76-0.93 USD/kWh. This is less than the electricity price of 1.37 USD/kWh. Therefore, this plant is feasible and attractive investment. The investment cost is 59,883 USD.

The feedstock availability is 463 tonne per year, which is only sufficient for the 10 kW plant capacity. The feedstock requires an area of 1549 hectares to produce two unit of 10 kW plant. This is a huge area requirement and therefore reducing the size of the feedstock by non-carbonized briquetting can be significant. Up to 15 households can be supplied with electricity from this plant and 15 potential jobs can be created from collection and processing of the feedstock.

The net present value and internal rate of return for all the plant capacities are positive. However, the feedstock readily available can only be sufficient for 10 kW. Therefore, it can concluded that, maize husk feedstock will be feasible for power generation only at 10 kW plant capacity. (See Figure 4.5 for other predefined capacities)

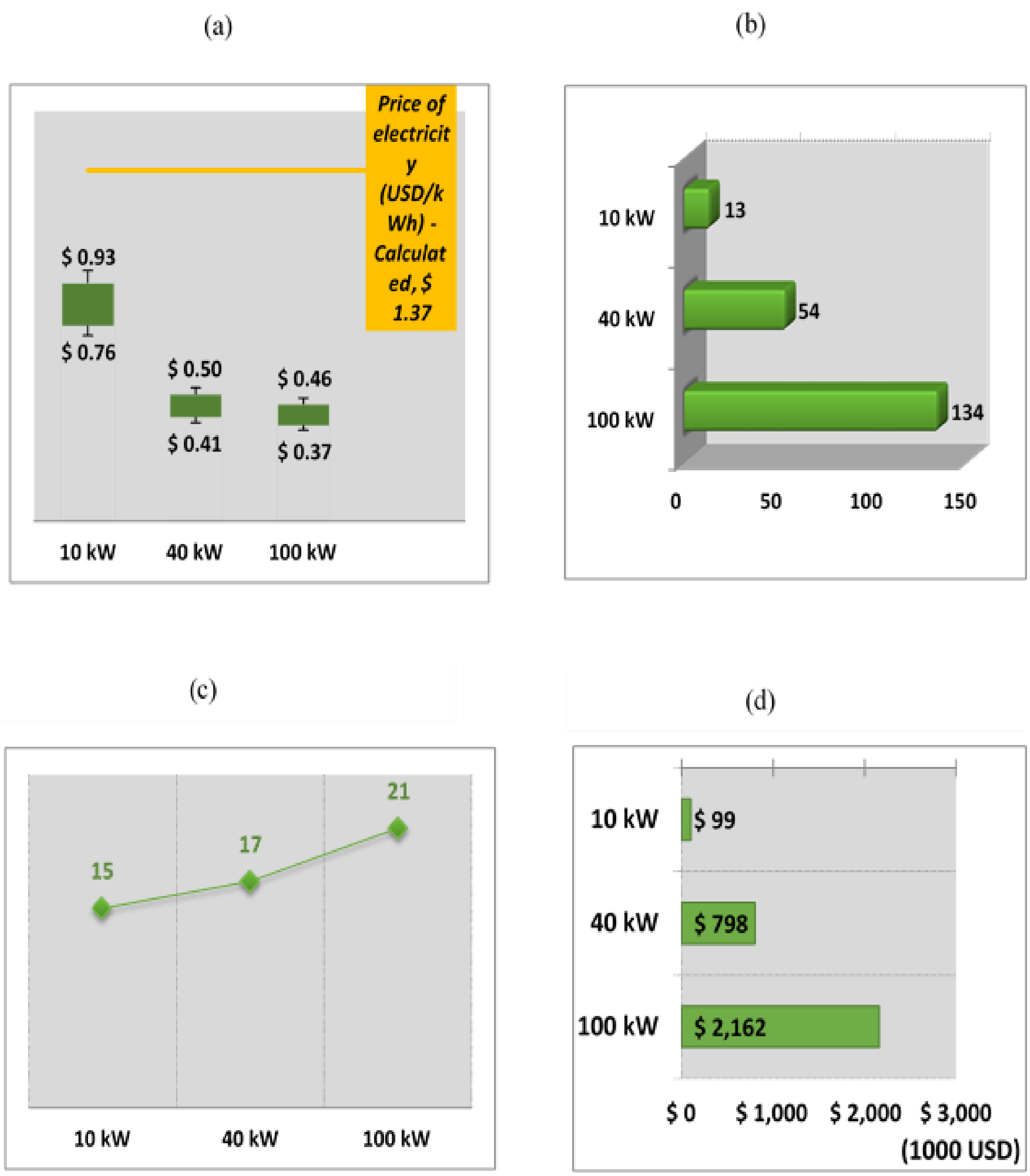


Figure 4.5: Summary results of rural electrification-gasification from maize husk; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.1.3 Maize cob

The total production and distribution cost of electricity of the 10 kW plant from maize cob ranges from 0.81-0.99 is less than the unit price of electricity which is 1.37 USD per kWh. Hence, this plant is feasible and attractive for investment. The investment cost of the 10 kW plant is 59, 883 USD and is the same as the investment cost of maize husk.

The total amount of feedstock readily available was 5,033 tonne per year. This amount is sufficient for all plant capacities. This means, all the plant capacities are potentially feasible. The feedstock requires an area of 161 hectares to produce two units of 10 kW plant capacity. Up to 13 households can be supplied with electricity from this plant. A total of five jobs can be created from collection and processing of feedstock.

The net present value and internal rate of return for all plant capacities are positive. It can be concluded that, it is feasible to generate electricity from maize cob at all plant capacities. (Refer to Figure 4.6 for other pre-defined capacities).

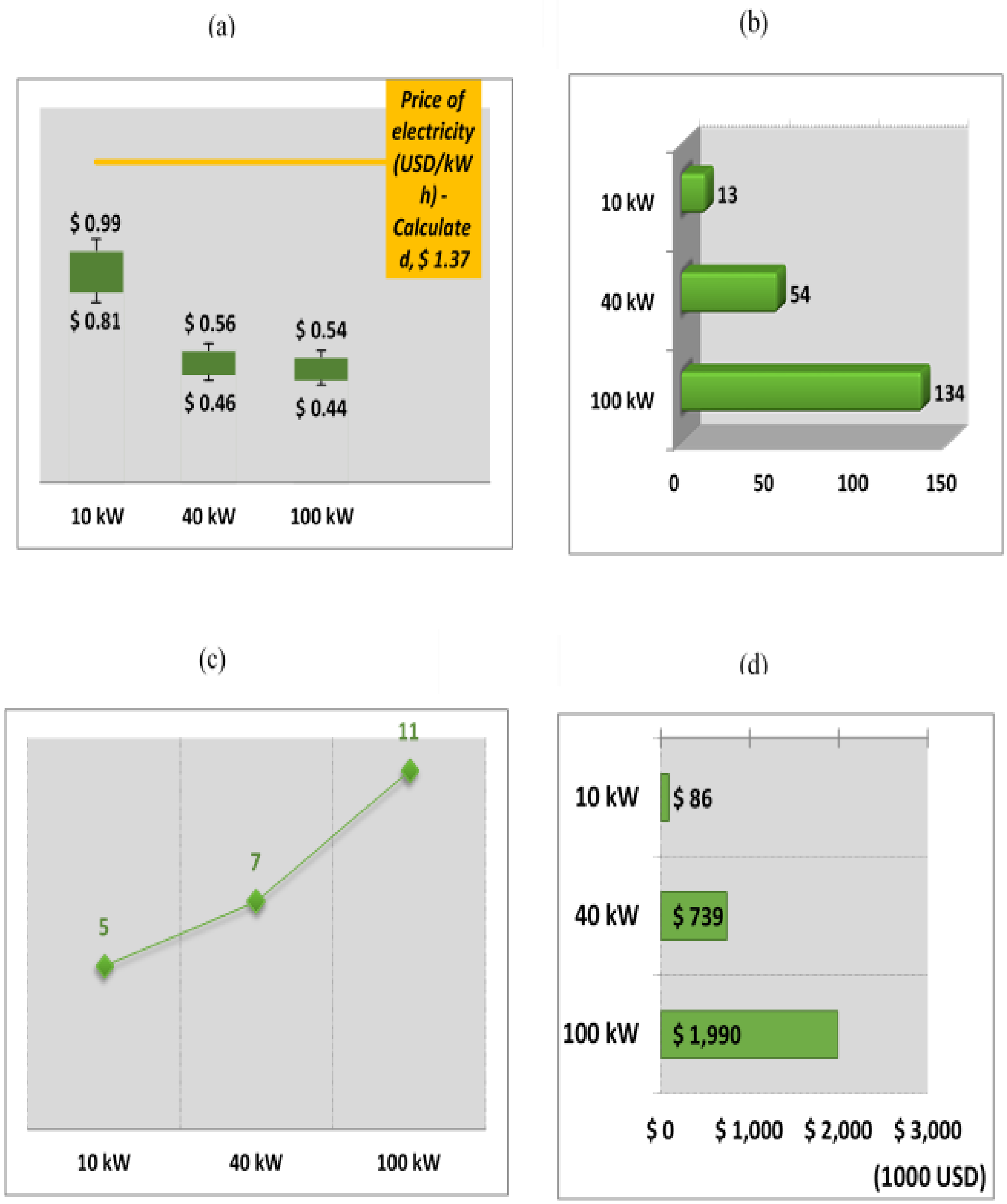


Figure 4.6: Summary results of rural electrification-gasification from maize cob; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.1.4 Rice husk

The production cost and distribution cost of electricity of 10 kW ranged between 0.91-1.12 USD per kWh. These unit costs are lower than the electricity price of 1.37 USD/kWh. Therefore, this plant is feasible and attractive for investment. The total investment cost of 10 kW is 59,883 USD.

The feedstock availability is 446 tonne per year, which is not sufficient for the plant capacities but can only supply the 10 kW plant. The feedstock requires an area of 395 hectares to produce one unit of 10 kW plant. Up to 13 households can be supplied with electricity from this plant and 15 potential jobs can be created from collection and processing of the feedstock

The net present value and internal rate of return for all the plant capacities are positive. However, the feedstock readily available can only be sufficient for 10 Kw. Therefore, it can concluded that, rice husk feedstock will be feasible for power generation only at 10 kW plant capacity. (See Figure 4.7 for other predefined capacities).

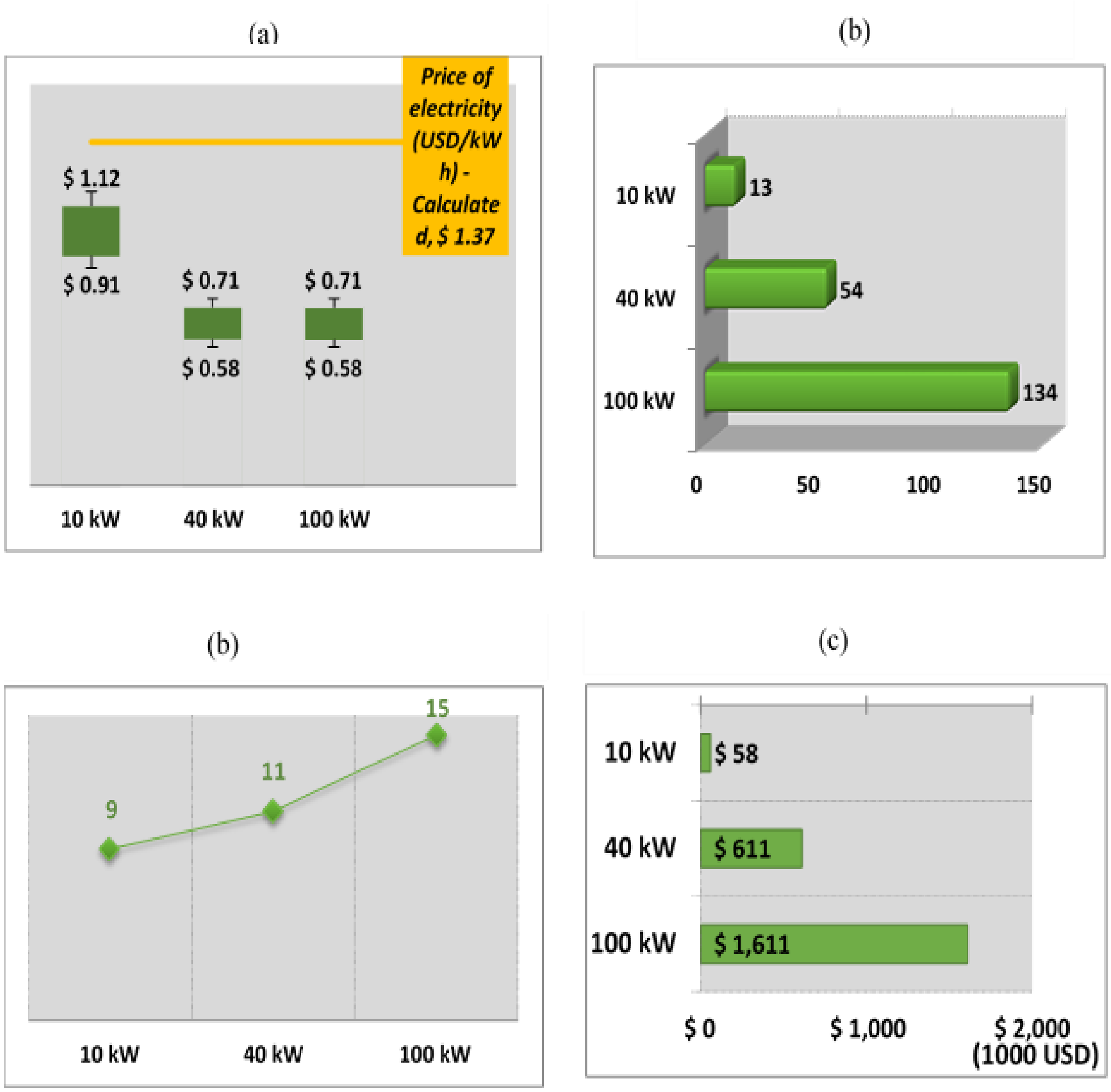


Figure 4.7: Summary results of rural electrification-gasification from rice husk; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.1.5 Results summary for all feedstock for gasification

The production cost of electricity of rice husk is the highest compared to other feedstock for plant capacities. Maize husk, maize stover and maize cob all have the lowest production cost as shown in Figure 4.8. In addition, all the feedstock provide positive NPV and IRR. Therefore, it can be concluded that:

a. Maize stover and maize cob are feasible options for power generation at all plant capacities.

b. Maize husk and rice husk are feasible for power generation at 10 kW but not sufficient for 40 kW and 100 kW.

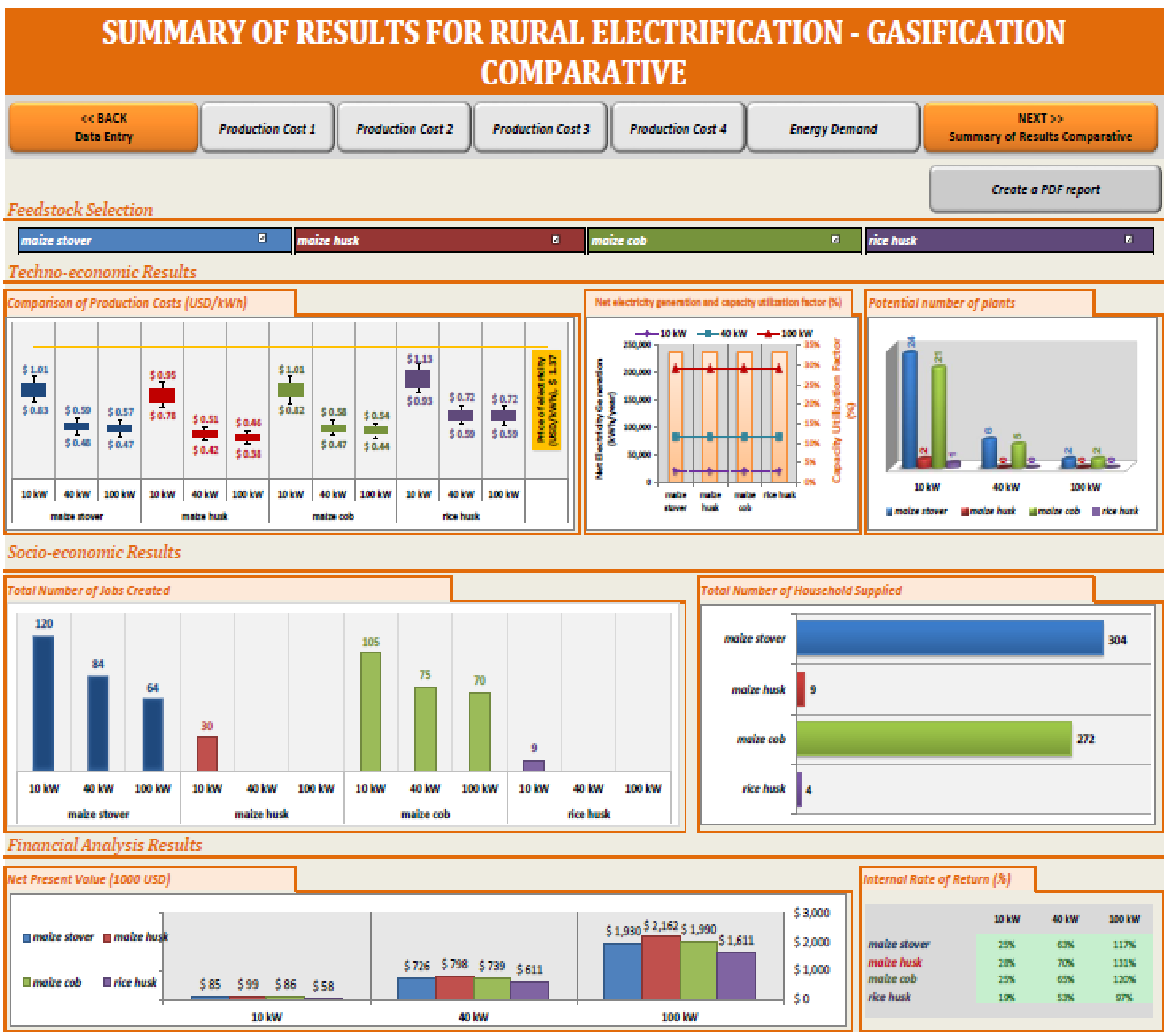


Figure 4.8: Layout of comparative results of Gasification

4.3.2 Combustion

4.3.2.1 Maize stover

The total production and distribution cost of electricity of the 10 kW plant from maize cob ranges from 0.69-1.04 USD per kWh is less than the unit price of electricity which is 1.36 USD per kWh. Hence, this plant is feasible and attractive for investment. The investment cost of the 10 kW plant is 37,765 USD.

The total amount of feedstock readily available was 6,603 tonne per year. This amount is sufficient for all plant capacities. This means, all the plant capacities are potentially feasible. The feedstock requires an area of 120 hectares to produce 29 units of 10 kW plant. Up to 13 households can be supplied with electricity from this plant. A total of four jobs can be created from collection and processing of feedstock.

The net present value and internal rate of return for all plant capacities are positive. The feedstock readily available is sufficient for all plant capacities. Therefore, it can concluded that, maize stover feedstock will be feasible for power generation at all plant capacities. (Refer to Figure 4.9 for other pre-defined capacities).

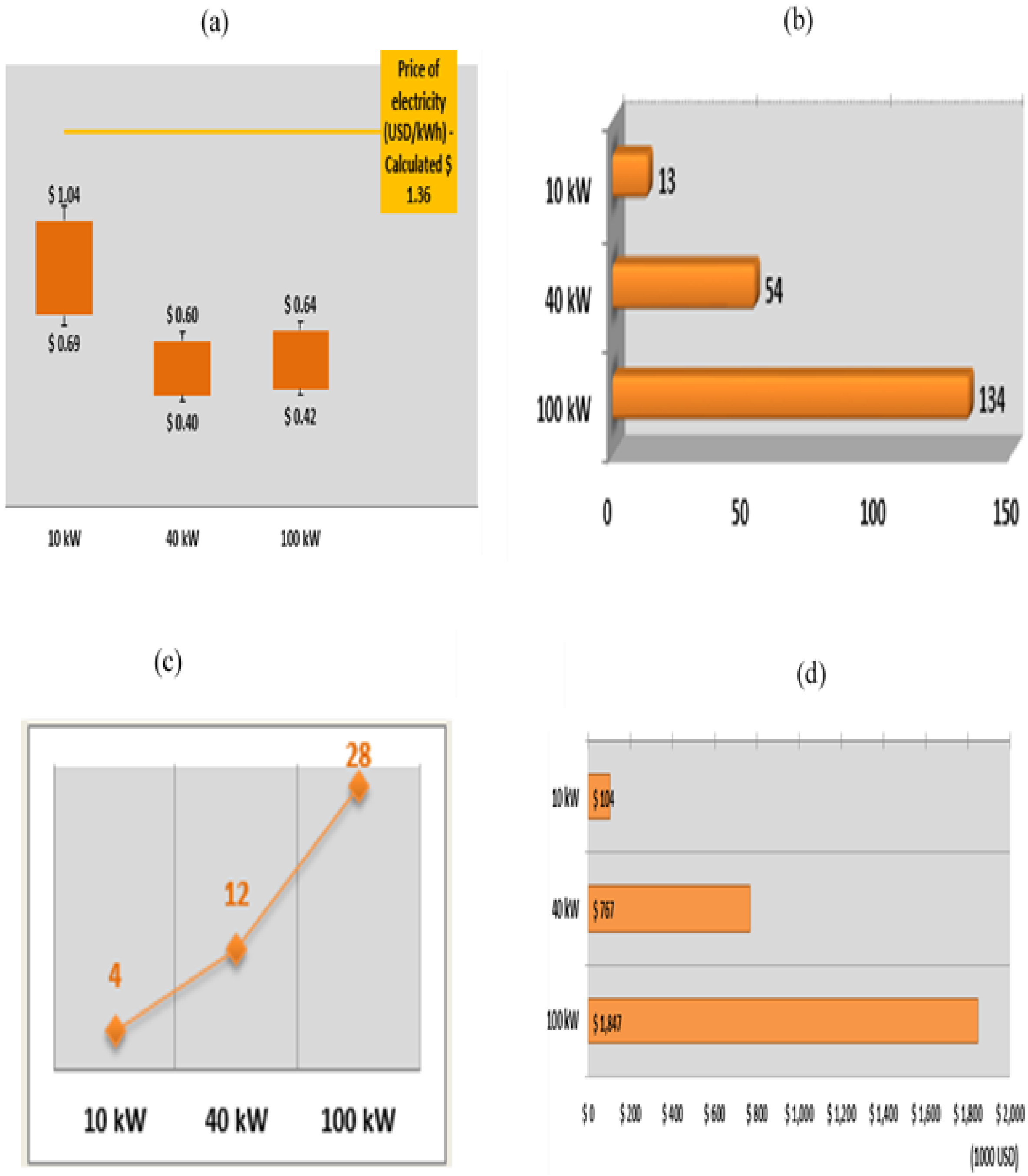


Figure 4.9: Summary results of rural electrification-combustion from maize stover; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.2.2 Maize husk

The production cost and distribution cost of 10 kW plant ranges from 1.06-1.59 USD/kWh. This is more than the electricity price of 1.36 USD/kWh. Therefore, this plant is not feasible and unattractive for investment. The investment cost is 37,765 USD.

The total amount of feedstock readily available was 463 tonne per year. This amount is not sufficient for all plant capacities. This is sufficient for only the 10 Kw plant. Which means, only the 10 kW plant is potentially feasible. The feedstock requires an area of 1561 hectares to produce two units of 10 kW plant capacity. Up to 13 households can be supplied with electricity from this plant. A total of 29 jobs can be created from collection and processing of feedstock.

The net present value and internal rate of return of the 10 kW plant is negative and zero respectively. Which means, maize husk is not feasible for power generation. On the contrary, the 40 kW and 100 kW have a positive net present value and internal rate of return as shown in Figure 4.12. These means, these capacities are feasible financially but there are not enough residues for power generation. (See Figure 4.10 for other pre-defined capacities)

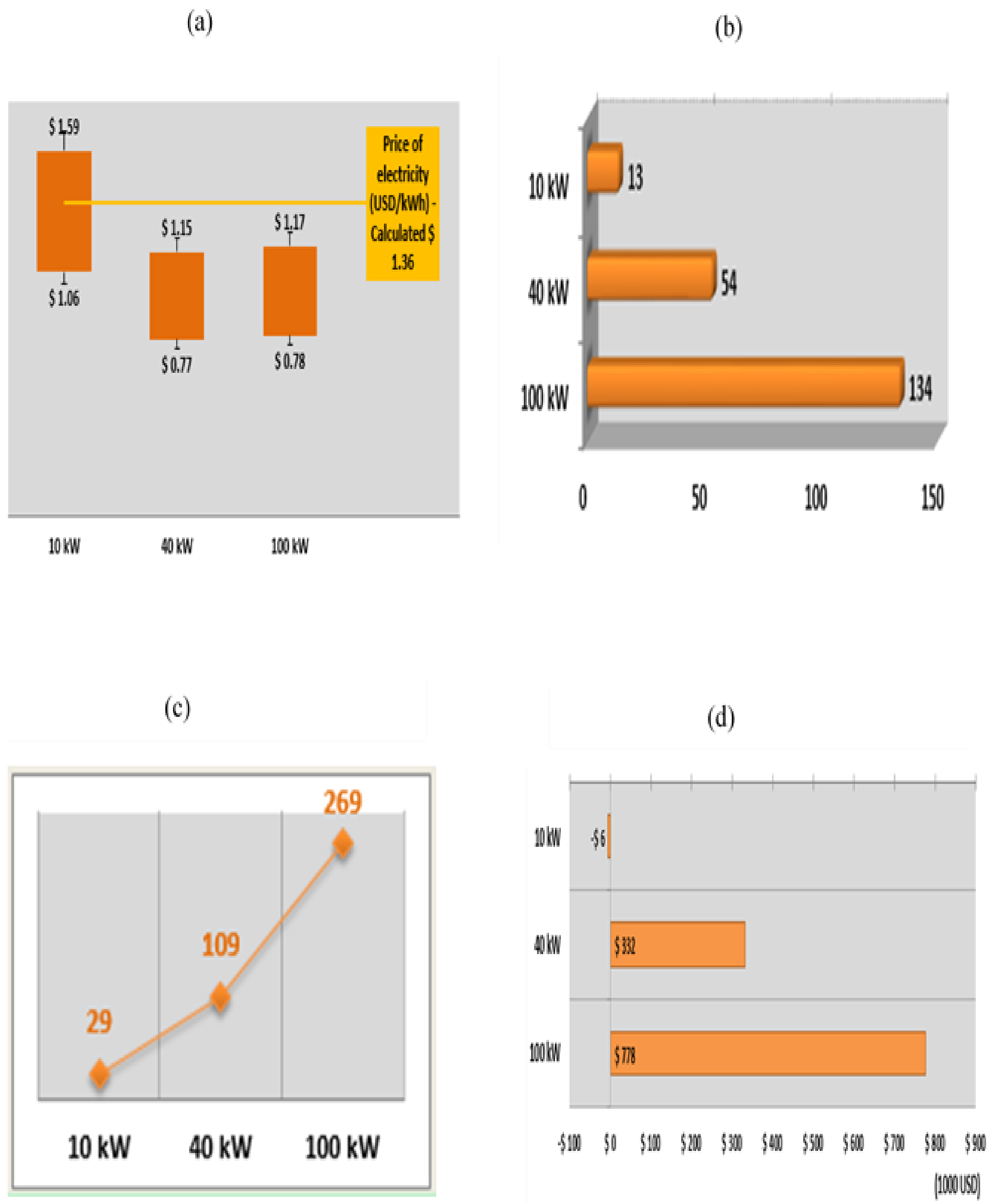


Figure 4.10: Summary results of rural electrification-combustion from maize husk; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.2.3 Maize cob

The production cost and distribution cost of electricity of 10 kW ranged between 0.70-1.04 USD per kWh. These unit costs are lower than the electricity price of 1.36 USD/kWh. Therefore, this plant is feasible and attractive for investment. The total investment cost of 10 kW is 37,765 USD.

There is sufficient crop residues for all plant capacities. The total amount of residue available is 5053 tonne per year. This means all the plant capacities are potentially feasible and attractive for investment. The feedstock requires an area of 148 hectares to produce 23 units of the 10 Kw plant. Up to 13 households can be supplied with electricity and a total seven jobs can be created from collection and processing.

The net present value and internal rate of return of all plant capacities are positive. The feedstock is sufficient for all plant capacities. Therefore, it can be concluded that, maize cob is feasible for power generation at all plant capacities. (Refer to Figure 4.11 for other pre-defined capacities)

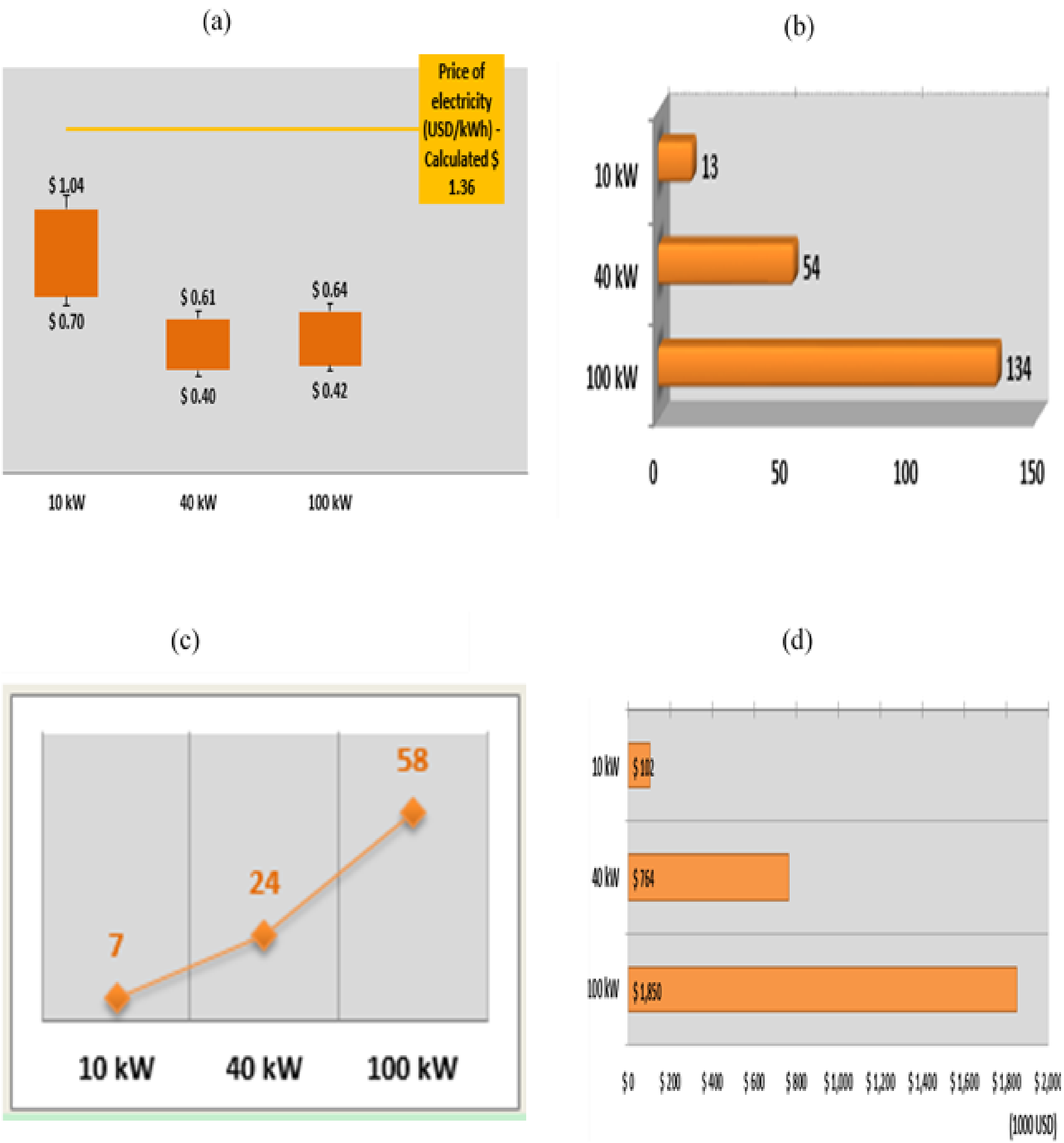


Figure 4.11: Summary results of rural electrification-combustion from maize cob; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.2.4 Rice husk

The production and distribution cost of electricity of the 10 kW is between 0.74-1.11 USD per kWh. This is less than the price of electricity, which is 1.36 USD per kWh. Therefore, this plant is feasible and attractive for investment. The total cost of investment is 37, 765 USD.

The total feedstock available for combustion is 446 tonne per year. This only sufficient for the 10 kW plant. Therefore, only the 10 Kw is feasible for investment. The feedstock requires an area of 320 hectares to produce one unit of the 10 Kw plant. Up to 13 households can be supplied with electricity and 13 jobs can be created from collection and processing.

The net present value and internal rate of return are positive. However, there are not enough residues for 40 kW and 100 kW as shown in figure 4.29. Therefore, it can be concluded that, rice husk is feasible for power generation at the 10 kW. (Refer to Figure 4.12 for other pre-defined capacities).

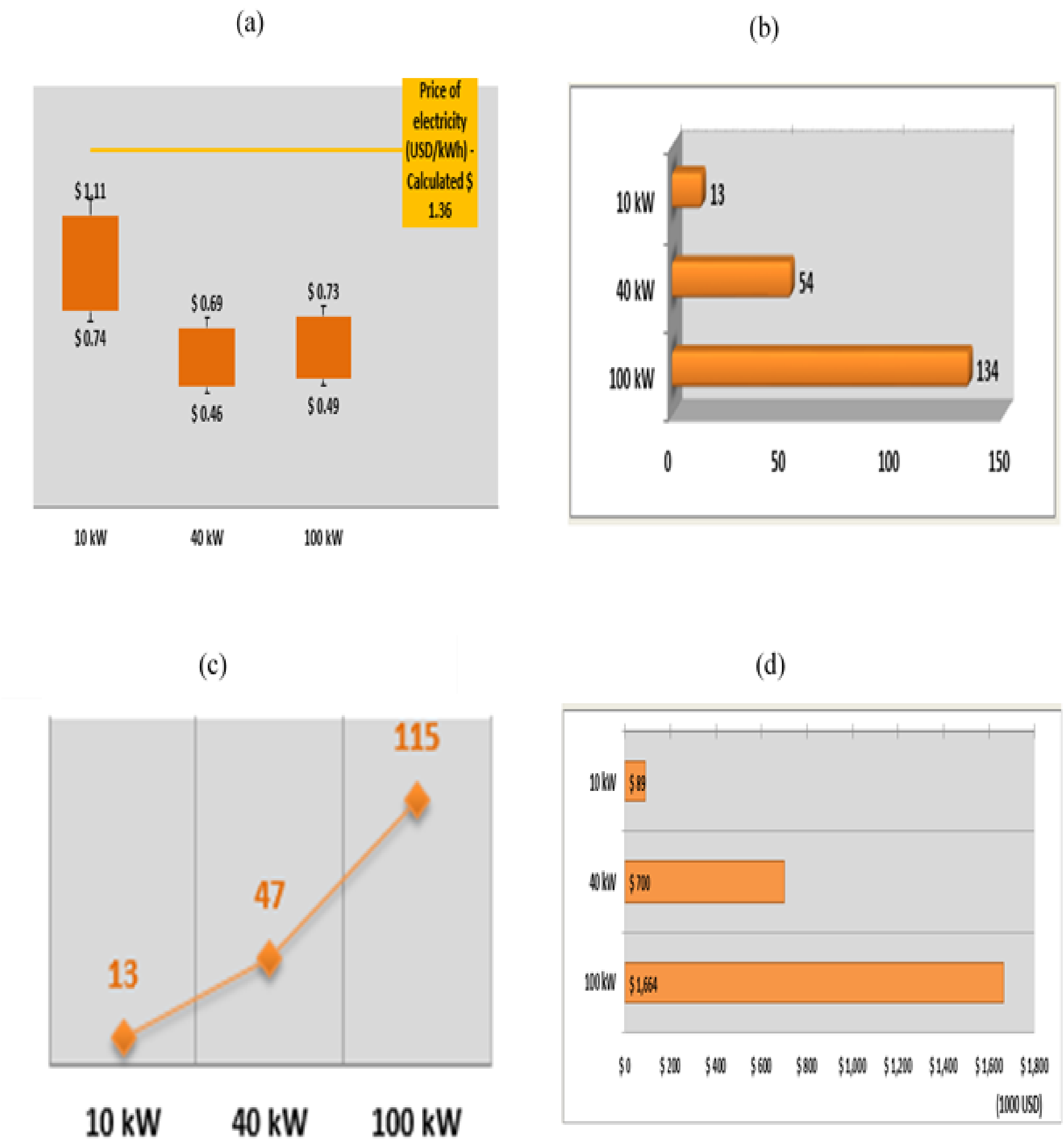


Figure 4.12: Summary results of rural electrification-combustion from rice husk; (a) production and distribution cost (USD/kWh); (b) households potentially supplied; (c) potentially job creation; (d) Net Present Value (NPV)

4.3.2.5 Results summary of all feedstock for combustion

The production cost of electricity of maize husk is the highest compared to other feedstock for plant capacities. The price of electricity production from maize husk exceeded the unit price of electricity. Maize stover, maize cob and rice husk all have the lowest production cost which are less than the unit price of electricity as shown in Figure 4.13. In addition, all the feedstock provide positive NPV and IRR except maize husk. Therefore, it can be concluded that:

a. Maize stover and maize cob are feasible options for power generation at all plant capacities.
b. Rice husk is feasible for power generation at 10 kW but not sufficient for 40 kW and 100 kW. However, maize husk is not feasible as its NPV is negative.

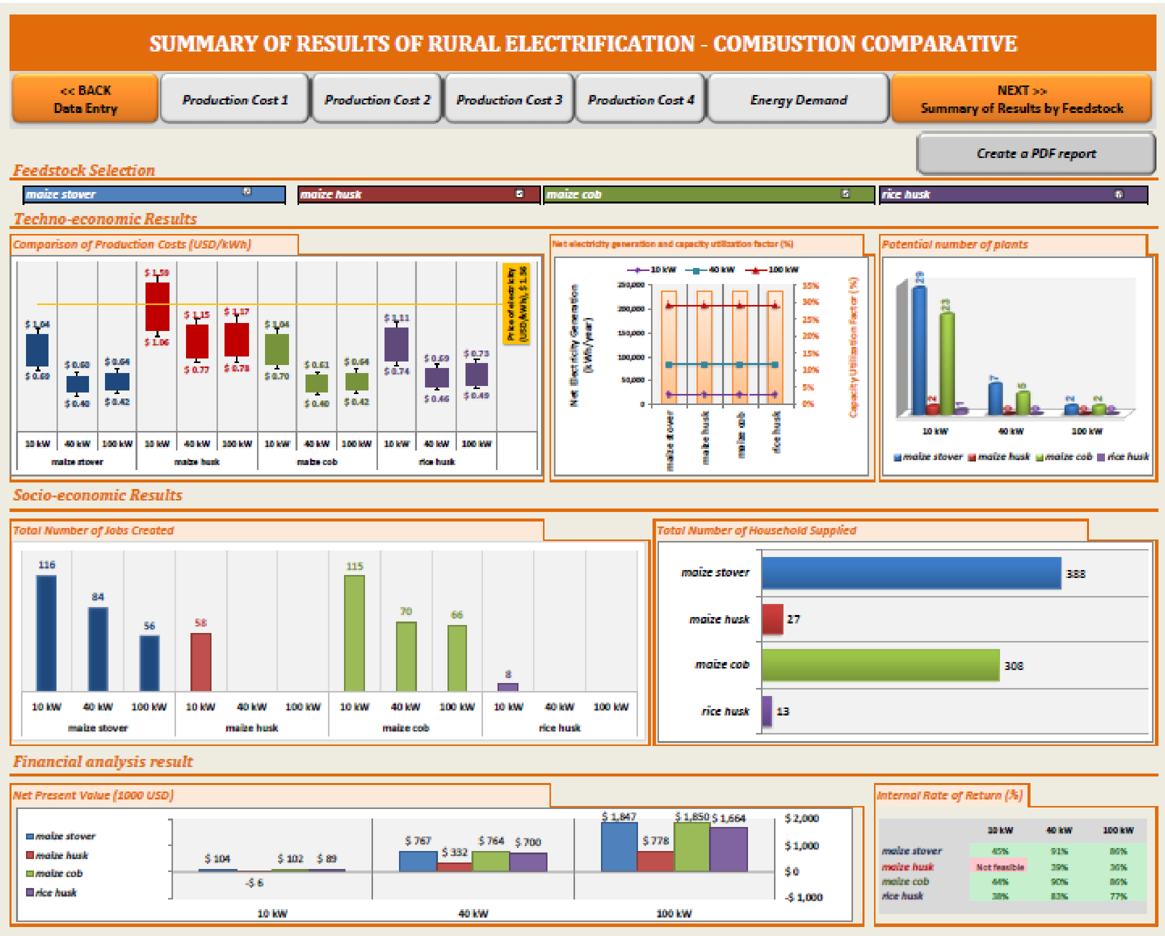


Figure 4.13: Layout of comparative results of Combustion

4.3.3 Comparison of the two pathway results

There are enough residues available for power generation by gasification and combustion. The 10 kW plant was used for the comparison because all the crop residues were sufficient for power generation at that capacity. The unit price of electricity by combustion technology is 1.36 USD per kWh whereas gasification is 1.37 USD per kWh as shown in Figure 4.13 and Figure 4.8 respectively. The average potential number of units of 10 kW combustion plant is 14 as compared to 12 units of a gasification plant. The combustion pathway can create 74 potential jobs while 66 jobs can be created by gasification.

Maize stover and maize cob are feasible for power generation at all plant capacities by gasification and combustion. However, due to insufficient crop residues, maize husk and rice husk were not sufficient for power generation at 40 kW and 100kW capacities by gasification and combustion. Maize stover and maize cob for 10 kW plant have a positive net present value and internal rate of return of feedstock for both gasification and combustion. However, the unit cost of electricity by gasification is higher, thus 1.37 USD per kWh compared to combustion of 1.36 kWh.

In addition, combustion has high job opportunities, high potential number of units and low investment cost than gasification. It can be concluded that, maize stover, maize cob and rice husk is feasible for 10 kW combustion plant. Again, Maize stover and maize cob are the feasible options for power generation at all plant capacities by combustion. (See Table 4.1)

Table 4.1 Comparison of Gasification and Combustion

	Gasification	Combustion
Unit price of electricity (USD per kWh)	1.37	1.36
Potential Number of plant	12	14
Number of job created	66	74
Number of household supplied	147	184

CHAPTER FIVE

5 Conclusion and Recommendation

Energy and agriculture have close relationship when looking at bioenergy. The use of food crops for bioenergy has become a heated debate in recent time. This problem has caused policy makers to look at an alternative approach to counter the problem. Bioenergy is a complex kind of renewable as it cut across a range of disciplines, which requires multidisciplinary way to ensure feasibility and sustainability.

The assessment of natural resources in a country or district can sometime be difficult due to the limited resources. The bioenergy and food security rapid appraisal (BEFS RA) approach makes it possible to do this assessment, as it integrates agriculture and energy sectors and prioritize the need of agriculture while ensuring sustainability. The tool was used for the analysis of maize and rice residues for the production of electricity for rural electrification in Ejisu-Juaben district in Ghana. Despite the high electrification rate in Ghana, thus 85%, there are still communities that do not have access to electricity. The analysis was based on maize and rice residues availability. Therefore, the amount of biomass that will be available was calculated and allocated to the conversion pathway thus gasification and combustion.

The study has shown that combustion would have the highest benefit for the district in terms of job creation, electricity price, number of unit of plants and number of household that can be supplied with electricity. Although, the investment cost in the combustion plant is lower than gasification plant according to the study, it is still capital intensive. This reflects in the unit cost of electricity, which is expensive when compared to the grid, as most of the deprived communities are inhabited by peasant farmers. From the policy point of view, it is important that further study is conducted to assess other crop residues to know the production cost and levelized costs, to enable a fair comparison.

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7 Appendix

Country status

Table 7.1: Country overview

POPULATION

Parameter (unit)	Value	Year	User-defined value	Year
Total population (1000 inhab)	-	-	28,206,728	2015
Rural population(%)	-		45%	
Urban population (%)	-		55%	
Population density (inhab/km2)	-		121.0	
Source:	FAO, 2016: FAOSTAT		The World Bank, 2017: WDI	

SOCIO-ECONOMIC INDICATORS

Parameter (unit)	Value	Year	User-defined value	Year
GDP per capita (current US$)	-	-	10,112	2015
GDP/capita, PPP (current int. $)	-	-	15691	2015
GDP/capita, PPP (const. 2011, int. $)	-	-	14725	2015
Agriculture, value added (% of GDP)	#N/A	#N/A	21%	2015
Source:	The World Bank, 2016: WDI		The World Bank, 2017: WDI	

LAND COVER / LAND USE

Parameter	1000 ha	% of land area	Year	User-defined value	Year
Country area	-		-	23,884	2015
Land area	-	-	-	23,884	2015
Agricultural area	-	-	-	13,600	2015
Arable land	-	-	-	6,421	2015
Permanent crops	-	-	-	1,100	2015
Forest area	-	-	-	8,746	2015
Source:	FAO, 2016: FAOSTAT			Facts and Figures, 2016: MoFA	

FOOD SECURITY AND ENERGY USE

Parameter (unit)	Value	Year	User-defined value	Year
Undernourished population (%)	#N/A	#N/A	5%	2015
Poverty headcount ratio at national poverty line (% of pop.)	#N/A	#N/A	24%	2012
Energy use (kg of oil eq. per capita)	-	-	260	2014
Electricity production (GWh)	-	-	12,963	2014
Access to electricity (% of population)	#N/A	#N/A	85%	2014
Source:	The World Bank, 2016: WDI		The World Bank, 2017	

FOOD SUPPLY AND KEY FOODSTUFFS

Rank	Food commodity	Food supply (kcal/capita/day)	Share in total food supply
1	Cassava and products	642	21.3%
2	Yams	437	14.5%
3	Plantains	311	10.3%
4	Rice (Milled Equivalent)	304	10.1%
5	Maize and products	222	7.4%
6	Sugar (Raw Equivalent)	136	4.5%
7	Wheat and products	109	3.6%
8	Roots, Other	79	2.6%
9	Beans	75	2.5%
10	Palm Oil	74	2.5%
	Subtotal	2,389	79.3%
	Total food supply	3,013	100%
Source:	FAO, 2017: FAOSTAT	*Year:*	2013

AGRICULTURAL TRADE - KEY COMMODITIES

Rank	Trade commodity	Export quantity (t)	Export value (1000 US$)	Export unit value (US$/t)	Share in total value of exports
1	Pineapple	43,461	20,539	473	1.2%
2	Yam	28,296	18,980	671	1.1%
3	Banana	95,180	25,443	267	1.5%
4	Orange	5,062	310	61	0.0%
5	Tuna Fish	12,138	27,785	2,289	1.6%
6	Cuttlefish & Octopus	1,020	3,803	3,728	0.2%
7	Cocoa products	220,308	649,997	2,950	38.4%
8	Cashew nuts	232,835	211,328	908	12.5%
9	Coffee	174	570	3,276	0.0%
10	Shear nut	134,651	33,572	249	2.0%
	Subtotal		992,327		59%
	Total value of export of agricultural commodities		1,694,476		
Source:	Facts and Figures, 2016: MoFA		*Year:*	2015	

Table 7.2: Net trade position for some key foodstuff in the past 10 years

Food crop 1 *Cassava and products*

Year	Production (t)	Import (t)	Stock variation (t)	Export (t)	Domestic supply (t)	NET TRADE POSITION %	position
2004	9,739	-	-	16	9,723	0.2%	Net exporter
2005	9,567	-	-	13	9,554	0.1%	Net exporter
2006	9,638	1	-	21	9,619	0.2%	Net exporter
2007	10,218	1	-	12	10,207	0.1%	Net exporter
2008	11,351	1	-	12	11,340	0.1%	Net exporter
2009	12,231	1	-	18	12,214	0.1%	Net exporter
2010	13,505	1	-	-	13,505	0.0%	Net importer
2011	14,241	1	-	6	14,236	0.0%	Net exporter
2012	14,547	1	-	-	14,549	0.0%	Net importer
2013	15,990	2	-	9	15,983	0.0%	Net exporter

Source: FAO, 2017: FAOSTAT

Food crop 4 *Rice (Milled Equivalent)*

Year	Production (t)	Import (t)	Stock variation (t)	Export (t)	Domestic supply (t)	NET TRADE POSITION %	position
2004	161	791	441	1	510	-154.9%	Net importer
2005	191	482	147	-	526	-91.6%	Net importer
2006	167	387	33	2	585	-65.8%	Net importer
2007	124	443	33	-	600	-73.8%	Net importer
2008	201	403	76	-	680	-59.3%	Net importer
2009	261	389	98	-	748	-52.0%	Net importer
2010	328	324	210	-	862	-37.6%	Net importer
2011	309	558	10	-	857	-65.1%	Net importer
2012	321	410	147	-	878	-46.7%	Net importer
2013	380	656	128	-	907	-72.3%	Net importer

Source: FAO, 2017: FAOSTAT

Food crop 2 *Yams*

Year	Production (t)	Import (t)	Stock variation (t)	Export (t)	Domestic supply (t)	NET TRADE POSITION %	position
2004	3,892	-	-	13	3,879	0.3%	Net exporter
2005	3,923	-	-	16	3,907	0.4%	Net exporter
2006	4,288	-	-	16	4,272	0.4%	Net exporter
2007	4,388	-	-	21	4,355	0.5%	Net exporter
2008	4,376	-	-	15	4,880	0.3%	Net exporter
2009	4,895	-	250	11	5,517	0.2%	Net exporter
2010	5,778	-	-	7	5,953	0.1%	Net exporter
2011	5,960	-	-	10	6,286	0.2%	Net exporter
2012	6,295	-	-	21	6,618	0.3%	Net exporter
2013	6,639	-	-	21	7,054	0.3%	Net exporter

Source: FAO, 2017: FAOSTAT

Food crop 5 *Maize and products*

Year	Production (t)	Import (t)	Stock variation (t)	Export (t)	Domestic supply (t)	NET TRADE POSITION %	position
2004	1,158	51		-	9,723	-0.5%	Net importer
2005	1,171	57		1	9,554	-0.6%	Net importer
2006	1,189	102		1	9,619	-1.1%	Net importer
2007	1,220	4		13	10,207	0.7%	Net exporter
2008	1,470	65		1	11,340	-0.6%	Net importer
2009	1,620	37		1	12,214	-0.3%	Net importer
2010	1,872	2		9	13,505	0.4%	Net exporter
2011	1,684	13		1	14,236	-0.1%	Net importer
2012	1,950	115		2	14,549	-0.8%	Net importer
2013	1,764	6		4	15,983	0.0%	Net importer

Source: FAO, 2017: FAOSTAT

Food crop 3 *Plantains*

Year	Production (t)	Import (t)	Stock variation (t)	Export (t)	Domestic supply (t)	NET TRADE POSITION %	position
2004	2,381	-	-	-	2,381	0.0%	Net importer
2005	2,792	-	-	-	2,792	0.0%	Net importer
2006	2,900	-	-	-	2,900	0.0%	Net importer
2007	3,234	-	-	-	3,234	0.0%	Net importer
2008	3,338	-	-	-	3,337	0.0%	Net importer
2009	3,563	-	-	-	3,562	0.0%	Net importer
2010	3,538	-	-	-	3,538	0.0%	Net importer
2011	3,620	-	-	-	3,619	0.0%	Net importer
2012	3,557	-	-	-	3,557	0.0%	Net importer
2013	3,675	-	-	-	3,675	0.0%	Net importer

Source: FAO, 2017: FAOSTAT

Table 7.3: Simplified aggregated energy balance

Unit:	Coal and peat	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Electricity	Heat	Total
Total primary energy supply	**0**	**696**	**7,024**	**621**	**0**	**721**	**0**	**3,629**	**-41**	**0**	**12,650**
Production	0	5,435	3,512	53	0	721	0	3,629	0	0	13350
Import	0	707	3,512	568	0	0	0	0	4	0	4792
Export	0	5,447	0	0	0	0	0	0	45	0	5491
Final consumption	**0**	**0**	**3272**	**0**	**0**	**0**	**0**	**2788**	**953**	**0**	**7013**
Industry	0	0	358	0	0	0	0	243	326	0	927
Transport	0	0	2,610	0	0	0	0	0	1	0	2610
Residential	0	0	185	0	0	0	0	2,407	410	0	3002
Commercial and public services	0	0	15	0	0	0	0	138	216	0	369
Agriculture / forestry	0	0	105	0	0	0	0	0	0	0	105
Fishing	0	0	0	0	0	0	0	0	0	0	0
Non-specified	0	0	0	0	0	0	0	0	0	0	0
Non-energy use	0	0	0	0	0	0	0	0	0	0	0

Source: National Energy Statistics, 2015 **Year:** 2014

Table 7.4: Household profile-rural household

Electrical devices used in an average rural household	Standard Capacity (W)	Duty cycle	Quantity	Operating time (h/day)	Monthly use (days/month)	Electricity consumption kWh/day	kWh/month
TV color 25 inch	**110**	100%	1	6	30	0.66	19.80
TV color 14 inch	**60**	100%				0.00	0.00
Computer	**237**	100%				0.00	0.00
Fan 16 inch	**40**	100%	1	3	30	0.12	3.60
Air conditioner (9,000 BTU)	**880**	100%				0.00	0.00
Electrical iron	**1,000**	100%	1	1	12	1.00	12.00
Rice cooker	**530**	100%				0.00	0.00
Microwave	**1,200**	100%				0.00	0.00
Clothes washer 5 kg	**305**	80%				0.00	0.00
Electrical boiler	**650**	100%				0.00	0.00
Refrigerator	**390**	30%	1	24	30	2.81	84.24
Electrical water shower	**4,000**	100%				0.00	0.00
Fluorescent lamp (ceiling T5)	**28**	100%	1	9	30	0.25	7.56
Compact fluorescent lamp T5	**14**	100%	1	6	30	0.08	2.52
User defined appliance						0.00	0.00
TOTAL						**4.92**	**129.72**

Agricultural residues

Table 7.5: Crop residue type

		Crop 1	Crop 2	Crop 3	Crop 4
Crop		maize	maize	maize	rice
Residue		stover	husk	cob	husk
Location of residue generation		field - spread	field - collected	field - collected	processing plant
Crop production					
Crop yield (t/ha)		1.20	1.20	1.20	3.60
No. of harvests/year		1.00	1.00	1.00	1.00
Annual production (t)		4,211.00	4,211.00	4,211.00	2,085.00
Total production area (ha)		**3,509.17**	**3,509.17**	**3,509.17**	**579.17**
Generation of crop residues					
Residue to crop ratio	*User defined*			1.50	0.31
	Default value	*1.96*	*0.22*		
Total residue production (t/year)		**8,253.56**	**926.42**	**6,316.50**	**646.35**
Residue yield (t/ha)		**2.35**	**0.26**	**1.80**	**1.12**
Residues burnt in the field (production area burnt after the harvest)					
Production area burnt after harvesting	*User defined (ha)*	230.00	230.00	230.00	59.00
	Default value (ha)		350.92	350.92	
Amount of residues burnt (t/year)		**540.96**	**92.64**	**631.65**	**0.00**
Current use of crop residues					
animal feed and bedding	%	0.00%	0.00%	0.00%	30.00%
	t	0	0	0	194
fuel (including charcoal)	%	0.00%	0.00%	0.00%	0.00%
	t	0	0	0	0
construction	%	0.00%	0.00%	0.00%	0.00%
	t	0	0	0	0
industry	%	0.00%	30.00%	0.00%	0.00%
	t	0	278	0	0
other: Mulch	%	0.00%	0.00%	0.00%	1.00%
	t	0	0	0	6
Total currently used	**(%)**	**0%**	**30%**	**0%**	**31%**
	(t/year)	**0.00**	**277.93**	**0.00**	**200.37**

Gasification

Table 7.6: Feedstock availability and cost for gasification

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
	maize	maize	maize	rice
Feedstock	stover	husk	cob	husk
Feedstock potential (t/year)	6,603	463	5,053	446
Feedstock yield (t/ha)	1.88	0.13	1.44	0.77
Moisture content	5%	11%	15%	9%
Average Size (mm)	41	38	59	30
Feedstock price (USD/t)	Price Calculator 1	Price Calculator 2	Price Calculator 3	Price Calculator 4
Use the price definition calculator	$ 3.40		$ 4.44	$ 8.31
Market price (transport excluded)				
Feedstock storage cost (USD/t)	$ 3.0	$ 3.0	$ 3.0	$ 3.0
	Storage Calculator 1	Storage Calculator 2	Storage Calculator 3	Storage Calculator 4

Select a method to determine the price of electricity	Method 1

Method 1	Unit
Comparative production cost of electricity	$ 1.37 USD/kWh
	Electricity Price Calculator

Table 7.7: Electricity price definition and financial parameters of gasification

Method 1	Unit	
Comparative production cost of electricity	$ 1.37 USD/kWh Electricity Price Calculator	**Method 1: Use a calculator to determine the production cost of electricity from diesel generator.**

Production Cost and Financial Parameters

Labour		Unit			Unit
Unskilled worker	$ 0.80	USD/person-h	*Skilled worker*	$ 2.40	USD/person-h
Utilities		Unit			Unit
Water	$ 2.00	USD/m^3	*Diesel* *==>Required to start up the engine*	$ 1.00	USD/litre
Feedstock collection		Unit			Unit
Working hours per day (manual)	8	h/day	*Working hours per day (mechanized)*	16	h/day
Transportation cost		Unit			
Feedstock (collection point to plant)	$ 1.40	USD/t/km			
Other costs		Unit			Unit
General and administrative (%)	5%		*Maintenance cost (%)*	10%	
Plant overhead (%)	30%		*Miscellaneous cost (%)*	10%	
Financial parameters		Unit	***Investment cost update***		
Discount rate	6%				
Loan ratio	50%		*Plant Cost Index during 8/2017*	144.60	
Loan interest rate	10%		http://www.intratec.us/free-tools/intratec-construction-index		
Loan term	5	year			

Combustion

Table 7.8: Feedstock availability and cost for combustion

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
	maize	maize	maize	rice
Feedstock	stover	husk	cob	husk
Feedstock potential (t/year)	6,603	463	5,053	446
Feedstock yield (t/ha)	1.88	0.13	1.44	0.77
Moisture content (%)	5%	11%	15%	9%
Size (mm)	41	38	59	30
Feedstock price (USD/t)	Price Calculator 1	Price Calculator 2	Price Calculator 3	Price Calculator 4
Use the price definition calculator	$ 3.40	$ 49.23	$ 4.44	$ 8.31
Market price (transport excluded)				
Feedstock storage cost (USD/t)	$ 3.00	$ 3.00	$ 3.00	$ 3.00
	Storage Calculator 1	Storage Calculator 2	Storage Calculator 3	Storage Calculator 4

Table 7.9: Definition of electricity and financial parameters of combustion

Method 1		Units	
Comparative production cost of electricity	$ 1.36	**USD/kWh**	**Method 1: Use a calculator to determine the production cost of electricity from diesel generator.**
	Electricity Price Calculator		

Production Cost and Financial Parameters

Labour		Unit			Unit
Unskilled worker	$ 0.80	USD/person-h	*Skilled worker*	$ 2.40	USD/person-h
Utilities		**Unit**			**Unit**
Water	$ 2.00	USD/m^3			
Feedstock collection		**Unit**			**Unit**
Working hours per day (manual)	8	h/day	*Working hours per day (mechanized)*	16	h/day
Diesel	$ 0.87	USD/litre			
Transportation cost		**Unit**			
Feedstock (collection point to plant)	$ 1.40	USD/t/km			
Other costs		**Unit**			**Unit**
General and administrative (%)	5%		*Maintenance cost(%)*	10%	
Plant overhead (%)	30%		*Miscellaneous costs (%)*	10%	
Financial parameters		**Unit**	***Investment cost update***		
Discount rate	6%				
Loan ratio	50%		*Plant Cost Index during 8/2017*	144.60	
Loan interest rate	10%		http://www.intratec.us/free-tools/intratec-construction-index		
Loan term	5	year			

Questionnaire for the analysis

Assess crop residues potential for rural electrification in Ejisu-Juaben District by gasification or combustion technology using the BEFS Rapid Appraisal tools and approach

Questionnaire for crop farmers in villages around Ejusu-Juaben District

June-July, 2017

Questionnaire number: 200 **Name of Community: Nobewam, Besease and Donaso**

We are assessing maize and rice residues potential for rural electrification in Ejisu-Juaben District by gasification or combustion technology using the BEFS Rapid Appraisal tools and approach. Gasification is the process in which combustible materials such as biomass are partially oxidized or partially combusted with a change of the chemical structure at 500-900°C in the presence of a gasifying agent to produce syngas which used to generate electricity. Combustion is a thermochemistry process where a fuel and oxidant agent thus air or oxygen react exothermally generating heat and series of converted named combustion gas to generate electricity. Of interest to us is the possibility of electricity as well as the employment and income gains that such a scheme could bring to this community.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Farmer's name:		Farmer's age:
Contact No.:		Educational background:
Location of homestead:		

1.1 General Household Information

Question	**Response (circle or enter)**
Gender of respondent	1. Male 2. Female
Language spoken	1.Akan (e.g. Twi, Fante, etc) 2. Hausa 3. Ewe 4. Others
Religious affiliation	1.Christian 2. Islam 3. other
What is your marital status:	1. Married/Cohabiting 2. Single/Never married 3. Divorced/separated 4. Widow/Widower
What relationship do you have with the head of household:	1. Wife 2. Son 3. Daughter 4. Other relative 5. Self
How many people live in this household:	Enter number:
How many children aged 14 or younger:	Enter number:
How many adults aged 15 or older:	Enter number:
What is the highest level of education attained by the head of household?	1. None 2. Primary 3. Secondary 4. Trade school 5. University 6. Other (specify):
What is the highest level of education attained by other members of household? (use response code as above) 1. 2.	

3. 4. 5.	
What is this household's main source of income?	
What is the second most important income source?	
What is the third most important income source?	

PART 2: Information on Maize and Rice cultivated

Plots cultivated by farmer	Plot 1	Plot 2	Plot 3	Plot 4
Size of plot (acres)				
Production per crop season(s) [eg. 10000 tonnes]				
How many seasons is plot cultivated per year?				

PART 3: Land ownership and accessibility

Plot ownership and accessibility	Plot 1	Plot 2	Plot 3	Plot 4
How did you acquire plot? 1. purchase; 2. received as gift or inheritance; 3. rented in for fixed payment; 4. borrowed; other (specify).				
How much was paid if purchased or rented?				
How accessible is plot from community center? (E.g. accessible by truck, tractor, motorbike, footpath)				

Part 4: Use of crop residues

Crop type	Residue type	Point of generation, esp. of process residues (home or farm)	Amount use(%)	What happens to unused residues?
Maize	Stalks			
	Husks			
	Cobs			
Rice	Straw			
	Husks			

Do termites eat crop residues after harvest? ☐Yes ☐ No

Which crop residues are usually eaten by termites? 1. Maize 2. Rice 3. Both

4.1 Willingness to accept removal of residues

Do you burn the residue on the field? ☐Yes ☐ No

If YES, what percentage do you burn on the field? ____________________

If NO, which of the following do you use the residue for and what amount in percentage:

☐ Animal feed and bedding ______%

☐ Fuel (including charcoal) ______%

☐ Construction ______%

☐ Industry ______%

☐ Other ______%

Do you intentionally leave the residues as organic fertilizer? ☐Yes ☐ No

If YES, what percentage do you use? ____________________

When ploughing, do you remove left over residue or is it ploughed into the soil?____________________

Would you have any objection to residues being lifted from your farm for energy purposes? ☐Yes ☐ No

Would you sell the residues or give it out for free? ____________________

What percentage of field based residues would you allow for removal? ____________

Why this amount? ____________________

How do you think that would affect the nutrient levels in your farmland? ____________________

4.2 Willingness to use and pay for Combustion or gasification plant– first explain importance of the technologies.

What is your current source of power?..

How much do you spend per month? GHC..

If crop residues were processed into electricity, would you like it? ☐Yes ☐ No

Would you be willing to pay for it (especially if you gave out the residues for free)? ☐Yes ☐ No

Would you be willing to pay 80Gp per kWh (Explain to the farmer)? ☐Yes ☐ No

If NO, how much would you be willing to pay?____________________

Why would you not want to pay?____________________

Part 5: Transportation

5.1 How is harvested crop currently transported from farm to community?
☐ truck ☐ tractor with trailer
☐ motorbike and bicycle ☐ Foot ☐ Other

5.2 How is harvested crop currently transported from community to market center?
☐ truck ☐ tractor with trailer

☐ motorbike and bicycle ☐ Foot ☐ Other

Part 6: Employment / job creation – explain that residues are available for collection at the end of the farming season when most farmers wouldn't be engaged in farm activities. This section intends to ascertain farmers' availability during the off-farm season for possible employment**.**

Are you available to collect the residues for the plant? ☐Yes ☐ No

What income generating activities are available to you during the off-farming season? ______________________________

____

Are you engaged in other jobs during the off-farming season? ☐Yes ☐ No

If available, would you want to be engaged to collect residues for income? ☐Yes ☐ No

7. Labour cost and Savings

7.1 What is the labour cost of engaging a farmer on a 'by-day' basis on an acre farm?

☐ < GHC150 ☐ GHC150-200 ☐ >GHC200

7.2 Are you able to make savings at the end of the year/farming season? ☐Yes ☐ No

From your experience, how much savings do you make at the end of the year? GHC ________________

Part 8: Electronic equipment owned by the household

Type of equipment	Number owned
Radio	
Mobile phone	
Car battery	
Generator	
Refrigerator	
Bulbs	
TV	
DVD player	
Other (specify)	

Guide for focus group discussions

1. Crop residue availability

Existing uses of crop residues in the community?

Does the community anticipate using crop residues in the future?

Do termites eat crop residues after harvest? Which crop residues are usually eaten by termites?

2. Transportation

How is harvested crop currently transported from farm to community and from community to market center? e.g. truck, tractor with trailer, motorbike, bicycle, etc.

What are transport charges for transporting produce from community to market center? Would transport operators charge similar amounts if they transport crop residues? [engage transport operators in a similar conversation]

Is road to Ejuaso-Juaben accessible throughout the year?

3. Labour costs (later perform field experiments to quantity amount that can be harvested per a certain period)

What is the labour cost of engaging a farmer on a 'by-day' basis on a farm? ______________________

Are labour fees different for young people and adults? E.g. 18-25, >25, etc.______________________

Would labour cost be different if engaged in a different activity, such as collect crop residues and transporting?

What would be the likely labour cost for collecting crop residues? ______________________

What is the source of water for community?

What is the distance of water source from community center?

Cost of drawing water

Is there water shortage during certain periods? E.g. dry season. What happens during water shortage?

4. Farmer co-operatives and access to credit

Is there a farmer cooperative in the community?

What is the role of the

cooperative? ____

Could the cooperative assist with organizing feedstock for electricity generation?

If there exist a farmer co-operative, what is their experience with access to credit?