Assessment of technical potential and selected sustainability impacts of second generation bioenergy in Ghana

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Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Kemausuor, F., Addo, A., Ofori, E., Darkwah, L., Bolwig, S., & Nygaard, I. (2015). *Assessment of technical potential and selected sustainability impacts of second generation bioenergy in Ghana*. Kwame Nkrumah University of Science and Technology.

ASSESSMENT OF TECHNICAL POTENTIAL AND SELECTED SUSTAINABILITY IMPACTS OF SECOND GENERATION BIOENERGY IN GHANA

By

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A Thesis submitted to the Department of Agricultural Engineering, Kwame Nkrumah
University of Science and Technology in partial fulfilment of the requirements for
the degree of

DOCTOR OF PHILOSOPHY

in

Bioengineering

COLLEGE OF ENGINEERING

May, 2015

DECLARATION

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgements has been made in the text.

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Dedication

This thesis is dedicated to my family: Ruth, Curtis, Casey and Cayden; and the late Prof. Abeeku Brew-Hammond of blessed memory, who have been my support and source of inspiration.

Acknowledgement

I wish to acknowledge the support of my family throughout this study: My father, my mother, my siblings and the entire extended family.

My supervisors, Prof. Ahmad Addo, Dr Emmanuel Ofori and Dr Lawrence Darkwah, were very helpful with their comments. Dr Emmanuel Ofori was part of the supervisory team until his untimely demise in October 2014. May his soul rest in perfect peace.

This work was supported with a grant from DANIDA Fellowship Centre (DFC) of the Danish Ministry of Foreign Affairs, as a part of the project “Biofuel production from lignocellulosic materials – 2GBIONRG”, DFC journal no. 10-018RISØ. For additional information, see http://2gbionrg.dk.

As part of the DANIDA project, I received invaluable support from my two Danish co-supervisors Simon Bolwig and Ivan Nygaard as well as from Gordon Mackenzie and Hanne Østergaard, all from the Technical University of Denmark – DTU.

As part of the same project, I worked closely with fellow PhD Students: Sune Tjalfe Thomsen (who has since graduated), Andreas Kamp, Edem Cudjoe Bensah and Kodwo Mieza.

Some aspects of this work were done at the University of Michigan, Ann Arbor, Michigan. Model preparation and drafting of a part-manuscript for Chapter 6 was carried out during a research fellowship at the University of Michigan as part of the University of Michigan African Presidential Scholars (UMAPS) Program, under the guidance of Prof Shelie Miller. The program Director Prof Kelly Askew and coordinators Devon Keen and Sandra Schulze were every helpful. Colleagues on the programme were inspiring.

I also want to acknowledge support received from staff of The Energy Center, and the Department of Agricultural Engineering, KNUST. I am also grateful to staff of the Ghana Energy Commission, especially Ms. Joyce Ocansey for commenting on the socio-economic assessment chapters.

Abstract

Biomass is an important renewable energy source that holds large potential as feedstock for production of different energy carriers in a context of sustainable development, peak oil and climate change. The aim of this thesis was to establish the technical potential of biomass for second generation biofuels production in Ghana; examine the extent to which the available biomass could contribute to future energy scenarios and analyse ex-ante socio-economic impacts of biomass energy systems using relevant case studies. The thesis found that the technical potential of bioenergy from agricultural residues, livestock manure, municipal solid waste and wood residues was approximately 275 PJ in 2011 alone. By 2030, the potential biomass available could gross over 900 PJ. Generating 4.0% of total electricity from biomass and replacing approximately 20% of transport fuels in 2030 with biofuels could reduce greenhouse gases (GHG) emissions by about 6 million tonnes of CO_{2eq} by 2030, equivalent to about 14% reduction relative to emissions from a business-as-usual scenario. A gradual household switch to biogas for cooking, as well as the increased use of more efficient charcoal carbonisation technologies and improved cookstoves could save 138 PJ of woodfuels by the same 2030. Socio-economic impact studies were conducted for biogas production from staple food systems and agro-industrial systems. In the staple food system, a 300 m^3 bio-digester would have a Net Present Value of approximately US$ 22,000, 16 year payback period and an Internal Rate of Return of 11%, assuming a 10% discount rate. The project will create four (4) full time unskilled labour positions during the investment year and three (3) positions during the operational years. Using methane from the bio-digester for cooking will displace approximately 170 t of firewood per year and save the women in the community a total of 3,400 h per year from not fetching firewood. However, only 5% of households are willing to pay the base tariff of US$ 30/month with up to 60% willing to pay less than half the monthly tariff.

Table of Contents

List of Figures xi
List of Tables xiii
CHAPTER ONE 1
1.0 GENERAL INTRODUCTION AND BACKGROUND 1
  1.1 Background Information 1
  1.2 Objectives of Study 6
  1.3 Research Questions 6
  1.4 Significance of the Research 7
  1.5 Hypothesis 8
  1.6 Scope and Structure of Thesis 9
  1.7 Limitations of Study 10
  1.8 Delimitations of Study 11
CHAPTER TWO 12
2.0 LITERATURE REVIEW 12
  2.1 Introduction 12
  2.2 Recent Trends in Renewable Energy 12
  2.3 Global Bioenergy Potentials 18
  2.4 Impact of Bioenergy Production 23
    2.4.1 Environmental Impacts 23
    2.4.2 Socio-economic Impacts 26
      2.4.2.1 Definition 26
      2.4.2.2 Socio-economic Impacts of Bioenergy at Different Levels 27
      2.4.2.3 Positive Socio-economic Impacts 28
      2.4.2.4 Negative Socio-economic Impacts 29
      2.4.2.5 Tackling Negative Socio-economic Impacts 32
  2.5 Bioenergy and Climate Change 34
  2.6 Bioenergy Sustainability Assessment and Sustainability Indicators 36
    2.6.1 Sustainability Assessment 36
    2.6.2 Bioenergy Certification 36

2.6.3 Bioenergy Sustainability Indicators 41
2.7 Review of Energy Situation in Ghana 44
2.7.1 Trends in Electricity Demand and Supply 45
2.7.2 Trends in Petroleum Products Consumption 49
2.7.3 Trends in Woodfuels Consumption 51
2.7.4 Efforts at Promoting Bioenergy 53
2.8 Key Research Gaps and Motivation 58
CHAPTER THREE 60
3.0 GENERAL MATERIALS AND METHODS 60
CHAPTER FOUR 65
4.0 ASSESSMENT OF TECHNICAL POTENTIAL OF BIOENERGY FEEDSTOCK 65
4.1 Background 65
4.2 Methodology 65
4.2.1 Mapping of Crop Residues 65
4.2.2 Assessment of Manure, Wood Residues and Municipal Solid Waste . 72
4.2.3 Estimation of Energy Potentials 73
4.3 Results and Discussion 75
4.3.1 Residue to Product Ratio (RPR) Analysis 75
4.3.2 Crop Residue Availability 78
4.3.2.1 Residue from Cereals 81
4.3.2.2 Residues from Roots, Tubers and Plantain 81
4.3.2.3 Residue from Legumes 82
4.3.2.4 Residue from Oil Crops 83
4.3.2.5 Residue from Other Crops 83
4.3.2.6 Residue uses and management 84
4.3.3 Geographical Distribution of Residues 85
4.3.3.1 Regional Distribution of Residues 85
4.3.3.2 District Level Analysis of Residues 87
4.3.4 Livestock Manure 90
4.3.5 Household / Municipal Solid Waste 91

4.4 Energy Potential of Identified Bioenergy Feedstock 93
4.5 Sustainability Challenges 94
4.6 Summary of Findings 99
CHAPTER FIVE 101
5.0 MODELLING ENERGY DEMAND AND SUPPLY WITH EMPHASIS ON BIOENERGY USE IN GHANA 101
5.1 Introduction 101
5.2 Methodology 101
5.2.1 Data Requirements 104
5.2.2 Scenario Analysis 106
5.2.2.1 Reference Scenario 106
5.2.2.2 Environmental Effect / GHG Emissions 108
5.2.2.3 Bioenergy Scenarios 108
5.3 Results and Discussion 111
5.3.1 Reference Scenario 111
5.3.1.1 Energy Demand 111
5.3.1.2 Greenhouse Gas Emissions 114
5.3.2 Bioenergy Scenarios 116
5.3.2.1 Electricity Generation 116
5.3.2.2 Transportation Sector 118
5.3.2.3 Residential Sector 120
5.3.2.4 Resource Requirement in Bioenergy Scenario 122
5.3.2.5 Emissions Savings in Bioenergy Scenarios 126
5.4 Summary of Findings 128
CHAPTER SIX 130
6.0 MODELLING SOCIO-ECONOMIC IMPACT OF BIOGAS OPTIONS IN SMALL SCALE STAPLE FOOD SYSTEMS 130
6.1 Background 130
6.2 Methodology 132
6.2.1 Model Description 132
6.2.2 Model Application – *Zambrama* Community 136

6.2.2.1 Input variables and Data Acquisition 138
6.2.2.1.1 Farmer Household and Cattle Ranch Survey........................... 140
6.2.2.1.2 Field/Fuel Use Experiments... 141
6.2.2.1.3 Residue-to-Product Ratios 141
6.2.2.1.4 Field Labour Requirements 142
6.2.2.1.5 Firewood Harvest Labour Requirements................................ 142
6.2.2.1.6 Woodfuels Consumption Estimation...................................... 142
6.3 Results and Discussion 143
6.3.1 Resource Availability... 143
6.3.2 Social Benefits 147
6.3.2.1 Job Creation and Income 147
6.3.2.2 Displacement of Woodfuels and Time Savings 149
6.3.3 Financial analysis of base scenario 151
6.3.4 Willingness to Pay 153
6.3.5 Sensitivity Analysis... 156
6.3.5.1 Effect of Government Subsidy with Reduced Methane Tariff....... 156
6.3.5.2 Effect of Government Subsidy with Reduced Methane Tariff and 'Zero' Manure Transport Cost 158
6.4 Summary of Findings 159
CHAPTER SEVEN.. 161
7.0 MODELLING SOCIO-ECONOMIC IMPACT OF BIOGAS OPTIONS IN AGRO-INDUSTRIAL SYSTEMS 161
7.1 Background.. 161
7.2 Methodology... 163
7.2.1 Model Description.. 163
7.2.2 Model Application – Agro-industrial Systems 163
7.2.2.1 Study Area 163
7.2.2.2 Description of Cassava Processing Activity................................. 165
7.2.2.3 Assessment of Peels and Manure 166
7.2.2.4 Measurement of Firewood Use 167
7.3 Results and Discussion 167

7.3.1 Cassava Peel and Biogas Potential 167
7.3.2 Financial Assessment of Biogas Development 172
7.3.3 Job Creation and Income Generation Potential 176
7.4 Summary of Findings 177
CHAPTER EIGHT 179
8.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH 179
8.1 Conclusions 179
8.1.1 Assessment of Bioenergy Feedstock Potential 179
8.1.2 Perspectives of Bioenergy Contribution to National Energy Mix 181
8.1.3 Socio-economic Assessment of Biogas Production 182
8.1.4 Contribution from Research Findings 184
8.2 Recommendations for Further Research 185
REFERENCES 187
APPENDICES 206

List of Figures

Figure 2.1: Historical Brent crude oil prices, nominal prices 14

Figure 2.2: Estimated RE share of global final energy consumption 15

Figure 2.3: Average annual growth rate of RE capacity and biofuels production..... 15

Figure 2.4: Biofuels production trends.. 17

Figure 2.5: Final energy consumed in 2012 [Total = 268 PJ].................................. 44

Figure 2.6: Electricity consumption by customer class 45

Figure 2.7: Trends in electricity generation by source fuel 47

Figure 2.8: Total WAGP gas supply to Ghana for second half of 2013 48

Figure 2.9: Petroleum products consumption 50

Figure 2.10: LPG consumption for different purposes 50

Figure 2.11: Woodfuels consumption.. 52

Figure 2.12: Access to cooking fuels shown against the fuel ladder 52

Figure 3.1: Schematic representation of methodological approach 60

Figure 3.2: Summary of data needs and modelling tools for analysis 61

Figure 4.1: Crop residue pathways 67

Figure 4.2: Map of Ghana showing RPR field locations 70

Figure 4.3: Residue generation at district level, 2011 (t).. 88

Figure 4.4: Residue generation density at district level, 2011 89

Figure 4.5: Conceptual overview of life-cycle approach to bioenergy...................... 96

Figure 5.1: Leap model interface 105

Figure 5.2: Projected energy demand by fuel type 112

Figure 5.3: Projected electricity generation by source.. 114

Figure 5.4: Projected net GHG emissions.. 116

Figure 5.5: Woodfuels demand in all three scenarios 122

Figure 5.6: GHG emissions in the various scenarios 127

Figure 6.1: Flow diagram of residue biogas system 133

Figure 6.2: A map of Ghana showing location of *Zambrama* 137

Figure 6.3: Fixed dome digester 138

Figure 6.4: Crop harvest pattern in *Zambrama*. S1 – Season 1; S2 – Season 2....... 145

Figure 6.5: Cattle manure in a ranch in Ejura 146

Figure 6.6: Cumulative cash flow of base scenario 152

Figure 6.7: Distribution of total production costs over project lifetime 153

Figure 6.8: Willingness-to-pay for methane gas and stove..................................... 154

Figure 6.9: Effect of government subsidy with reduced tariff 157

Figure 6.10: Effect of government subsidy with reduced tariff and manure transport cost 159

Figure 7.1: Map showing study locations 164

Figure 7.2: Flowchart for processing cassava into *gari* 165

Figure 7.3: Pile of cassava peels undergoing open combustion 169

Figure 7.4: Distribution of total production costs over project lifetime 175

List of Tables

Table 2.1: Potential Socio-economic Benefits of Biofuels Development 27

Table 2.2: Selected Bioenergy Certification Initiatives 39

Table 2.3: GBEP Bioenergy Sustainability Indicators... 42

Table 2.4: GBEP sub-indicators for Indicator 12 - Jobs in the bioenergy sector....... 43

Table 2.5: Installed electricity generation capacity at end of September 2014 46

Table 2.6: Electricity generation from biomass resources 55

Table 4.1: Field determined RPR compared to RPR from literature 76

Table 4.2: Residue to Product Ratio for maize from different locations 76

Table 4.3: Residue to Product Ratio for cassava.. 77

Table 4.4: Residue to Product Ratio for rice 77

Table 4.5: Residue to Product Ratio for other crops 78

Table 4.6: Crop residue generation from agricultural crops in 2011 80

Table 4.7: Summary of regional crop residue availability 86

Table 4.8: Availability of livestock manure in Ghana in 2011 91

Table 4.9: MSW collected by each region of Ghana in 2011 92

Table 4.10: Energy potential of identified residues 93

Table 4.11: Biomass energy potential projected to 2030.. 94

Table 5.1: Possible technology options that allow fossil fuels to be substituted with biomass based fuels 109

Table 5.2: Highlight of assumptions in the different scenarios 111

Table 5.3: Electricity generation in bioenergy scenarios 118

Table 5.4: Percentage of transport fuels in bioenergy scenarios, by energy content119

Table 5.5: Bioenergy requirement in the bioenergy scenarios................................ 119

Table 5.6: Assumptions of biomass resource requirement in the bioenergy scenarios 123

Table 5.7: Resource requirement for ethanol demand assuming first generation technology 125

Table 5.8: Resource requirement for biodiesel 126

Table 6.1: Selected input variables for base scenario 139

Table 6.2: Residue availability in *Zambrama* community 145

Table 6.3: Annual socio-economic benefits of project 148

Table 6.4: Key output variables of the base scenario.. 153

Table 7.1: Field determined ratio of peels to cassava 168

Table 7.2: Cassava peel and biogas production details... 168

Table 7.3: Estimates of firewood needed for *gari* production 171

Table 7.4: Key financial variables of the analysis 173

Table 7.5: Annual socio-economic benefits of project 177

LIST OF ACRONYMNS

ACRONYM	**DEFINITION**
CO_2	Carbon dioxide
EFB	Empty Fruit Bunches
EJ	Exajoules
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information Systems
Gl	Gigalitres
Gt	Gigatonnes
GWh	Gigawatt hours
H	Hour
Ha	Hectare
kg	Kilogram
km	Kilometre
kWh	Kilowatt hours
L	Litre
m^2	Squared metre
m^3	Cubic metre
Mha	Million hectares
MJ	Megajoules
MOFA	Ministry of Food and Agriculture
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatt hours
PJ	Petajoules
RPR	Residue-to-Product Ratio
t	Tonnes
TJ	Terajoules
LPG	Liquefied Petroleum Gas
SE4ALL	Sustainable Energy for All
TED	Technology and Environment Database

CHAPTER ONE

1.0 GENERAL INTRODUCTION AND BACKGROUND

1.1 Background Information

Ghana's energy sector is faced with two principal challenges: the inability to provide adequate electricity generation capacity to ensure reliable power supply (Mensah *et al.*, 2014) and the increased use of woodfuels as main cooking fuel for more than 75% of households who do not have access to modern cooking fuels (Ghana Statistical Service, 2012). The country's electricity generation infrastructure, which in the past relied mainly on hydropower, is increasingly shifting towards thermal generation. Low water inflows into the hydropower dams and increasing cost of crude oil has resulted in intermittent power supply as the power generation companies struggle to import fuel to run existing thermal plants. Ghana's own gas processing plant began generating gas for electricity production in December 2014 but the amount produced is lower, compared to what is needed. For a country with peak electricity demand at just over 2300 MW, as much as a 500-1000 MW has often been unavailable from the about 2,800 MW installed capacity, throwing several parts of the country into darkness under a load shedding programme. Meanwhile, the global trend in the cost of crude oil suggest further price increases, especially as reserves get used up with fewer new discoveries (Shafiee and Topal, 2009). This has led to the extraction of crude oil and natural gas from 'unconventional' reserves such as tar sands and shale formations which were previously untouched for environmental reasons (Charpentier *et al.*, 2009; Brasier *et al.*, 2011; Vidic *et al.*, 2013). Other factors, such as the irregularities in supplies and distributions, the challenges of accessing and procuring unconventional fuels, and occasional political instabilities in major supply regions, have caused general uncertainty regarding global reliability in fossil fuels in the coming decades (Fisk, 2013; Hughes and Lipscy, 2013; Nathan *et al.*, 2013) which may have repercussions for countries such as Ghana.

The cooking fuel sector in Ghana is dominated by woodfuels. As of the year 2010, about 75% of households in the country rely on traditional biomass as main cooking fuel with only 18.2% using gas as main[1] cooking fuel (Ghana Statistical Service, 2012). This is higher than the average in developing countries globally, where about 50% of the population rely on traditional biomass as main cooking fuel source in 2011 (REN21, 2014). The situation is worse in Ghana's rural communities where 89 % of households depend on woodfuels as main cooking and heating fuel source. Data available from the Ghana Energy Commission indicates that in the year 2012, woodfuels contributed 49.8% to the 268 PJ total energy consumed in Ghana (Energy Commission 2013a). In a business-as-usual scenario, the percentage share contribution of woodfuels to total energy supply could decrease but absolute consumption is expected to increase (Energy Commission 2013b).

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[1] A household using LPG as main cooking fuel could still be using other fuels such as charcoal and firewood when the need arises.

Whereas the effect of woodfuels use on deforestation is debatable[2], the impact of kitchen smoke emissions on the health of women is a generally accepted fact (Smith *et al.*, 2014; Perez-Padilla *et al.*, 2010). Burning woodfuels in inefficient stoves has health effects for households in poor rural communities. Data on health effects from indoor smoke in Ghana is not readily available but estimates from the World Health Organisation indicate that globally, over 1.6 million deaths a year are caused by exposure to solid fuel smoke resulting from the burning of traditional biomass (Perez-Padilla *et al.*, 2010).

Efforts to reduce woodfuels consumption and fast-track the adoption of modern energy sources is a priority for most governments, led by the top echelons of global politics. The UN Secretary General recently outlined a plan, called 'Sustainable Energy for All' (SE4ALL) Initiative' which seeks to 'catalyse major new investments to speed the transformation of the world's energy systems, pursue the elimination of energy poverty, and enhance prosperity' (United Nations, 2012). The SE4ALL initiative calls on all stakeholders to take concrete action towards three critical objectives to be achieved by 2030. The three objectives are (1) ensuring universal access to modern

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[2] While use of woodfuel for cooking by developing countries has been perceived of as leading to deforestation, today most scholars agree that agriculture and logging industry is the main driver for the observed decreasing forest vegetation in most developing countries, and that use of wood fuel is mainly causing local effects around big cities (Arnold *et al.*, 2006). For more details in this debate, see. e.g. Hiemstra-van der Horst and Hovorka, (2009), Mwampamba *et al.* (2013), Hansfort and Mertz (2011), Gazull and Gautier (2014). Scientific literature on linkages between woodfuel use and deforestation in Ghana is limited. However, in research on reasons for deforestation in the tropical area in Ghana, Appiah *et al.* (2009) do not mention woodfuel among the four most significant drivers for decreased forest cover.

energy services; (2) doubling the global rate of improvement in energy efficiency; and (3) doubling the share of renewable energy in the global energy mix (United Nations, 2012). The initiative also seeks to assist low income countries with low access to modern energy to chart a path towards attaining an energy secured future by 2030, calling for decisive shift away from business-as-usual and increasing momentum for cleaner and more efficient energy solutions that can leapfrog existing systems.

In order to achieve the objectives of the SE4ALL initiative, several countries have also prepared or are in the process of preparing national action agenda following the overall objectives of the UN Secretary General's SE4ALL agenda. Ghana is the first country globally to have prepared a national SE4ALL Country Action Plan (Mensah *et al.*, 2014). The Ghana SE4ALL Country Action Plan focuses on clean modern energy – liquefied petroleum gas (LPG) and improved cookstoves – which are considered to have some bottlenecks that can cost-effectively be removed through concerted action over the short to medium term (Government of Ghana, 2012). But even before the SE4ALL Action Plan, the Ministry of Energy in 2010 had also outlined an 'Energy Policy and Energy Sector Strategy' with a key policy objective to increase LPG access to households and public institutions from 9.5% in 2008 to at least 50% by 2015. However, Mensah *et al.* (2014) argue that on a business-as-usual scenario, only 40% of households in Ghana could be using LPG as their main source of cooking fuel by 2020 with the 50% target being achieved closer to 2025 rather than the 2015 target set by the government. This is mainly because the locations of LPG retail stations make it difficult for rural communities to access LPG (Kemausuor *et al.*, 2012). The government has since recognised the high impossibility of meeting the target by 2015 and has revised the target date to 2020, with an ambitious plan to distribute about 50,000 units of 6kg-LPG cylinders to rural communities.

Transport fuels in Ghana are wholly dependent on petroleum products which have implications for greenhouse gas (GHG) emissions in the country. Energy sector emissions in the country represent the fastest growing source of GHG emissions and accounted for 41% of emissions in 2006 (EPA-Ghana, 2011a). Between 1990 and 2006, energy sector emissions increased by 183%, from 3.3 $MtCO_2eq$ in 1990 to 9.2 $MtCO_2eq$ in 2006 (EPA-Ghana, 2011a). Within the energy sector, transport was the largest source of emissions with about 43%. Increase in fuel consumption within the transport sector was due to increasing vehicle fleets and poor fuel efficiency (EPA-Ghana, 2011b).

The need to address these issues resulted in the enactment of a Renewable Energy Act by the Parliament of the Republic of Ghana (RE Act) in 2011, in order to promote the increased use of renewable energy. The principal aim of the RE Act is to provide for the development, management, utilization, sustainability and adequate supply of renewable energy for electricity generation, transportation and residential fuel use in Ghana. The RE Act set a 10% target for electricity from renewables (from solar, wind, mini-hydro and biomass) in the national electricity mix by 2020. With regard to fuels, the RE Act calls for the promotion of increased use of improved bioenergy technologies as well as support for the use of biomass resources through legislation, fiscal incentives and attractive packages. An incoming bioenergy legislation calls for 10% biofuels in transportation mix by 2020 and 20% by 2030. A gradual shift to domestically produced renewable fuels has the potential to create employment, ensure energy security and reduce GHG emissions.

1.2 Objectives of Study

The overall aim of this thesis was to examine the role that bioenergy can play in Ghana’s energy mix. The specific objectives were to:

1) Assess the availability and perform an analysis of feedstock sources for second generation bioenergy production in Ghana.
2) Analyse the feasibility of bioenergy contribution to future energy scenarios based on its use in the transportation, electricity generation and residential fuel use sectors and determine their possible impacts on Ghana’s energy system with respect to GHG emissions.
3) Assess the socio-economic impacts of bioenergy production from selected systems which are expected to contribute towards meeting expected demand for bioenergy.

1.3 Research Questions

The research is based on a number of key research questions. The research questions have been detailed within the following sections.

Research question 1 - What is the potential of biomass resources for the production of second generation bioenergy in Ghana?

The aim of this research question was to determine the technical potential of biomass resources at the national, regional and district levels for second generation bioenergy production in Ghana.

Research question 2 - What are the prospects for integrating second generation bioenergy as an important source in Ghana's energy mix?

This research question was aimed at examining the extent to which future energy scenarios in Ghana could rely on second generation bioenergy based on moderate and high use of bioenergy in the transportation, electricity generation and residential fuel use sectors and determine their possible impacts on Ghana's energy system. This was done using the Long Range Energy Alternative Planning (LEAP) model.

Research question 3 – What are the socio-economic impacts attributable to biogas at the community level and in agro-industrial systems?

The aim of this research question was to examine the socio-economic effects of biogas at the community level and in agro-industrial settings but focussed on a single bioenergy pathway, biogas from anaerobic digestion. A model was developed for this purpose. Biogas was considered for the socio-economic analysis because of the difficulty in accessing modern cooking fuels by rural communities and its implication for forest degradation. Electricity extension was not considered because government's plan to extend access to all communities by 2020 is progressing on schedule, based on recent analysis (Mensah *et al.*, 2014).

1.4 Significance of the Research

Reliable supply of energy is closely linked to the rapid socio-economic growth of every emerging economy in the world today. Lack of reliable energy supply undermines a country's stride towards economic and social advancements. This research identifies feedstock sources, opportunities and impacts for biomass contribution to the energy mix in Ghana. The findings would be useful to governments, energy planners, policy makers, utilities and international organisations that are engaged in assessing renewable energy technology development in Ghana. Specifically, the study has the following significance:

- The study is expected to make a contribution to the subject of biomass energy and improve understanding in the area of biomass energy for the Ghanaian energy sector. This study reveals the technical potential of biomass energy as well as indicate how energy from biomass could contribute to Ghana's energy mix.
- The findings of this study are expected to guide policy makers in developing policies and regulations for bioenergy that will secure energy supply in the country.
- For a liberalized market like Ghana's, this study should additionally aid the decision making process for investors who want to venture into renewable energy development and energy generation.

1.5 Hypothesis

Second generation bioenergy production, through advanced combustion/biological technologies, has the potential to contribute energy resources for transport, electricity, and cooking fuels supply in Ghana. Bioenergy may provide economic benefits to the country's rural economy. Specifically, a well-planned second generation bioenergy programme will offer opportunities for additional value to be derived from agricultural residues and waste resources in Ghana. New employment opportunities will arise in harvesting and collecting biomass, transportation, handling and plant operation; there will also be extended employment opportunities for equipment manufacturers and maintenance personnel in project locations. Modern bioenergy deployment will contribute to important elements of national/regional development: economic growth through business earnings and employment; import substitution with direct and indirect effects on Gross Domestic Product (GDP) and trade balance; security of energy supply and diversification.

1.6 Scope and Structure of Thesis

Second generation bioenergy in this thesis refers to modern forms of bioenergy produced from feedstock that are non-food based and / or are not cultivated on agricultural lands: the use of biomass to produce liquid fuels, biogas and electricity. The term modern forms of bioenergy is used to show a distinction from traditional bioenergy forms such as the direct use of biomass resources (firewood, manure, crop residues, etc.) as pertains in many developing countries in the world. Modern bioenergy can be produced from both food and non-food feedstock sources. Even though a lot of emphasis will be laid on non-food sources, bioenergy from food sources will also be discussed under appropriate sections, especially in the literature review. Non-food feedstock sources include agricultural residue, organic portions of Municipal Solid Waste (MSW), certain grass types (such as Switchgrass), woody species (such as Poplar and Miscanthus), and wood and forest residues.

The thesis is structured into eight chapters. Chapter one is the general introduction. Chapter two reviews literature relevant to the objectives of the study. Chapter three presents a general materials and methods. The general materials and methods chapter does not present a detailed methodology for the thesis, rather, it briefly presents a general overview of how the research questions are linked together to prepare the background for subsequent chapters. Chapters four, five, six and seven present details of methods used to gather and analyse data as well as present results and discussion for each of the research questions in this thesis. Chapter eight summarises the study by presenting the general conclusions and recommendations for further research.

1.7 Limitations of Study

The limitations applied in this study are as follows:

1. Except where detailed fieldwork was done, data collection for most biomass resources was limited to the district level. Where data was not available at the district level, regional data was used.
2. For the socio-economic sustainability analysis, this study could not address all indicators related to socio-economic sustainability. Indicators were selected based on their measurability for ex-ante projects of the nature considered.

1.8 Delimitations of Study

The delimitations of the study are enumerated as follows:

1. The sustainability analysis in this study is only limited to social and economic sustainability. Environmental sustainability was not considered within the scope designed for this thesis.
2. Even though many bioenergy types (electricity, transport fuels and cooking fuels) are considered in this study, emphasis was placed on biogas systems for socio-economic sustainability. This is because biogas can be easily produced on small scale basis and is therefore more suited for addressing rural cooking energy challenges.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter discusses relevant literature on bioenergy development and the associated impacts. The chapter begins with a brief review of the global trends in renewable energy, followed by global potential for bioenergy from different feedstock sources as well as future outlook for modern bioenergy. Bioenergy production and use has environmental and socio-economic implications. The subsequent sections of the literature review therefore discuss environmental and socio-economic impacts of bioenergy. The review on impact assessment presents information on efforts underway to develop indicators for sustainability assessment and some certification schemes for bioenergy development. Towards the end, this chapter presents a detailed discussion of energy situation in Ghana in an attempt to present a historical perspective of bioenergy and to chart a path towards work done in this thesis.

2.2 Recent Trends in Renewable Energy

Despite a small minority of sceptics, there is a general agreement that the reserves of fossil fuels, especially crude oil, are dwindling and that it is only a matter of time before they run out (Shafiee and Topal, 2009). Globally, the decline of crude oil is due to a combination of factors. These factors, which have increased demand for energy, include population growth, urbanization, and socio-economic development. The increasing demand, coupled with market forces, has led to rising costs (see Figure 2.1). Other factors, such as the irregularities in supplies and distributions, the challenges of accessing and procuring unconventional fuels, and occasional political instabilities in major supply regions, have caused general uncertainty regarding global reliability in fossil fuels in the coming decades. Countries such as the United States and Canada have resorted to fracking and extracting oil from tar sands as a result of increasing cost of crude oil from conventional technologies, notwithstanding campaigns against such by environmental groups. Though costs have reduced significantly towards the end of 2014 and in early 2015, this may not last, judging from historical precedence. Also, increased use of fossil fuels has implications for global warming. Global warming is directly linked to the production and combustion of fossil fuels (IPCC, 2007) due to the emission of carbon into the atmosphere. In 2011, it was estimated that global emissions of carbon from fossil fuel combustion and cement production were 9.5±0.5 Pg C, three percent above 2010 levels (Peters *et al.*, 2012; Le Quéré *et al.*, 2012). To tackle this situation, several countries/regions are seeking alternative energy futures (IEA, 2013). Indeed, developed and developing countries alike are intensifying their search for alternative fuel sources due to the socio-economic and environmental cost of dependence on fossil fuels. The use of solar, wind, mini-hydro, tides and biomass as alternative energy sources is gaining prominence globally.

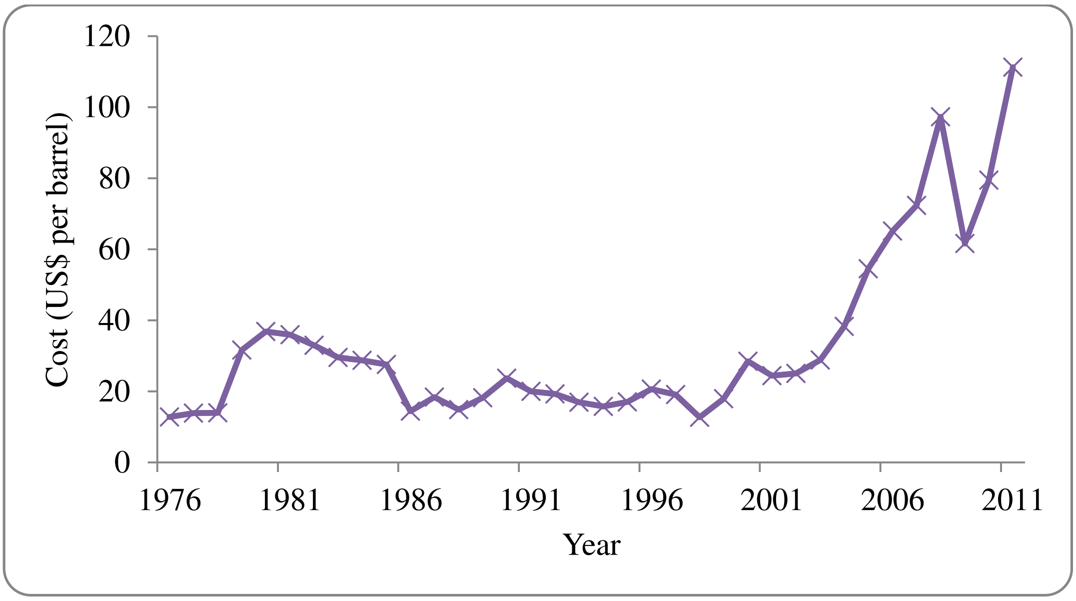

Figure 2.1: Historical Brent crude oil prices, nominal prices
Source: Based on BP (2012)

In 2011, modern Renewable Energy (RE) contributed 9.7% to global energy consumption (See Figure 2.2). These RE sources included 4.1% biomass/solar/geothermal heat and hot water, 3.7% hydropower, 1.1% wind/solar/biomass/geothermal power generation and 0.8% biofuels (REN 21, 2013). There has been high growth in solar and wind energy penetration, compared to the other renewable energy sources. To illustrate, Figure 2.3 shows 61% growth for concentrating solar thermal power in 2012, 42% for solar PV and 19% for wind. Growth in liquid biofuels was modest with 0.4% for biodiesel and – surprisingly – a negative growth rate for bioethanol. After several years of enormous growth in ethanol production, things appear to be slowing down. The negative growth in 2012 may be as a result of a slowdown in the use of US corn for the production of ethanol due to socio-economic concerns.

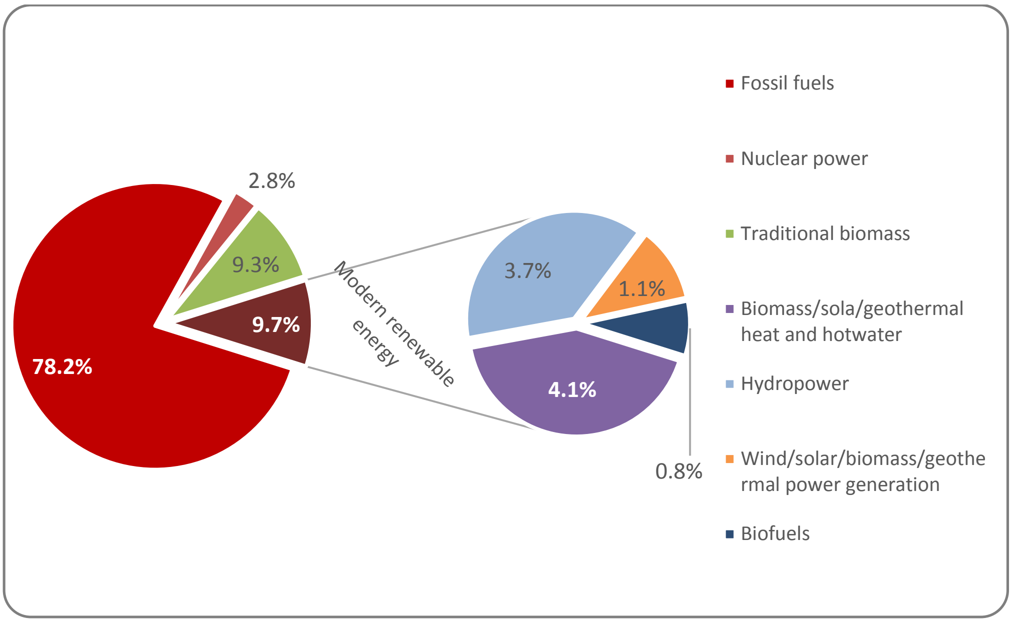

Figure 2.2: Estimated RE share of global final energy consumption
Source: Modified from REN21 (2013)

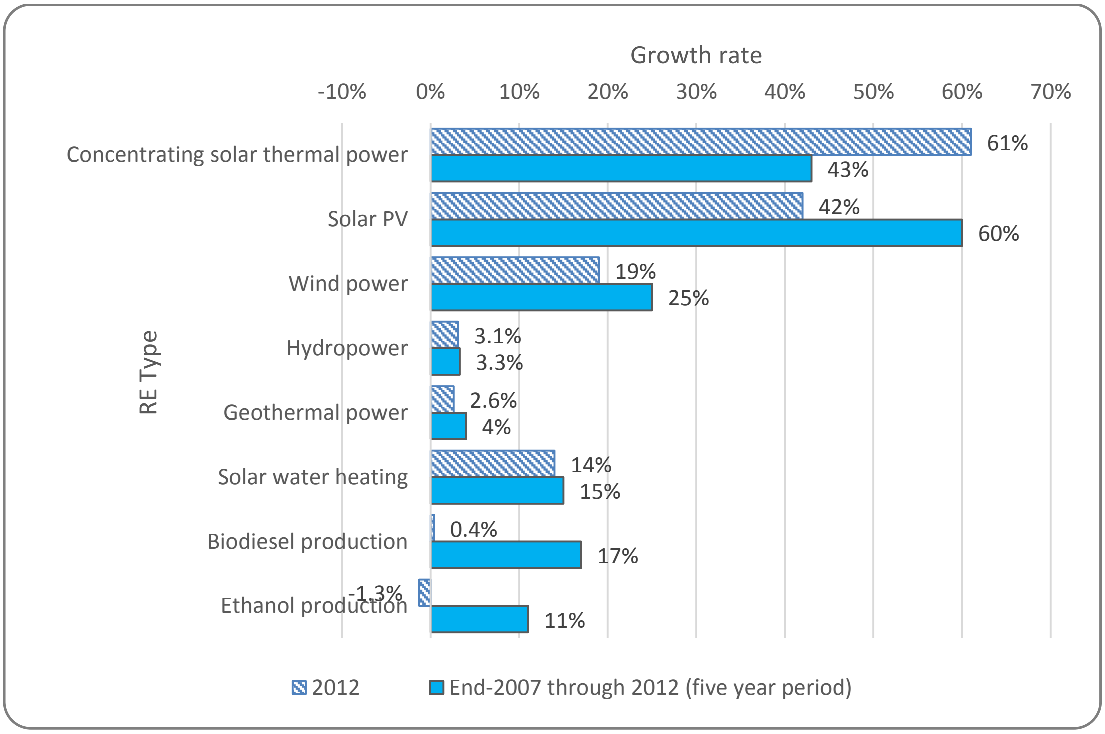

Figure 2.3: Average annual growth rate of RE capacity and biofuels production
Source: Modified from REN21 (2013)

The leading countries in RE utilisation are China, United States, Germany, Spain, Italy and India (REN21, 2013). Africa has experienced only modest activity compared to the rest of the world. With the exception of South Africa and Northern African countries which have started to gain momentum with wind and solar power, there is little activity in most sub-Saharan African countries where experience with RE is more in the form of 'traditional biomass': used as firewood and charcoal in inefficient cooking stoves. The continued use of traditional biomass in large quantities has implications for health in poor rural communities in developing countries.

The public health concerns of traditional biomass use can be addressed by future applications of bioenergy, which are already in motion in some countries. These are aimed at more modern forms of bioenergy such as the production of biogas for cooking. Other more appropriate forms to convert biomass into modern cooking fuels are ethanol gel fuels. The use of biogas and ethanol gel fuels as modern cooking fuels hold advantage for small rural communities in developing countries where poor transportation infrastructure may militate against economies of scale for commercial scale production of other bioenergy forms, such as liquid biofuels for transportation.

Over the past decade or so, the conversion of biomass into liquid biofuels for transportation has increased to more than five-folds globally (IEA, 2013). Led by the United States, Brazil and Europe, biofuels production – both ethanol and biodiesel – has increased from 16 billion litres in 2000 to more than 100 billion litres in 2011, providing around 3% of total road transport fuel globally (on an energy basis) (IEA, 2013). The United States led production with about 15 billion gallons of biofuels in

2011, closely followed by Brazil. Other major producers include Germany, France, Argentina and China (see Figure 2.4).

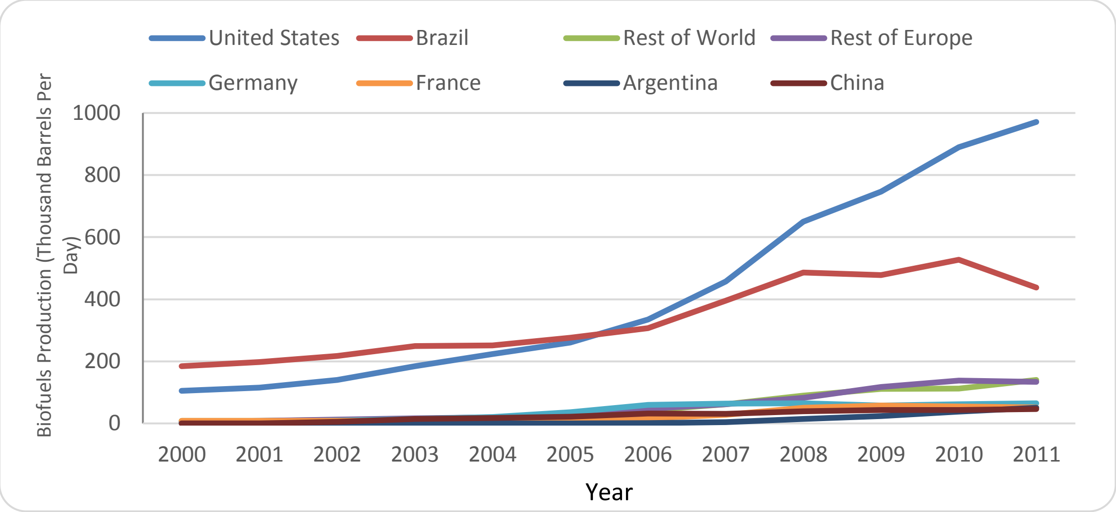

Figure 2.4: Biofuels production trends

Source: Data from US Energy Information Administration (2013)

The bulk of biofuels consumed currently has come from first generation biofuels, in that they are either dependent on food crops as feedstock, or they use feedstock that are cultivated on arable agricultural lands. First generation biofuels have often been criticised because of these two principal challenges as they are regarded as a threat to food systems. The need to tackle these challenges has led to calls for innovation in the biofuels value chain. Specifically, there are calls for the production of biofuels whose feedstock production would have limited or no competition with food crop production and agricultural land use.

2.3 Global Bioenergy Potentials

Several research papers have been published on the global potentials of modern bioenergy. Many of these studies point to a high potential but also call for a cautious and conscientious approach to developing this potential. This section will focus more on bioenergy from lignocellulosic materials and also from degraded and marginal lands. As a matter of reference, it is important to point out projections for global energy demand in order to put into proper perspective bioenergy potentials in this regard. World energy demand is projected to rise to 1000 EJ or more by 2050 if economic growth continues its course of recent decades (Moriarty and Honnery, 2012). It is also worth pointing out, that studies that have estimated present and future global and regional amounts of biomass show large uncertainties (Pavanan *et al.*, 2013). These uncertainties are due to differences in methodologies, scenarios and other assumptions (Faaij *et al.*, 2010). Forest biomass, agricultural residues and energy crops constitute the three major sources of biomass for energy. Land Use and Land Use Change (LULUC) is a key issue in sustainable bioenergy production as land availability is an ultimately limiting factor (Niclas and Claus, 2012).

According to Fallot *et al.* (2006), biomass resources represent, potentially, one of the world's largest and most sustainable energy sources and deserves special attention. Hall *et al.* (1993) estimates global bioenergy potentials at about 38 EJ using a 25% residue recovery rate from the World's major crops, i.e., wheat, rice, maize, barley, and sugar cane. Smil (1999) has expanded this to include all possible crops, estimating 3.5-4 Gt of biomass resources with energy potential of 65 EJ. A later assessment by

BTG (2006) estimate 1.5 Gt biomass resource and 19.1 EJ as the practical potential based on specific residue recovery rate.

Some studies have focussed specifically on ethanol potentials from crop residues. Kadam and McMillan (2003) estimate the amount of corn stover that can be sustainably collected at 80-100 million dry tonnes/year. The potential for rice husk as feedstock for ethanol alone is estimated in the region of 20.9 to 24.3 Gl per annum, and could potentially satisfy about 20% of global ethanol demand for a 10% gasohol fuel blend (Abbas and Ansumali, 2010).

With regards to specialised grassy and woody bioenergy crops, Popp *et al.* (2011) has estimated that resources such as Miscanthus or Poplar, can contribute approximately 100 EJ in 2055 and up to 300 EJ of primary energy in 2095 but will require integrated policies for energy, land use and water management. Beringer *et al.* (2011) opines that this can be done earlier with an estimated bioenergy potential of between 130 and 270 EJ/y in 2050, equivalent to 15–25% of the projected global future energy demand.

Other studies have also considered potentials for energy crops cultivated on degraded, marginal and abandoned lands[3]. Field *et al.* (2008) estimate abandoned lands at approximately 450 Mha worldwide, compared to 5700 Mha used for crop and livestock production worldwide (Carroll and Somerville, 2009). Nijsen *et al.* (2012) estimate the total global potential energy production on degraded lands to be slightly

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[3] While the definition of degraded, marginal and abandoned lands are disputed, marginal lands are often defined as 'land unsuitable for crop production, but ideal for the growth of energy plants with high stress resistance' (Field *et al.*, 2008). Abandoned lands refer to 'areas that have been abandoned to crop and pasture due to the relocation of agriculture and due to degradation from intensive use' (Lu *et al.*, 2012). Degraded lands are lands not in use as forest, cropland, pastoral land, or urban (Nijsen *et al.*, 2012).

above 150 and 190 EJ/y, for grassy and woody energy crops, respectively. Most of the potential energy crop production on degraded land is located in developing regions. China has a total potential of 30 EJ/y. Also USA, Brazil, West Africa, East Africa, Russia and India have substantial potentials of 12–18 EJ/y.

The International Energy Agency (IEA, 2005) has expanded the bioenergy potential scope to include all possible sources of biomass discussed in preceding paragraphs with estimates of about 220 oven-dry Gt of annual primary production with corresponding annual bioenergy potential of about 2,900 EJ, almost three times the estimated world energy demand by 2050. The IEA argue however, that only a fraction can be considered available for energy on a sustainable basis and at competitive prices due to reasons such as soil re-fertilisation and difficulty in assessing agricultural plots in low income countries.

What is clear from all these estimates is that the solution is not within a single feedstock or process. Instead, various technologies specific and optimized for a particular geographical location are necessary, taking into consideration the financial and material resources available (Takara *et al.*, 2010). Also, bioenergy can contribute its part to energy supply but is not the panacea to world energy problems. This is because even if all crops, forests and grasslands currently not used were used for biofuels production it would be impossible to substitute all fossil fuels used today in transport (Ajanovic, 2011). An integration of all renewable energy sources may help to some extent. Even so, when energy costs are considered, it is unlikely that all renewable energy types can provide anywhere near a 1000 EJ by 2050 (Moriarty and Honnery, 2012; Deng *et al.*, 2012).

Mindful of the potentials, a number of countries and regions have targets for the development of bioenergy. For example, the United States Energy Independence and Security Act of 2007 mandated 9.0 billion gallons of renewable fuel in 2008, rising to 36 billion gallons by 2022 (United States Congress, 2007). Of the latter total, 21 billion gallons is required to be obtained from advanced bioenergy. The European Union Renewable Energy Directive (EU RED) specifies a 10 percent renewables content by 2020 across the entire membership – with 7 percent of that expected from biofuels (EC, 2009a). The EU RED cautiously accentuates ‘commercial availability of second generation biofuels’ without giving any clear targets. China plans to develop a bioenergy capacity of 30GW by 2020 (Zhuang *et al.*, 2010). Other countries have plans for the gradual development of modern bioenergy in the near future, a desire that is encouraged by the need for a secure energy supply, a reduction of fossil CO_2 emissions and a revitalization of rural areas (Cherubini and Jungmeier, 2010).

Even though the potentials are encouraging, there are challenges to be addressed before these potentials can be realised. Firstly, the cost of enzymes for converting plant biomass materials to fermentable sugars is a major impediment to the development of a practical modern bioenergy industry, especially in the production of ethanol (Banerjee *et al.*, 2010). Other challenges and limitations include biomass transport and handling, logistical issues, efficient pretreatment methods and expensive combustion technologies (Sarkar *et al.*, 2012; Banerjee *et al.*, 2010).

There have been large uncertainties in the estimation of bioenergy potentials. This has arisen largely because of the lack of a harmonised methodology, for which reason researchers have often defined their own methods or modified existing methods. It is also clear from existing studies that researchers have often combined different feedstock sources in their analyses. The sources of data for feedstock have also been different, with differences in accuracy levels. The difficulty in global assessments could be understood as coming from the wide range of data at the disposal of researchers, as well as the fact that calorific values of different varieties of resources differ. Often times, researchers have chosen to work with their preferred datasets based on ease of access and researchers' expertise. This makes regional and national as well as local level and project specific studies much easier to undertake, with a higher level of accuracy, as calorific levels obtained from specific biomass varieties could be used in the analysis. Another shortcoming of the assessments available is that the majority of them have only assessed the theoretical potential. This could also be due to the fact that existing uses of residues are not uniform globally as different regions and cultures have different uses for residues. Transportation access to resources is also more of a challenge in poor developing countries than in the developed world where farms are large and mechanised. The few studies that have attempted the technical potential have used different recoverability fractions, further pointing out the difficulty in technical potential assessment at the global level. This again highlights the need for more localised studies.

The costs of developing bioenergy on a larger scale has not been the subject of much research as evidenced by published studies. It is therefore not clear how the increased use of biomass could impact the economics of energy production globally. So far, very little financial and economic analysis of biomass utilisation has been conducted in developing countries.

2.4 Impact of Bioenergy Production

The development of bioenergy, like any other energy type, has a range of impacts, including environmental and socio-economic impacts. This section will discuss both positive and negative environmental and socio-economic impacts of bioenergy development.

2.4.1 Environmental Impacts

There are conflicting reports as to the true environmental impacts of bioenergy. The general assertion is that the use of sustainably produced bioenergy can help reduce GHG emissions by displacing petroleum in the transportation sector, by displacing fossil-based electricity, and by sequestering atmospheric carbon (Lemoine *et al.*, 2010). Perennial bioenergy crops such as jatropha, Miscanthus and rubber trees have the potential to prevent soil erosion and regenerate agricultural potential on marginal lands, providing shade and nutrients for other crops (Senelwa *et al.*, 2012).

The negative environmental impacts tend to arise when land use changes are taken into consideration. The cultivation of conventional energy crops is said to be the most land-intensive form of energy production (McDonald *et al.*, 2009). A global biofuels programme that is dependent on the use of agricultural lands will potentially lead to intense pressures on land supply and cause widespread transformations in land use

(Hallgren *et al.*, 2013). Fulfilling current mandates for biofuels in the US and EU alone would have substantial impact on global land use (Hertel and Tyner, 2010). For example, it has been estimated that replacing just 30% (~1 billion barrels) of transportation fuel consumed in the US by 2030 with alternative fuel will require 385% and 148% of the current available farm land in the US for corn ethanol and soy based biodiesel respectively (Quinn *et al.*, 2013), though modern biotechnology tools could reduce this to some extent. There is a similar situation in the case of the EU Directive on biofuels, raising fears that the intended scale of biofuels demand will require the use of large agricultural lands (Koh and Ghazoul, 2008; Scharlemann and Laurance, 2008; Frondel and Peters, 2007) or force food crops to be grown at new locations (Anderson and Fergusson, 2006). Such land requirements for energy crops have potential negative consequences for biodiversity and GHG emissions by causing, either directly or indirectly, the conversion of natural ecosystems to cropland (Fargione *et al.*, 2010; Hellmann and Verburg, 2010). For example, there has been concerns over Brazil's extension of sugarcane production into the Amazon forest area and destruction of forests for oil palm plantation expansions in Indonesia and Malaysia (Oberling *et al.*, 2013; Edwards *et al.*, 2012; Mekhilef *et al.*, 2011; Walker, 2011).

Apart from the potential use of agricultural lands for bioenergy crop cultivation, the impact of increased bioenergy production on water resources is also a subject under scrutiny. Bioenergy expansion can significantly impact water resources (Uden *et al.*, 2013), but the impact is dependent on the state of the resource base that is drawn upon (Fingerman *et al.*, 2011). Hoogeveen *et al.* (2009) assessed the impact of increasing demand for biofuels on global water resources in the coming decade and estimated that the amount of water to be withdrawn for biofuel production would increase by 74% if agricultural practices remain the same. Indeed, many certification schemes for sustainable bioenergy production have identified water as a core issue, and have developed related criteria and indicators (Fehrenbach, 2011).

Bioenergy environmental impacts can be reduced with the use of feedstocks that do not compete with food for land (Tilman *et al.*, 2009) and targeting abandoned and degraded cropland for bioenergy crop production (Campbell *et al.*, 2008). An analysis has shown that another way to meet the US mandate, for example, is to use approximately 72.1 million tonnes of corn stover, 23.5 million tonnes of wheat straw, and 24.7 million acres to produce 109 million tonnes of switchgrass by 2025 (Dicks *et al.*, 2009). Notwithstanding the benefits that agricultural residue could offer to alternative energy exploration, it has been predicted that a higher stover removal rate could also increase sediment yield on agricultural fields (Wu and Liu, 2012). Other options available to reduce environmental impacts include increasing yields of agricultural produce and thus reducing the amount of new demand that is met with agricultural expansion, prohibiting direct conversion of natural ecosystems, and bolstering the protection of natural areas (Fargione *et al.*, 2010).

The review shows clearly that first generation biofuels can be problematic, because of the possibility of cutting down forest cover to make way for the cultivation of feedstock. When these are accounted for in GHG emissions analysis, there isn't any clear benefit over conventional fossil fuels as indicated by published literature. Even though perennial crops like jatropha have been suggested in existing studies as erosion control crops, evidence shows that they are often cultivated on arable lands, which could have supported food crops all the same.

The issue of resorting to marginal and degraded lands is quite debatable because again the definition of marginal and degraded lands could differ from one region to another. A marginal land in a country with abundant agricultural land could be an important arable land in a country with scarce agricultural resources. The impacts on water resources is one very important area that needs more research, especially in some developing countries where drinking water and water for irrigating food crops is already a scarce commodity. The rush to second generation biofuels to mitigate the effects of the first generation must also proceed cautiously. The effects of residue removal on agricultural lands must be subjected to further study, especially in developing countries where fertilisers are expensive and difficult to access.

2.4.2 Socio-economic Impacts

2.4.2.1 Definition

The Inter-organizational Committee on Guidelines and Principles for Social Impact Assessment (1994) defines social impacts as “the consequences to human populations of any public or private actions that alter the way in which people live, work, play, relate to one-another, organise to meet their needs and generally cope as members of society”. Socio-economic impact studies are commonly used to evaluate the local, regional and/or national implications of implementing particular development decisions. In reality, local socio-economic impacts are diverse and will differ according to factors such as the nature of the technology, local economic structures, social profiles and production processes (Krajnc and Domac, 2007). A summary of some of the benefits associated with local bioenergy production is presented in Table 2.1.

Table 2.1: Potential Socio-economic Benefits of Biofuels Development

Dimension	Benefits
Macro level	Security of supply, regional growth, reduced regional trade balance, export potential
Supply side	Increased productivity, enhanced competitiveness, labour and population mobility (induced effects), improved infrastructure
Demand side	Employment, income and wealth creation, induced investment, support of related industries

Source: Modified from Domac *et al*. (2005)

2.4.2.2 Socio-economic Impacts of Bioenergy at Different Levels

Like many other developmental projects, the development of bioenergy on their own can have very large socio-economic effects, either positive or negative (de Gorter and Just, 2010). These socio-economic impacts are typically very case and site specific and are more relevant on the local than on the global level (Markevicius *et al*., 2010). From a social impacts perspective, small scale production of bioenergy could be beneficial as it links the producer with the consumer in repeated exchanges that include both financial transactions and social interactions (Van der Horst and Vermeylen, 2010). This reduces the likelihood that negative social impacts will go unnoticed or unmitigated. Large scale and globalised production models are much more likely to result in negative social impacts, caused or exacerbated by the geographical, cultural and power divide between governments and large companies who are driving this agenda forward and the individuals and communities affected ‘on the ground’ (Van der Horst and Vermeylen, 2010). But the nature and extent of any particular bioenergy plant’s socioeconomic impact will also depend on a number of factors, other than the scale of production. These factors include the level and nature of the capital investment, the availability of local goods and services, the degree of regional monetary leakages, the time scale of both the construction and operation of the plant, and various institutional and energy policy-related factors such as capital grants and subsidies (Krajnc and Domac, 2007).

2.4.2.3 Positive Socio-economic Impacts

Socio-economic impacts are often spread across the value chain of bioenergy projects, beginning with feedstock production. The provision of feedstock provides an opportunity for farmers to increase their income. This is a substantial market because more than 60% of the cost for bioenergy is in feedstock costs (Liu and Gu 2008). Biomass resource cultivation, harvesting, and processing could have a direct impact on rural development and rural livelihoods by providing new income opportunities to rural farmers and their families (Macrelli *et al.*, 2012; Duku *et al.*, 2011). An analysis has shown that producing ethanol in Thailand would generate employment of about 5–6 person-years per TJ or 17–20 times more workers than gasoline production (Silalertruksa *et al.*, 2012). Also, producing biodiesel from palm oil would generate about 3 person-years per TJ or about 10 times more workers than diesel. Direct employment in agriculture is the most essential employment benefit, contributing more than 90% of the total employment generation (Silalertruksa *et al.*, 2012). In many regions, policy makers are beginning to perceive these potential socio-economic benefits of bioenergy, with regards to increased employment and incomes (Domac *et al.*, 2011).

Apart from incomes and employment, the provision of modern bioenergy to, especially, rural communities is another important socio-economic benefit of bioenergy that can help replace traditional biomass. The conversion of biomass resources into various energy carriers, can increase access to modern forms of energy (Duer and Christensen, 2010). The production of biogas, using cattle manure and other relevant feedstock such as agricultural residues, provides an alternate source of energy for cooking and lighting in rural areas (Suthar, 2011). The impacts of decentralised bioenergy can be increased by using local resources, upgrading them locally, and developing the technologies (for both supply chains and end-use), as well as models for local energy services (Lehtonen and Okkonen, 2013). Other potential benefits are social corporate programmes instituted by bioenergy companies. In Ghana, some bioenergy companies provide community water projects and grinding mills, and plough agricultural lands for local farmers, as part of their contribution to community development in their operational areas.

2.4.2.4 Negative Socio-economic Impacts

On the other hand, it has been asserted that bioenergy production could result in the hiking of food prices, and poor countries could be at the receiving end of such high prices. Bioenergy production may likely increase the pressure on food stability or increase the risk of chronic food insecurity (FAO, 2008). A number of studies suggest that production of bioenergy may adversely affect food availability if food crops or productive resources are switched from the production of food to that of bioenergy (Kgathi *et al.*, 2012). There could be threats to food security when high quality land suitable for agricultural food crops is allocated for the production of bioenergy (Jumbe *et al.*, 2009). Even though increase in commodity food prices tends to cause what is called the "food-price dilemma" because it affects net-food buyers negatively and net-food sellers positively (Lustig, 2009), most low-income countries are net food importers and would be vulnerable to the impacts of price increases of agricultural food crops (Amigun *et al.*, 2011). An analysis by Wise (2012), estimates the cost of U.S. ethanol expansion to food-importing developing countries at $6.6 billion over six years, arising from the higher costs of food imports.

In many instances, bioenergy has been cited as directly responsible for food price hikes (see for example Negash and Swinnen, 2013; Jørgensen and Andersen, 2012; Kuchler and Linnér, 2012; Ajanovic, 2011) due to the increasing share of food crops use. In the United States, for example, corn is the principal biofuel crop which conflicts directly with its use as a staple food crop in several countries. Data from the United States Department of Agriculture's National Agriculture Statistics Service indicates that in 2012, about 42% of corn in the United States was used for ethanol production, rising from about 4.5% two decades before. The increasing use of corn to produce ethanol in the United States is thought to have contributed to increased food prices although it is difficult to indicate exactly how much this has occurred due to other factors such as high price of oil, speculation activity in commodity markets, drought in major producing regions and export restrictions imposed by some countries as well as increased demand for food in developing countries (National Academy of Sciences, 2013).

Other studies suggest that there is no direct long-run price relations between fuel and agricultural commodity prices (Zhang *et al.*, 2010) or that there is no clear cut line (Gorter *et al.*, 2013; Timmer, 2010). Others have also found that higher commodity prices may impact positively on agricultural economies but nations must be positioned to enjoy this benefit. A study in Argentina, for example, finds that if international prices of biodiesel, soy oil and soybeans increase, Argentina will gain in terms of GDP and social welfare (Timilsina *et al.*, 2013). This is because Argentina is one of the largest producers of those resources and will benefit from the higher export sales to other countries.

In order to avoid negative socio-economic implications of biofuels production, some studies argue in favour of using marginal or "abandoned" crop lands to avoid competing with food crops (Field *et al.*, 2008; Tilman *et al.*, 2009). Land of marginal agricultural productivity is often viewed by developers as 'cheap' and therefore attractive for conversion into biofuel plantations. However there are indications to show that this 'waste' land is rarely uninhabited or unused by the people who live there. According to Van der Horst and Vermeylen (2010), the more marginal their livelihoods are, the more likely rural people will depend on the land for their day-to-day struggle for survival. The land will yield fuel, medicines, wild food, building materials, etc. to people who do not have the means to obtain equivalent (or better quality) goods or services in the formal economy.

2.4.2.5 Tackling Negative Socio-economic Impacts

An attempt to tackle these problems is focused again on the development of next generation bioenergy that will use a wider range of feedstock including lignocellulosic material that will not compete with food production (Perimenis *et al.*, 2011). However, these technologies are still in development phase and questions concerning their technical and economic performance as well as their environmental and social effects are not well answered (Schwietzke *et al.*, 2008). The cost of producing fuels from lignocellulosic materials is comparatively more expensive than when food crops are used. The higher costs are as a result of pre-treatment procedures that the feedstock must undergo.

Others argue in favour of small-scale production, creating employment and income opportunities for local populations through contract farming (Clancy, 2008). More empirical research would be required to assess the social impacts of small-scale bioenergy production systems in rural areas of developing countries, but it could be envisaged that such systems, when developed ('bottom-up') by the people involved, would share many of the characteristics of the small scale and localised systems in developed countries and thus potentially yield similar positive social impacts (Van der Horst and Vermeylen, 2010).

Similar to environmental impacts, the socio-economic impacts of biofuels are case specific and it is difficult to generalise the impacts at the global or even national level. It appears that different regions/countries are affected differently, depending on local economic structures. Impacts on localities may differ, even for the same project type and size. Whereas large systems could be beneficial to developed countries because of the agricultural models that already exist in those countries, an example being ethanol production in the United States, the situation cannot be the same in poor developing countries. Weak structures in poor developing countries have opened up avenues where large energy systems may be exploitative of the poor if not properly monitored. But then again, these issues are site specific and deserve to be given attention at the project level. The impacts in one location may not necessarily be present in another, depending on how local laws and law enforcement authorities engage with project developers to protect indigenous people and local interests.

Generally, developing countries have been slow in the preparation of land use maps, for which reason project developers are forced to compete with indigenous farmers for the arable land at their disposal. This tend to be the case in most African countries. Land use maps must be prepared in potential bioenergy producing countries as a matter of urgency in order to lessen or eliminate exploitation of food crop lands by bioenergy producers.

2.5 Bioenergy and Climate Change

One of the arguments used by proponents of bioenergy, in support of its development, is its ability to reduce GHG emissions such as CO_2 when compared to fossil fuels. Indeed some types of bioenergy activities, such as biofuels for transportation, could have the potential to contribute to reduced risk to climatic challenges or reduced vulnerability, or even increased capacity for poor people to cope with and adapt to climatic variability and change (Ulsrud, 2012). GHG balance of first generation bioenergy has been more debatable but some studies have shown positive GHG balances. It has been indicated, for example, that GHG savings could be positive for some first generation feedstock with savings of 58-71% for sunflower, 48-62% for rapeseed, soybean oil (47-60%) and cottonseed oil (35-47%) (Fontaras *et al.*, 2012; Skoulou *et al.*, 2011). However, other studies have suggested that GHG benefits from biomass feedstock would be significantly lower if the effects of direct or indirect land use change are taken into account (Gopalakrishnan *et al.*, 2009).

There appears to be little doubt however, that second generation bioenergy, even though more expensive, could contribute to reduced emissions of GHGS, especially if produced from agriculture and wood residues. An analysis by Havlík *et al.* (2011) has shown that second generation bioenergy perform best from a GHG emission perspective. Li *et al.* (2010) has shown that non-grain based bio-ethanol production can potentially reduce CO_2 emissions from the 2007 levels by 11 million tonnes and 49 million tonnes in 2015 and 2030, respectively (5.5 and 25 times the reduction capacity in 2007).

Production and use of bioenergy must therefore fulfil a number of criteria in order to ensure that it can contribute to the reduction of climate change risks (Schubert and Blasch, 2009). A comprehensive carbon balance assessment must take into account "indirect" land use change, which refers to emissions from lands in which biofuel feedstock replaces food crops (Finco and Doppler, 2010). A global bioenergy programme will potentially lead to intense pressures on land supply and cause widespread transformations in land use. These transformations can alter the earth's climate system by increasing GHG emissions from land use changes and by changing the reflective and energy exchange characteristics of land ecosystems (Hallgren *et al.*, 2013).

A number of scientific studies have shown positive potential for GHG savings from the use of bioenergy at the national level. A study in Mexico, for instance, has shown that the use of ethanol, biodiesel and electricity obtained from primary biomass as well as the sustainable use of residential biomass could potentially save GHGs the equivalent of 87.44 million tonnes of CO_2 by 2030 (Islas *et al.*, 2007). This savings is equivalent to 17.84% of the potential CO_2 emissions under a business-as-usual scenario. Another study in the UK has indicated that an estimated 23.8% of biofuels in transport fuels could results in a 6% reduction in emission from transportation (Acquaye *et al.*, 2012). Another analysis by Shin *et al.* (2005) shows that utilising landfill gas to generate electricity in Korea could reduce global warming potential of the landfill by 75%, compared to spontaneous emission of CH_4.

2.6 Bioenergy Sustainability Assessment and Sustainability Indicators

2.6.1 Sustainability Assessment

According to Schmitz (2007), different sustainability problems require different approaches. The negativities regarding bioenergy has necessitated the need for sustainability assessments when developing bioenergy projects. Sustainability assessments often cover the three pillars of sustainable development: environmental, economic and social impacts, either on a global or local level. But sustainability assessment is often viewed as complicated and challenging due to the lack of a unique, objective, and commonly agreed methodology (Markevicius *et al.*, 2010). The assumptions used in any sustainability assessment have a significant impact on the results and are subject to significant uncertainties and sensitivities. In order to ensure sustainable production of bioenergy, several initiatives and certification systems on sustainability criteria been proposed or are being prepared by various organisations, institutions, and countries (Markevicius *et al.*, 2010). Sustainability criteria have been introduced principally to help ensure that bioenergy has lower GHG emissions than fossil fuels (Ackrill and Kay, 2011) and contribute to a modern energy supply. In a rural context, it also ensures that rural households are not worse off than they were before project development. Sustainability criteria have been developed into certification systems, managed by independent institutions.

2.6.2 Bioenergy Certification

Certification is the process whereby an independent third party assesses the quality of data in relation to a set of predetermined standards (Pavanan *et al.*, 2013; Mohr and

Bausch, 2013). To be certified, a set of laid down criteria has to be fulfilled. Standards and certification processes are needed in order to guarantee bioenergy's sustainability (Schubert and Blasch, 2009). They are often seen as institutional arrangements that could influence environmental and social impact of bioenergy production (Lewandowski and Faaij 2006; Mol 2007; Stupak *et al.*, 2007). Whiles high standards are encouraged, very high standards make bioenergy less attractive from an economic point of view (Tomei *et al.*, 2010).

Many countries and regions are beginning to make it mandatory for bioenergy to be certified and a few certification initiatives have been developed for this purpose. To be eligible for financial support, liquid biofuels in the EU are required to fulfil mandatory sustainability criteria and reporting requirements which are included in the Renewable Energy Directive 2009/28/EC of the European Union (EC, 2009a) and the Fuel Quality Directive 2009/30/EC (EC, 2009b). Apart from its own criteria, the European Commission also recognise voluntary sustainability certification schemes. Table 2.2 shows a summary of some bioenergy certification schemes (with details in Appendix 1). Some of the voluntary certification schemes were proposed by national state authorities in cooperation with major stakeholders (such as the Cramer Commission in the Netherlands; the Low Carbon Vehicle Partnership in the UK and the National Ethanol Vehicle Coalition in the USA). Other initiatives, such as the Roundtable on Sustainable Palm Oil or the Roundtable on Sustainable Soy have been initiated by non-state actors (Partzsch, 2011). One principal challenge, when dealing with the numerous certification initiatives is that there is a lack of harmonisation, across the different initiatives, including in the areas of definitions, approaches and methodologies (Scarlat and Dallemand, 2011). The harmonization of certification systems are key issues to resolving potential negative effects of increased biomass trade (Magar *et al*., 2011).

Undoubtedly, the development of bioenergy can have positive implications for many rural economies. Similar to what the cultivation of cocoa has done in Ghana and Cote d'Ivoire for instance. Even the cultivation and sale of the feedstock alone, at internationally acceptable prices, could become an income generation source for rural farmers. Further processing into intermediary and final products could create both skilled and unskilled jobs for the people within and outside project specific locations. But when left to the big players alone, the possibility of little players being marginalised is high. While certification systems are laudable, they appear to target large projects in developed countries. Certification systems demand large datasets that are often very difficult to assess in developing countries. Going forward, there might be the need to develop certification systems that have lower data requirements and yet are robust enough to ensure environmental integrity of projects as well as protect the poor and vulnerable in developing countries.

Table 2.2: Selected Bioenergy Certification Initiatives

Certification Initiative	**Summary**
Roundtable on Sustainable Palm Oil (RSPO)	The principles and criteria for certification are generic, and that is because countries differ in their laws for the same criteria, such as minimum wages for workers for example, and there are cultural and other differences.
Roundtable for Responsible Soy Production (RTRS)	The pillars of the RTRS Standard of Production are: legal compliance and good business practices, responsible labour conditions, responsible community relations, environmental sustainability and good agricultural practices.
International Sustainability and Carbon Certification (ISCC)	The ISCC standard comprises six principles and corresponding criteria (1) biomass shall not be produced on land with high biodiversity value or high carbon stock; (2) biomass shall be produced in an environmentally responsible way, including protection of soil, water and air and application of Good Agricultural Practices; (3) Safe working conditions through training and education; (4) biomass production shall not violate human rights, labour rights or land rights; promote responsible labour conditions and workers' health, safety and welfare; (5) biomass production shall take place in compliance with regional and national laws and relevant international treaties; (6) good management practices.

The Council on Sustainable Biomass Production (CSBP)	CSBP is a diverse, multi-stakeholder group developing voluntary biomass-to-bioenergy sustainability standards for the production of feedstocks for second-generation (cellulosic) bioenergy facilities. It is made up of growers, environmental and social interests, and all sectors of the industry. The intent is to create a sustainable production system from the very outset for the emergent biomass-to-bioenergy industry, with an initial focus on dedicated fuel crops, crop residues, and native vegetation in the United States.
Roundtable on Sustainable Biofuels (RSB)	. The RSPO criteria cover major economic, social and environmental aspects, including the establishment and management of plantations and processing: (1) transparency, (2) legality, (3) commitment to long-term economic and financial viability, (4) use of best practices by growers and millers, (5) environmental responsibility and conservation of natural resources and biodiversity, (6) responsible consideration of employees, individuals and communities, (7) responsible development of new plantings and (8) commitment to continuous improvement in key areas
Global Bioenergy Partnership (GBEP)	GBEP Task Force on Sustainability established in June 2008 and has since developed the GBEP Sustainability Indicators for Bioenergy. The indicators are intended to guide any analysis undertaken of bioenergy at the domestic level with a view to informing decision making and facilitating the sustainable development of bioenergy in a manner consistent with multilateral trade obligations.

2.6.3 Bioenergy Sustainability Indicators

All certification schemes are guided by a set of core indicators that can be used to quantify bioenergy sustainability. Indicators provide information about an energy system (Bradley Guy and Kibert, 1998) and show how well the system is working or help to determine what direction should be taken to address any issues with the system (Hiremath *et al.*, 2013). They can be appropriate tools for communicating and promoting dialogue related to sustainable development between stakeholders, policy makers and the public (Vera and Langlois, 2007) as well as enable decision makers to choose when, how, and where to deploy systems for sustainable development (Buchholz *et al.*, 2007). Indicators of bioenergy sustainability can be applied conceptually to a region, but actual applications are context specific (Sovacool and Mukherjee, 2011). There are numerous indicators which often present a challenge to implementation (Dale *et al.*, 2013a) and may lead to confusing rather than informing decision-makers (Junginger *et al.*, 2011). Agreement on a few common measures of bioenergy system sustainability and selecting a small set of specific indicators requires compromise but is essential to develop bioenergy markets (Dale *et al.*, 2013a; Dale *et al.*, 2013b).

The RSB set the tone for sustainability indicators by becoming the first agency to develop comprehensive indicators for biofuels in 2007. Other initiatives have also developed indicators since the RSB published theirs. The GBEP published its sustainability indicators for bioenergy in the year 2011. The GBEP publication comprise a set of 24 sustainability indicators which are further disaggregated into social, economic and environmental indicators. There are 8 social, 8 economic and 8 environmental indicators as shown in Table 2.3. The GBEP has further disaggregated each of the 24 indicators into sub-indicators. See for example sub-indicators for job creation in Table 2.4. Some of the indicators are applicable at the national/regional level. Others are also more applicable to first generation bioenergy that relies on agricultural lands.

Table 2.3: GBEP Bioenergy Sustainability Indicators

Environmental indicators	Social Indicators	Economic Indicators
1. Lifecycle GHG emissions	9. Allocation and tenure of land for new bioenergy production	17. Productivity
2. Soil quality	10. Price and supply of a national food basket	18. Net energy balance
3. Harvest levels of wood resources	11. Change in income	19. Gross value added
4. Emissions of non-GHG air pollutants, including air toxics	12. Jobs in the bioenergy sector	20. Change in consumption of fossil fuels and traditional use of biomass
5. Water use and efficiency	13. Change in unpaid time spent by women and children collecting biomass	21. Training and re-qualification of the workforce
6. Water quality	14. Bioenergy used to expand access to modern energy services	22. Energy diversity
7. Biological diversity in the landscape	15. Change in mortality and burden of disease attributable to indoor smoke	23. Infrastructure and logistics for distribution of bioenergy
8. Land use and land-use change related to bioenergy feedstock production	16. Incidence of occupational injury, illness and fatalities	24. Capacity and flexibility of use of bioenergy

Table 2.4: GBEP sub-indicators for Indicator 12 - Jobs in the bioenergy sector

Indicator 12.1	Net number of jobs created in the bioenergy sector
Indicator 12.2	Indicator 12.1 / energy produced or power installed (/MJ or MW)
Indicator 12.3	Net number of skilled jobs created
Indicator 12.4	Net number of unskilled jobs created
Indicator 12.5	Net number of indefinite jobs created
Indicator 12.6	Net number of temporary jobs created
Indicator 12.7	Indicator 12.3 / per energy produced / power installed (/MJ or MW)
Indicator 12.8	Indicator 12.4 / per energy produced / power installed (/MJ or MW)
Indicator 12.9	Indicator 12.5 / per energy produced / power installed (/MJ or MW)
Indicator 12.10	Indicator 12.6 / per energy produced / power installed (/MJ or MW)
Indicator 12.11	Total number of jobs in the bioenergy sector in Ghana
Indicator 12.12	Total number of jobs adhering to national standards / Indicator 12.11 (%)
Indicator 12.13	Total number of jobs in other (comparable) sector / Indicator 12.11 (%)

Existing studies show clearly that an extensive work has gone into the development of indicators and certification schemes for the development of bioenergy. Even though a few of these schemes are location and technology specific, a good number of them can be broadly applied to several locations and technologies. For second generation technologies that depend on residues as feedstock, many of the developed indicators may not be useful. For example, in the GBEP indicators, which are arguably one of the most comprehensive indicators developed, such indicators as water use, water quality, land use for feedstock cultivation, allocation and land tenure, which are very important indicators for first generation bioenergy, may not apply to second generation bioenergy. As of now, none of the certification schemes have developed indicators targeted specifically at second generation bioenergy and this must be given some consideration.

2.7 Review of Energy Situation in Ghana

In the year 2012, total energy consumed in Ghana amounted to 268 PJ. Biomass in the form of firewood and charcoal contributed 49.8% followed by petroleum products at 39% and electricity representing 11.2% as shown in Figure 2.5. This section presents an overview of the energy situation in Ghana, drawing upon statistical information from the Ghana Energy Commission and other relevant agencies.

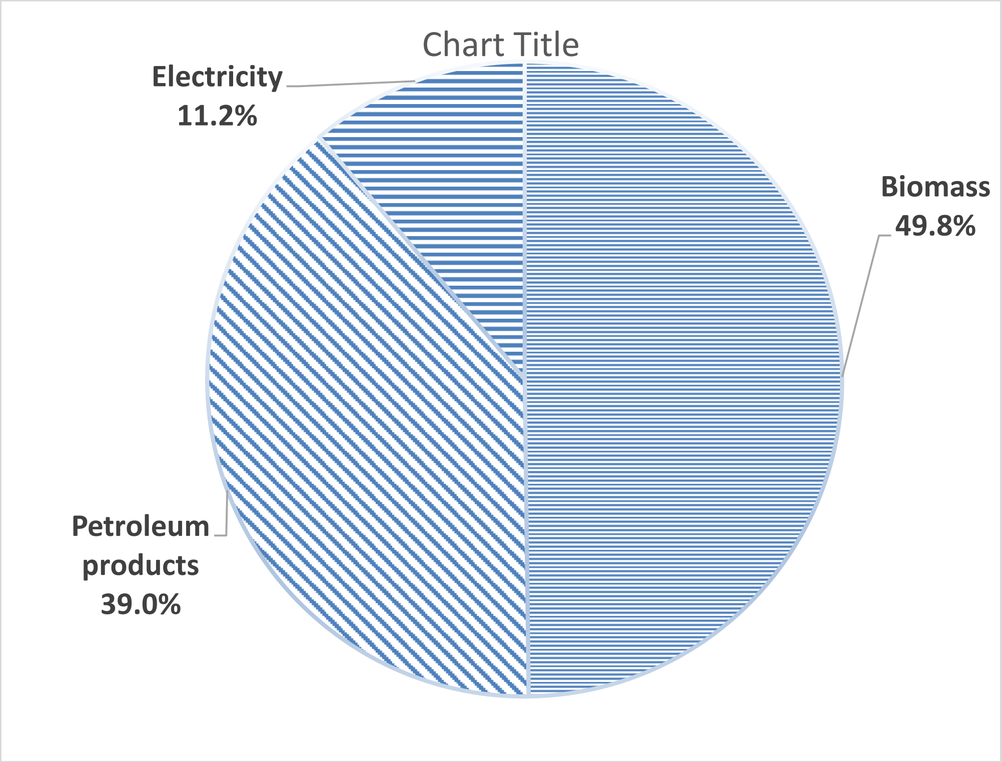

Figure 2.5: Final energy consumed in 2012 [Total = 268 PJ]

2.7.1 Trends in Electricity Demand and Supply

The electricity demand sector in Ghana is disaggregated into residential, non-residential, industrial and street lighting demand. The industrial sector is the highest consumer of electricity in Ghana followed by residential and non-residential sectors (Figure 2.6). There has been a gradual reduction in industrial consumption share over the last decade. On the other hand, the share of residential consumption has increased during the same period, from 23% in 2000 to 34% in 2012. Apart from the increase in income level which often goes with increased demand for electricity, residential consumption has increased also because more communities are being added on to the electricity grid as the country seeks universal electrification by a target date of 2020.

Figure 2.6: Electricity consumption by customer class

Data Source: Energy Commission, 2013

At the end of September 2014, total installed electricity generation capacity in Ghana is 2,846.5 MW. Hydro generation capacity is 55.55% and thermal generation capacity accounts for 44.41% of the total (See Table 2.5). Total electricity supply amounted to 12,122 GWh in 2012. Historical generation trend, by source of fuel, is shown in Figure 2.7. Hydro power is supplied by three hydroelectricity dams, namely, the Akosombo hydroelectricity dam, the Kpong hydroelectricity dam, and the Bui hydroelectricity dam.

Table 2.5: Installed electricity generation capacity at end of September 2014

Plants	Installed Capacity (MW)	Type	Fuel Type	Ownership
Akosombo	1,020	Hydro	Water	VRA
Kpong	160	Hydro	Water	VRA
TAPCO (T1)	330	Thermal	LCO/Gas	VRA
TICO (T2)	220	Thermal	LCO/Gas	VRA
T3	132	Thermal	LCO/Gas	VRA
TT1PP	110	Thermal	LCO/Gas	VRA
TT2PP	50	Thermal	DFO/Gas	VRA
MRP	80	Thermal	DFO	VRA
Solar	2.5	Renewable	Solar	VRA
Bui	400	Hydro	Water	BPA
Sunon Asogli	200	Thermal	Gas	IPP
CENIT	126	Thermal	LCO/Gas	IPP
TOTAL	**2,846.5**			

Source: VRA, 2014

Thermal generation began in the late 1990s and has grown gradually to the current 1,264 MW installed capacity. The first thermal plant in Ghana was commissioned by the Volta River Authority (VRA) in 1997 when it became apparent that hydro generation alone was not enough to support a growing population and fledging economy. There are currently eight thermal plants operating in Ghana out of which six are owned and operated by the VRA and the remaining two owned by Independent Power Producers (IPP).

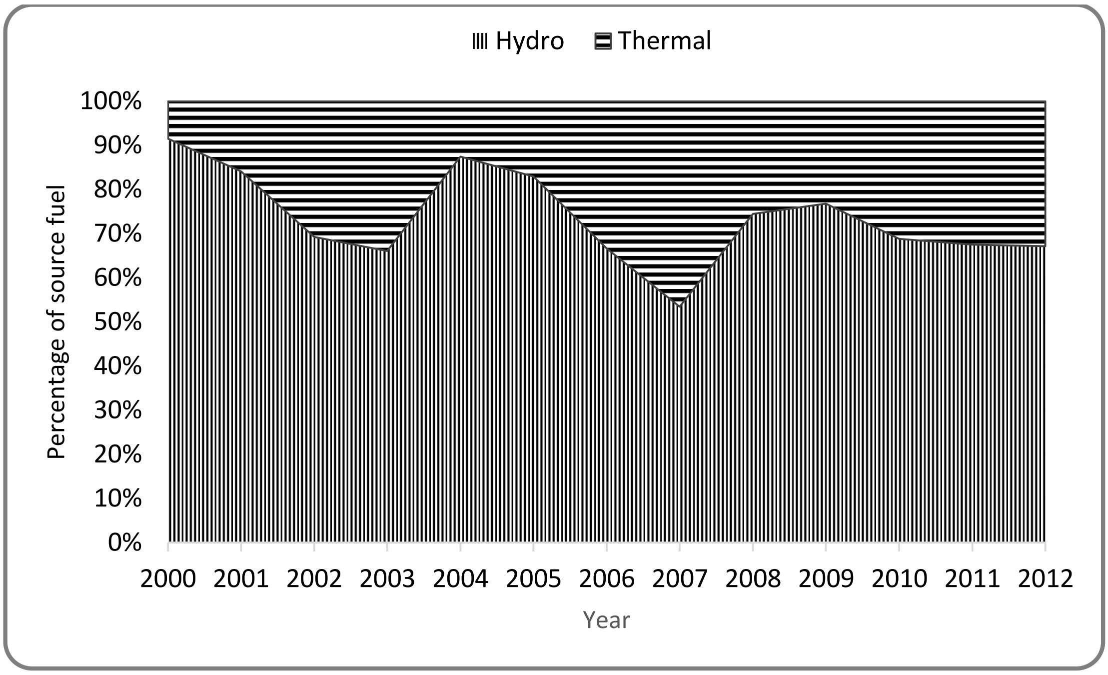

Figure 2.7: Trends in electricity generation by source fuel

Data source: Energy Commission, 2013

Fuels used for thermal electricity generation include Light Crude Oil (LCO), Natural Gas and to a limited extent Distillate Fuel Oil (DFO). Even though natural gas is the preferred fuel choice for thermal electricity generation in Ghana, challenges with the acquisition of natural gas has necessitated the frequent use of LCO, a more expensive fuel, for electricity generation. Natural gas is currently obtained from the West Africa Gas Pipeline (WAGP)[4] which has proven unreliable (see Figure 2.8), often resulting

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[4] The West Africa Gas Pipeline is a natural gas pipeline that supplies gas from Nigeria to Benin, Togo and Ghana.

in power disruptions. Gas flow to Ghana averages about half of expected flow and is a source of concern to Ghana's power generation sector. In times of natural gas shortage, some of the thermal power plants resort to the use of crude oil which raises the cost of electricity generation. Other plants, such as the Sunon Asogli plant, shuts down completely during natural gas shortage as it operates only on natural gas. The transmissions network is owned and operated by Ghana Grid Company Limited (GRIDCO), a state-owned sole transmissions system operator in Ghana.

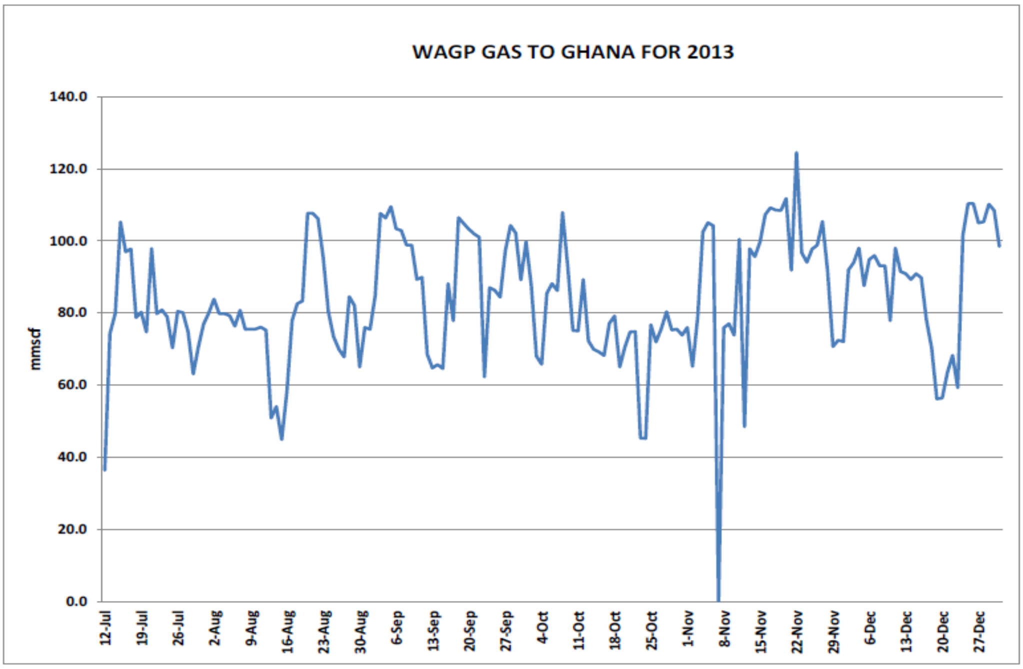

Figure 2.8: Total WAGP gas supply to Ghana for second half of 2013

Source: Energy Commission, 2014

There are three electricity distribution companies in Ghana: The Electricity Company of Ghana (ECG), which has responsibility for the six regions in the Southern parts of the country, the Northern Electricity Distribution Company Limited (NEDCo) which distributes electricity in the four northern regions and Enclave Power which distributes power to industries in the Free Zones Enclave of Tema.

2.7.2 Trends in Petroleum Products Consumption

The most used liquid fuels in Ghana are diesel and gasoline (see Figure 2.9). Diesel is principally consumed in the transport and industrial sectors. Gasoline is also predominantly used in the road transport and haulage sub-sector (Government of Ghana, 2012). More than 770,000 new vehicles were registered in Ghana between 2000 and 2010, driving demand for diesel and gasoline over the period. Liquefied Petroleum Gas (LPG) has historically been used for cooking but there is an increasing use for transportation since 2000 (Figure 2.10). In the year 2010, 18.2% of the about 5.5 million households in Ghana used LPG as their main cooking fuel.

Ghana consumed approximately 3.5 million toe (tonnes of oil equivalent) of petroleum for various applications in 2012, rising from just over 1.6 million toe in 2000. Over the period, there was an 89% increase in gasoline consumption and 150% increase in the consumption of diesel. Even though LPG rose to nearly 500% above the 2000 consumption level, its quantity is far lower than gasoline and diesel in energy terms. In 2012, about 1.2 million tonnes of crude oil was imported to meet domestic consumption. Electricity production accounted for 58.2% of the crude oil consumption while primary refinery operations accounted for the remaining 41.8%.

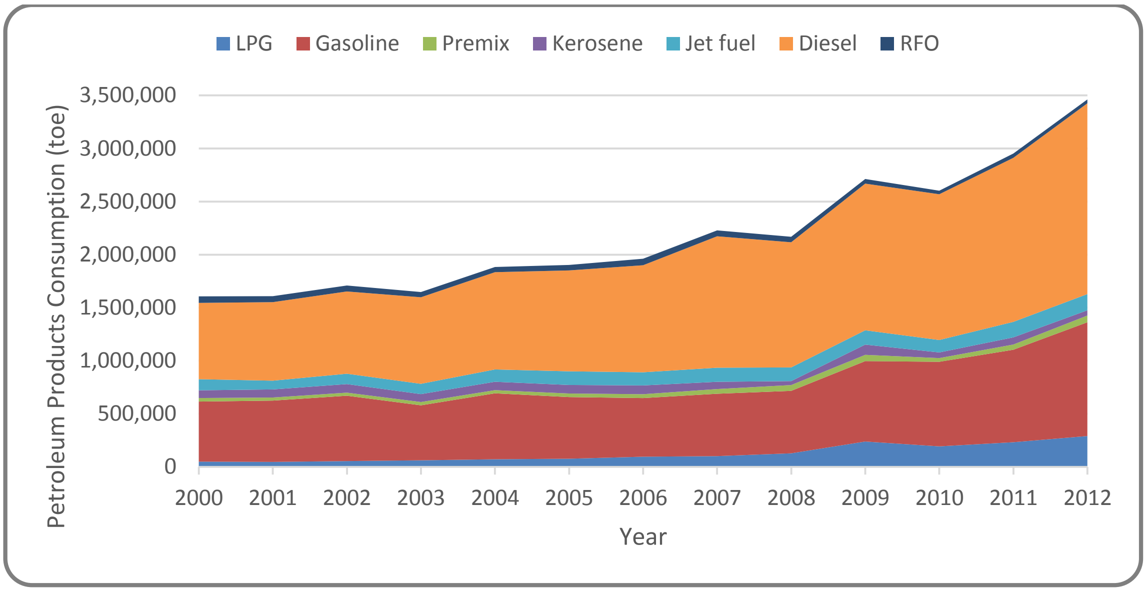

Figure 2.9: Petroleum products consumption

Source: Data compiled from Ghana National Petroleum Authority by Energy Commission, 2013

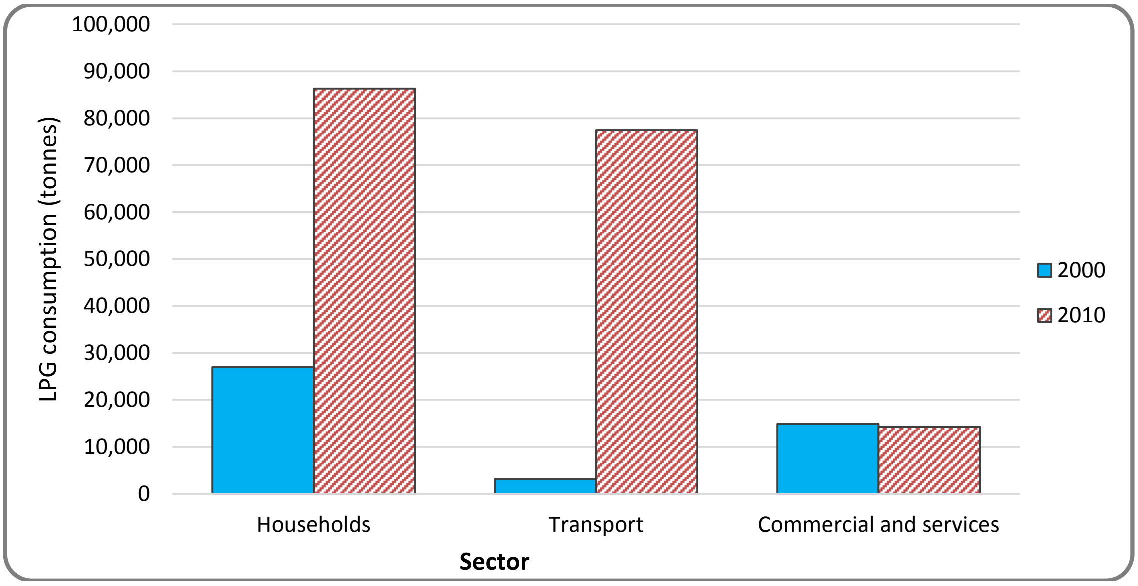

Figure 2.10: LPG consumption for different purposes

Source: Data from Energy Commission, 2013a

Even though Ghana owns a petroleum refinery, the bulk of petroleum fuels consumed is imported. The country's only petroleum refinery, the Tema Oil Refinery (TOR), has a capacity of about two million tonnes per annum but produces far less due to management and operational challenges. Only a quarter of its production capacity, just about 506,000 tonnes was refined at TOR in 2012. About 2.5 million tonnes of petroleum products, including gasoline and diesel was imported in 2012 (Energy Commission, 2013a).

2.7.3 Trends in Woodfuels Consumption

Biomass, in the form of firewood and charcoal, is the most consumed fuel in Ghana, accounting for close to 50% of total energy consumed in 2012. Although the consumption of firewood has reduced from about 9 million tonnes in 2000 to 5 million tonnes in 2012, charcoal consumption has increased (Figure 2.11). Charcoal consumption has increased from less than 1 million tonnes in 2000 to over 1.4 million tonnes in 2012. The reduction in firewood consumption and increase in charcoal consumption may be a result of increased GDP and improved living conditions. On the fuel ladder, shown in Figure 2.12, this implies that most households are moving upwards the ladder from the use of firewood to the use of charcoal and modern fuels. In addition to firewood and charcoal, there are other biomass resources in the form of agricultural and forest wastes, livestock wastes, saw-dusts, etc. According to the 2010 population and housing census, 40% of households in Ghana use firewood for cooking, 34% use charcoal and 1% use other biomass fuel types mentioned above (Ghana Statistical Services, 2012). On average a household in Ghana uses 1,064.7kg of firewood annually, but there are regional and rural/urban disparities. Households in urban areas consume an average of 986.2kg of firewood per year compared to a rural household of 1,113.4kg[5].

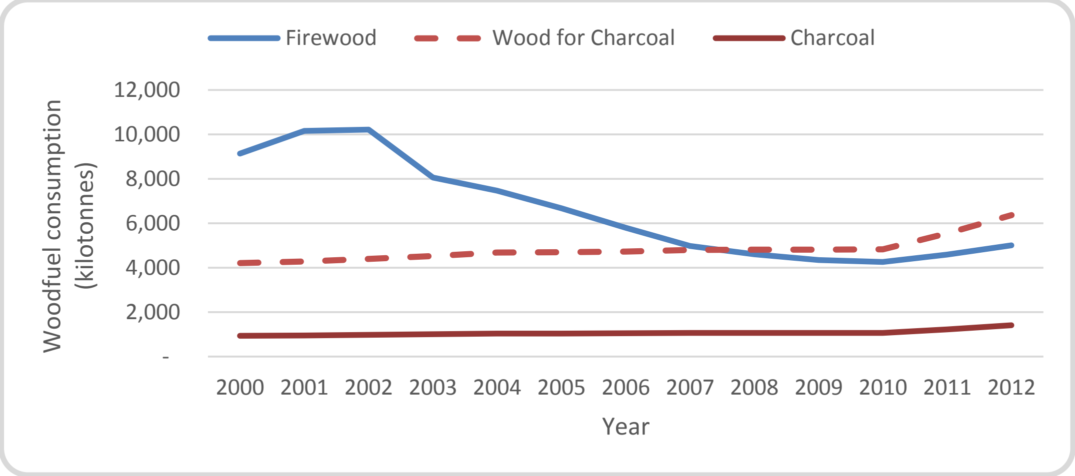

Figure 2.11: Woodfuels consumption

Source: Data from Energy Commission, 2013

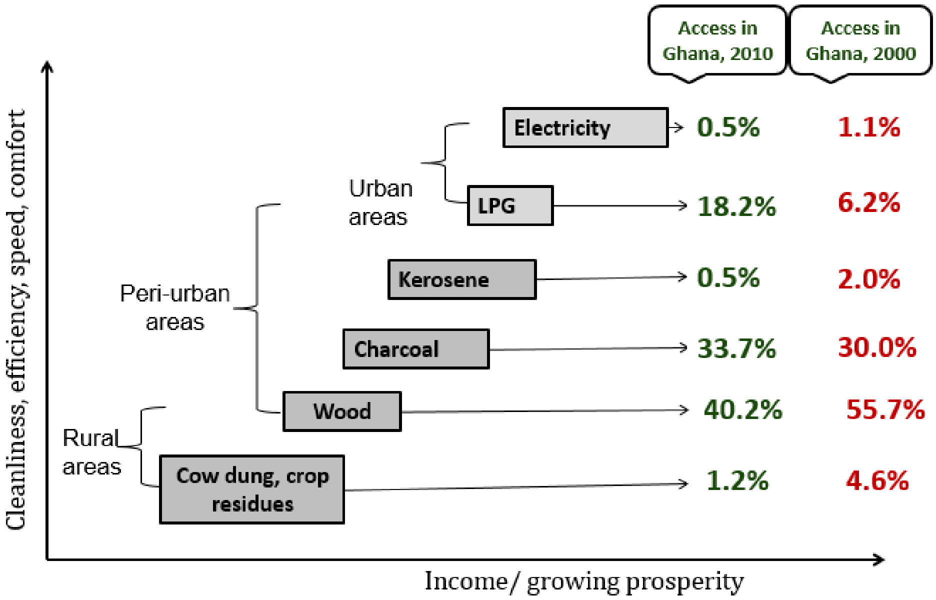

Figure 2.12: Access to cooking fuels shown against the fuel ladder
Source: Energy access data from Ghana Statistical Service, 2012.

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[5] Unpublished national energy survey report by the Ghana Energy Commission, 2012

Although it is still debatable if the exploitation of wood resources for woodfuels is the main cause of deforestation, there are indications that the preferred woodfuel species are gradually disappearing with major charcoal production areas showing physical signs of depleted woodfuel resources (Government of Ghana, 2012). As a result, producers have to travel longer distances in search of wood for charcoal production. Efforts to reduce the use of woodfuels are underway through the introduction of improved cookstoves such as the Gyapa and the Toyola improved charcoal stoves. The introduction of LPG was also to market a more environmentally friendly cooking fuel but frequent LPG shortages mean that charcoal remains the most trusted cooking fuel source for most urban households.

2.7.4 Efforts at Promoting Bioenergy

Agriculture is a major activity in Ghana. According to the 2010 population and housing census, about 41.3% of Ghanaians above the age of 15 are engaged in skilled agriculture, forestry and fishing. Notwithstanding the large workforce in agriculture, the sector contributes just about a fifth of GDP. In 2013, agriculture contributed 22.6% to GDP. The crop sub-sector contributed the largest share with 16.9%. Ghana's agricultural sector is characterised by a large number of dispersed small-scale producers, employing manual cultivation techniques dependent on rain with little or no purchased inputs but which provides over 90% of the food needs of the country (Duku *et al.*, 2011). As of 2010, it was estimated that about 55% of Ghana's agricultural lands, representing about 13.6 million hectares were unutilised (Quansah *et al.*, 2011).

Bioenergy, which in a way started as an agricultural activity, came to the limelight in Ghana about a decade ago with the consideration of the jatropha crop as a probable feedstock for bioenergy. There were lots of interest in jatropha then and several initiatives sprung up (Kemausuor *et al*., 2011). As time has gone by, feasibility of other crops were discussed. Currently, only jatropha and sunflower are purposely cultivated for the production of first generation biofuels in Ghana. Other crops such as corn, cassava, sugarcane, sweet sorghum, oil palm and soybean are cultivated in the country mainly for food purposes and in the case of cassava and palm oil, also for other industrial purposes. There are indications however that the cultivation of cassava for instance could, in the near future, be expanded for the production of ethanol as transportation fuel (Kemausuor *et al*., 2011).

Ghana has suitable climate for bioenergy feedstock production and hence present a potential for business investment. The existing feedstock farming arrangements in Ghana consist mainly of private companies who lease large plots of land from land owners and chiefs on which to cultivate the feedstock. There are currently no known cases of smallholder farmers cultivating and selling the feedstock as income generating activities. The business is also dominated by foreign companies, sometimes with minimum shares owned by locals. Apart from Tropical Agricultural Marketing and Consultancy Services (Tagrimacs), a company that produces biodiesel from sunflower in Ghana, there is no known commercial liquid biofuels production outfit in the country. Most of the jatropha plantations in the country sell their seeds in smaller quantities to interested buyers and also extract the oil to use in their own machines.

Other bioenergy types such as the production of electricity from residues exist, but on a small scale. Table 2.6 shows oil palm mills that generate electricity from their process waste. A recent assessment for the Ministry of Energy (Addo *et al.*, 2014) shows that there is indeed huge potential and a lot more could be done. Other assessments by *Deutsche Gesellschaft fur Internationale Zusammenarbeit* (GIZ, 2014) also point to high potentials from agro-process waste.

Table 2.6: Electricity generation from biomass resources

Plant location	Installed capacity (kW)	Average annual energy (GWh)
Kwae Oil Mills	2,500	6.8
Benso Oil Mills	500	1.9
Twifo Mills	610	2.1
Juaben Oil Mills	424	1.5
Volta Forest Products*	700 kW_{heat}	

Source: Government of Ghana (2012); *Data from survey conducted by The Energy Center at KNUST.

Currently, some of the critical issues bothering biofuels in Ghana include the lack of a clear cut policy from the government to provide the impetus for the private sector to increase investment in the area. The Parliament of the Republic of Ghana recently passed a Renewable Energy Act which seeks to create a platform for the diversification of energy generation sources (especially electricity) including an enabling environment for independent power producers to join the energy supply sector with energy from renewable sources. Even though biomass for electricity generation falls under the various renewable energy technologies considered under electricity, very little is said about biomass for transport and residential fuels. A draft bioenergy framework document prepared in 2010 that could address the peculiar needs of the transport and residential fuel sector, is yet to be approved. The document proposes the substitution of fossil fuels with biofuels by 10% by 2020 and 20% by 2030; and for Ghana to become a net exporter of biofuels in the long to medium term (Energy Commission, 2010). These targets are too ambitious and may not be met, especially because nothing has been done by way of production and the pronouncement of a mandate to encourage consumption. According to early estimates, Ghana would have to produce roughly 336 million litres of liquid biofuels to equal 10 per cent of expected transport fuels in 2020 (Antwi *et al.*, 2010). In order to achieve these targets, the document calls for the encouragement of commercial scale production of bioenergy feedstock; creating demand for it; and sustaining supply. The document makes very little mention of second generation bioenergy, presupposing that the emphasis is on the first generation. It however alludes to the fact that second generation bioenergy would need research and much more funding to materialize. Currently, there are research needs in engineering, science and technology development. Engineers and technicians are required to undertake all manner of engineering activities including design of equipment for production and supply, while agronomists and chemists are needed to develop the science aspects of the technology.

A number of studies have put forward estimations for both first and second generation bioenergy potentials in Ghana. According to Afrane (2012), using 1.96% and 17.3% of the cassava and palm oil produced in 2009 could produce biofuels to replace 5% of both petrol and diesel in that year. Kemausuor *et al.* (2013) evaluated the energy production potential of extra food crops grown on available arable agricultural land under two principal scenarios: using 2.5% and 5% of the available arable land for energy crop expansion. The evaluation showed that using 5% of uncultivated arable land dedicated to four traditional crops grown in Ghana (maize, cassava, sweet sorghum and oil palm) could potentially replace 17.3% and 13.3% of transportation fuels by 2020 and 2030 respectively. An analysis by Antwi *et al.* (2010) estimates that about 336 million total biofuels will be needed to meet demand for 10% of all transport fuel demand by 2020. A more recent estimate by Osei *et al.* (2013) shows that on an energy equivalent basis, more than 350 million litres of ethanol will be needed to substitute for just 20% of the petrol demand (not all transport fuels) in 2020, using a combination of cassava, yam and corn. It has been noted however, that because the crops under consideration are major staple foods in Ghana, any intention to use them for biofuels will have to increase its production levels considerably to avoid creating food shortage or price hikes in the food market (Antwi *et al.*, 2010).

Other studies have assessed bioenergy production from wood residues (Derkyi *et al.*, 2011) palm oil mill effluent (Arthur and Glover, 2012) and livestock manure (Edem *et al.*, 2011). Estimates by Arthur and Glover (2012) shows that Ghana could have produced 162.8 and 268.1 GWh of energy in 2002 and 2009 respectively from palm oil effluent. Estimates by Duku *et al.* (2011) and Mohammed *et al.* (2013) place bioenergy potentials from crop residues at between 75 and 100 PJ. Approximately 976,000 m^3 of forestry residues were generated in the country in 2008, a potential source of bioenergy production (Duku, *et al.*, 2011). Ofori-Boateng *et al.* (2013) estimate that only 10% of the over 4.5 million tonnes of waste generated in 2010 was managed through proper incineration and landfilling and that MSW hold promise as a bioenergy source. There is potential for bioenergy to replace portions of traditional cooking fuel (firewood and charcoal) with biogas that is much more efficient at the point of use. The technical potential for household, manure-fed biogas installations in Ghana is estimated at about 162,066 (Edem *et al*., 2011).

2.8 Key Research Gaps and Motivation

The key issues arising out of the review include:

1. Bioenergy technologies specific and optimized for a particular geographical location are necessary, taking into consideration the financial and material resources available within the region.
2. Bioenergy socio-economic impacts are diverse and will differ according to factors such as the nature of the technology, local economic structures, social profiles and production processes. Other important factors include the level and nature of the capital investment, the availability of local goods and services, the degree of regional monetary leakages, the time scale of both the construction and operation of the plant, and various institutional and energy policy-related factors such as capital grants and subsidies.
3. Biomass socio-economic impacts are typically very case and site specific and are more relevant on the local than on the global level.
4. More empirical research would be required to assess the social impacts of small-scale bioenergy production systems in rural areas of developing countries.

5. Indicators of bioenergy sustainability can be applied conceptually to a region, but actual applications are context specific. There are numerous indicators which often present a challenge to implementation and may lead to confusing rather than informing decision-makers. Agreement on a few common measures of bioenergy system sustainability and selecting a small set of specific indicators requires compromise but is essential to develop bioenergy markets.

CHAPTER THREE

3.0 GENERAL MATERIALS AND METHODS

The general methodological approach to the study is shown in Figure 3.1. Guided by the research questions, the study was structured into three principal stages. The first stage was a mapping of bioenergy feedstock sources with emphasis on agricultural residues. The second stage was a demand and supply mapping of energy in Ghana. The most important aspect of the second stage was to examine the extent to which bioenergy feedstock sources mapped in stage one could contribute to demand for cooking and heating fuels, electricity generation and transportation fuels. In the third and final stage, a socio-economic analysis was conducted for cooking and heating fuel (biogas) production using a case study approach. Two cases were used for the socio-economic assessment: staple food systems using resources from rural communities, and agro-industrial systems processing cassava into *gari*.

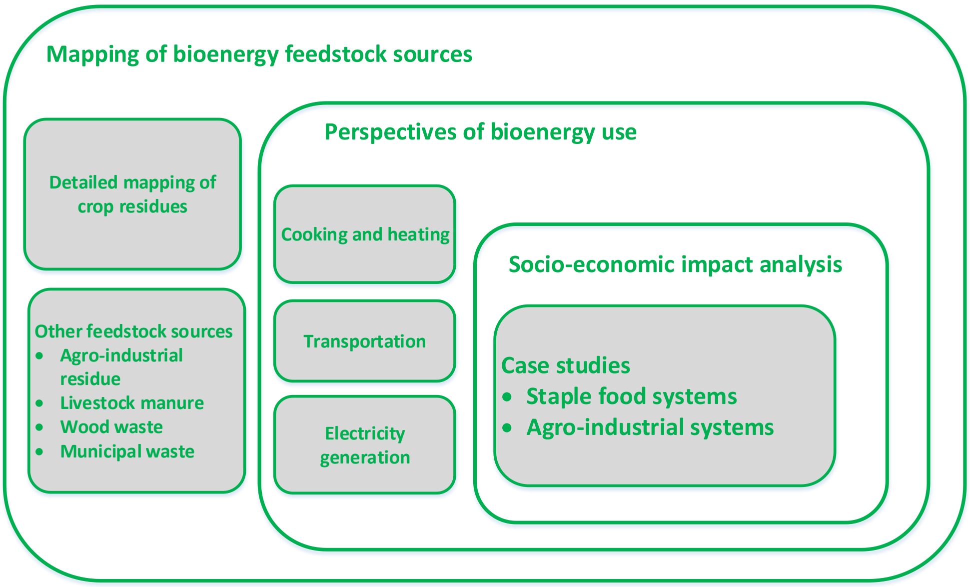

Figure 3.1: Schematic representation of methodological approach

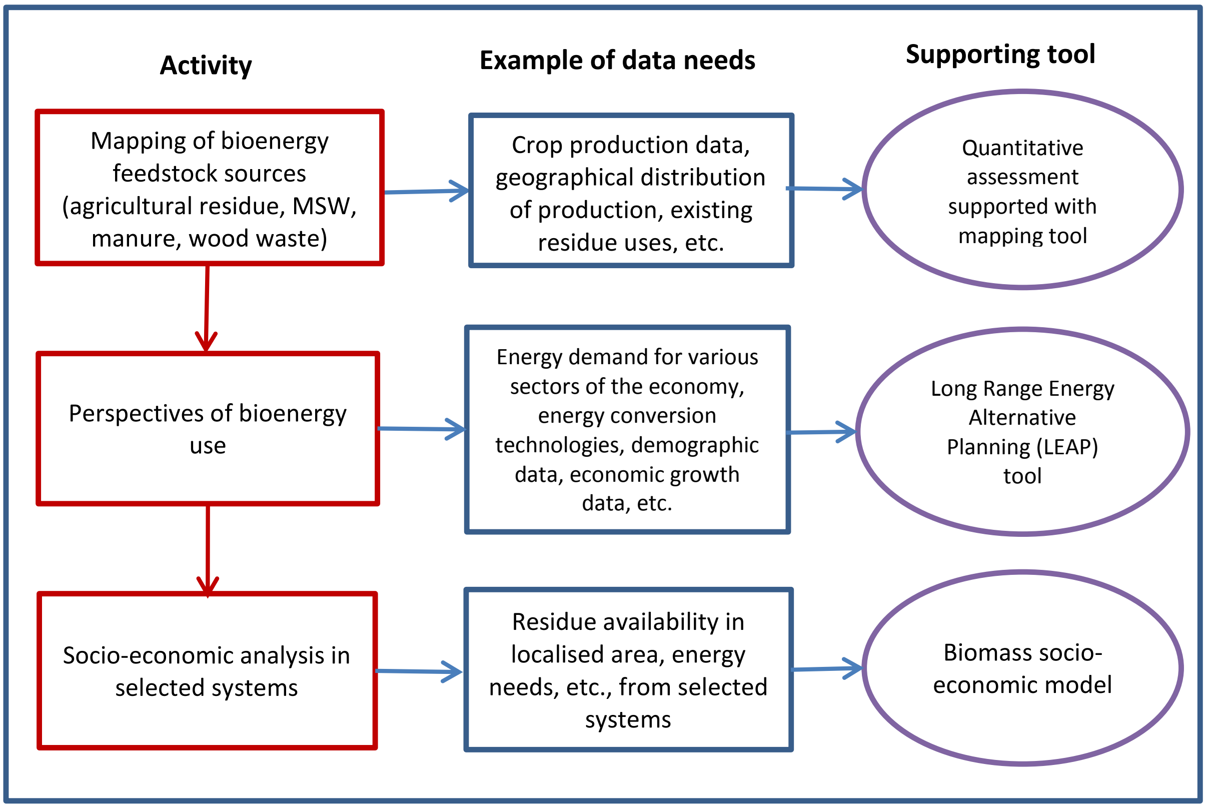

Figure 3.2: Summary of data needs and modelling tools for analysis

Figure 3.2 shows a summary of data needs and modelling tools that were used for the analysis of the different study stages. The mapping of feedstock sources was based primarily on data obtained from the relevant government agencies and ministries, such as the Ministry of Food and Agriculture (MOFA) as well as data obtained from field studies. The demand and supply mapping was conducted using the Long range Energy Alternatives Planning (LEAP) model. Socio-economic impact analysis was performed using a socio-economic model. A number of socio-economic models were evaluated but none was found suitable for the purposes of this thesis. The models evaluated were

‘Evaluation of Local Value Impacts for Renewable Energy (ELVIRE model)’, ‘Biomass Socio-Economic Multiplier (BIOSEM model)’, ‘Renewable Energy Crop Analysis Programme (RECAP model)’, ‘SAFIRE model’, and ‘Biochains Economic Evaluation (BEE)’. Many of these models were project led and had objectives that were specific to the projects at the time of building them. None of them were applicable to all the indicators that were selected for the socio-economic analysis in this thesis. A model was therefore developed that captured the key indicators required for this thesis.

This thesis uses the energy unit of Joule to show the energy potential of all forms of biomass resources in order to ensure consistency in comparison and analysis. Where necessary and for the sake of special emphasis, appropriate units of measurements were used for different energy carriers: such as kWh (kilowatt-hours) for electricity and litres for liquid fuels.

The methodology is so structured to test the applicability of seven (7) economic and social indicators, in addition to GHG emissions savings at the national level, under the Global Bioenergy Partnership (GBEP) sustainability indicator framework. These indicators are:

1. Change in consumption of fossil fuels and traditional use of biomass
    i. Substitution of fossil fuels with domestic bioenergy measured by energy content

    ii. Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content

2. Bioenergy used to expand access to modern energy services
    i. Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of energy and numbers of households and businesses
    ii. Total number and percentage of households and businesses using bioenergy, disaggregated into modern bioenergy and traditional use of biomass
3. Energy diversity
    i. Change in diversity of total primary energy supply due to bioenergy
4. Productivity
    i. Production cost per unit of bioenergy
5. Change in income
    i. Wages paid for employment in the bioenergy sector
    ii. Net income from the sale, barter and/or own-consumption of bioenergy products, including feedstocks
6. Jobs in the bioenergy sector
    i. Skilled/unskilled
    ii. Indefinite/temporary
7. Change in unpaid time spent by women and children collecting biomass

i. Change in average unpaid time spent by women and children collecting biomass as a result of switching from traditional use of biomass to modern bioenergy services (Global Bioenergy Partnership, 2011).

CHAPTER FOUR

4.0 ASSESSMENT OF TECHNICAL POTENTIAL OF BIOENERGY FEEDSTOCK

4.1 Background

The wide range that exists in the results of most global biomass assessments suggests the need for more precise information about the potential biomass at country levels for planning purposes. Various forms of biomass exist in Ghana which could be examined for the production of different forms of modern bioenergy. For planning and feasibility study purposes, it is important to establish the types, amounts and locations of these biomass resources in the country. Such improved information about available biomass resources would assist project developers and policy makers to make better informed decisions regarding bioenergy interventions and form the basis for more detailed studies in preparation of specific interventions and policies. This chapter discusses potential of bioenergy feedstock from four principal sources in Ghana, namely, agricultural residue (comprising crop residue and agro-industrial residue), livestock manure, municipal solid waste and wood waste. A detailed description of the methodology is provided in the section below.

4.2 Methodology

4.2.1 Mapping of Crop Residues

Crop residues are the non-edible plant parts of crops which are left in the field after harvest or after primary processing such as dehusking and/or shelling. In most farming communities, crop residues represent a low cost biomass supply available within a few days/weeks after harvest and before land preparation for the next crop season. Even though most crops produce some form of residue, not all crop residues can be effectively utilized for energy production due to the nature of the residue produced or its composition. Based on the potential for utilisation, residues have been categorised into three pathways, as shown in Figure 4.1. The first pathway is made up of residues left on the farm and in the immediate vicinity of farm communities. Examples are corn stover, sorghum stalks, millet straw, cassava stems and plantain trunks. These residues are often concentrated on farm plots and available in large quantities. They may also be used on the farm as source of fertiliser or mulching material or as erosion control material. The second pathway consists of residues left at primary/secondary processing sites, which may also be on the farm, within the farming community or at a processing facility. These residues include corn cobs, corn husks, rice husks, and cassava peels produced during cassava processing. These residues are often concentrated in one location and available in variable quantities depending on the scale of production. The third pathway consists of residues left at places of consumption, including cassava peels, plantain peels, yam peels, cocoyam peels, and potato peels. These residues, which could also be referred to as process residues, are scattered in homes and restaurants and are available in small quantities. They are difficult and expensive to collect (Simon *et al*., 2010) and often end up in Municipal Solid Waste (MSW) stream. Their collection and disposal often are the responsibility of waste management authorities. Generally, the straw and stalk from these crop types are the main source of residues that can be removed (Ericsson and Nilsson, 2006; Kim and Dale, 2004;

Lal, 2005). Peelings emanating from such crops as cocoyam, potato, yam, plantain and cassava[6] consumed in the household are not considered in the analysis of crop residues for energy generation.

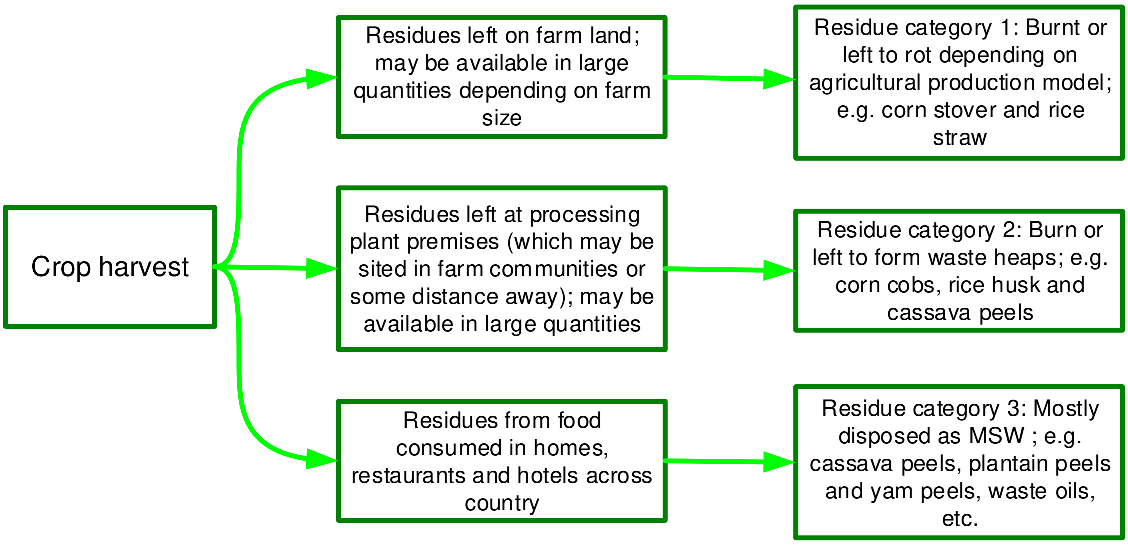

Figure 4.1: Crop residue pathways

Data on historic crop production was obtained from MOFA and allied agencies. This data was compared with similar data from the Food and Agriculture Organisation (FAO) of the United Nations. Existing residue management structures were examined to appropriately determine present uses of crop residues and their availability as energy production feedstock. Geographic Information System (GIS) software, ArcGIS, was used to show the spatial distribution of feedstock sources at the regional and district levels.

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[6] For cassava, only residue at the household is not available. Cassava residue from agro-industrial processing is widely available for collection.

When determining the amount of residue available from a crop, the residue-to-product ratio is an important parameter used in estimation. Residue-to-product ratio (RPR) simply means the ratio by weight of a particular residue generated by a certain crop to the amount of crop harvested. For the same crop, RPR could vary for different farms, communities and countries. Some of the factors that contribute to the difference in RPR for different locations include moisture content at time of measurement, yield of crops, and yield of biomass, which all depend on climatic conditions and the level of farm management. Since no known field study has been conducted in Ghana to determine RPR for various crops, field experiments were performed in selected parts of the country to determine RPR of some crops. The study took place in sixteen (16) different towns in eight districts and five regions in the country (shown in Figure 4.2). The field work locations were major agricultural towns in the country and were selected to roughly represent the diverse agro-ecological zones in the country. Due to ease of access, the majority of the towns were selected from the Ashanti and Brong Ahafo regions, with others selected from the Upper West, Greater Accra and Western regions. For every locality where fieldwork was conducted, at least two major crops based on the cultivated area in the district were selected for RPR determination. Ten small-holder farms were selected for each crop. The following procedure was used for the RPR measurements:

a) Four plots each of size 20m by 20m square were obtained by random sampling from each of the farms visited.
b) The residue to product ratio (RPR) of the various residues was determined using the weight of the product and residues obtained from the plants.

c) An average RPR was determined for each farm from the different plots.

d) An average RPR was derived for the various locations.

When determining RPR, an important parameter is moisture content. Moisture content is the quantity of water contained in biomass. This is important in the computation of dry matter content, which is necessary for the determination of energy potentials. Moisture content (wet basis) of each of the residue types was therefore determined in the laboratory using the following procedure:

a) A sample of fresh peel (W_w) from each variety was weighed.

b) The fresh residues were dried in a hot oven at 103°C for 24 hours

c) The weight of the dried residues (W_d) were recorded.

d) The moisture content (MC) was determined using equation 4.1.

$$\boldsymbol{MC = \frac{(W_w - W_d)}{W_w} \times 100\%} \qquad \textbf{4.1}$$

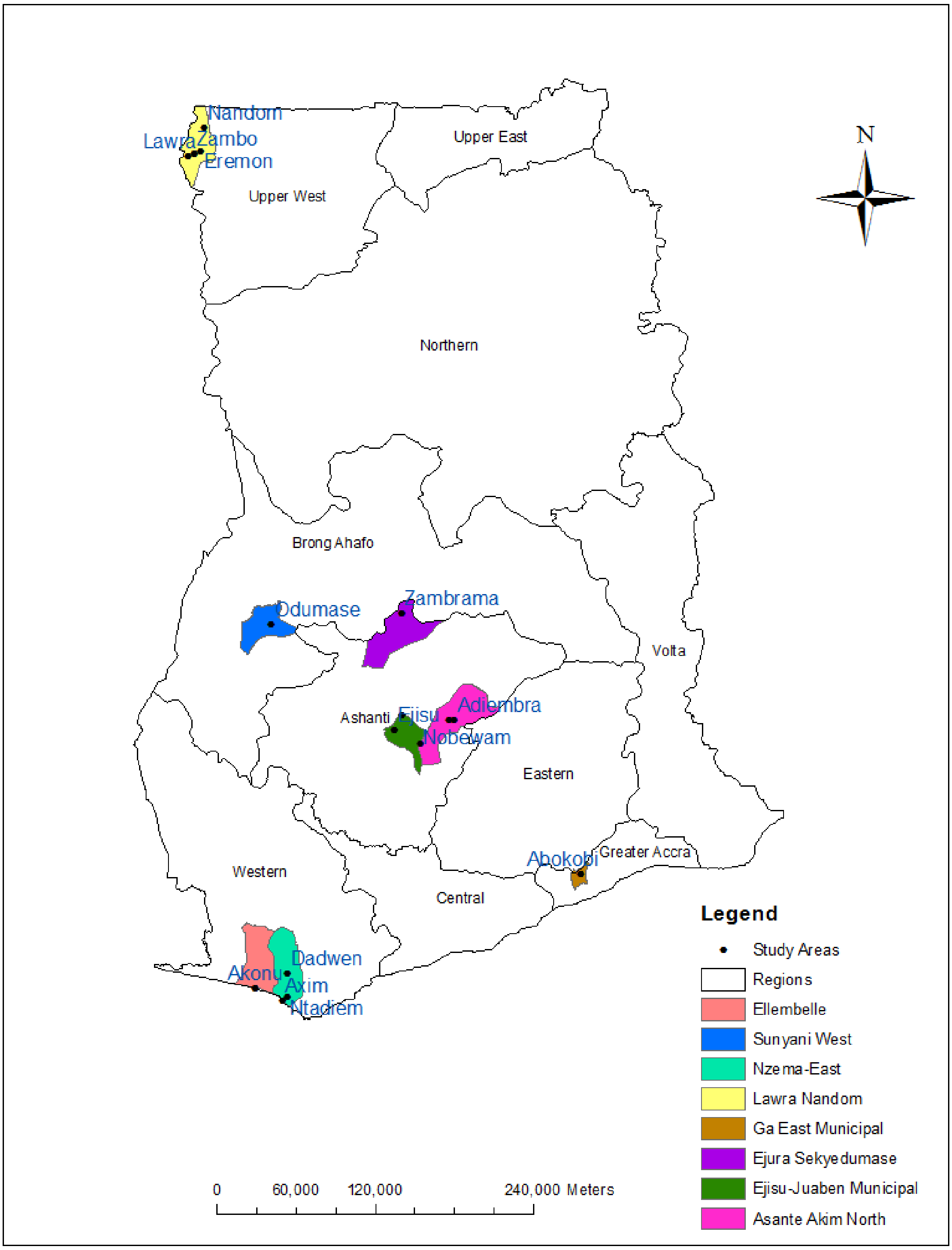

Figure 4.2: Map of Ghana showing RPR field locations

The theoretical potential of crop residues is computed using equation 4.2.

$$\boldsymbol{P_{AR} = \sum_{i=1}^{n}(C_i \times RPR_i)} \qquad \textbf{4.2}$$

where, P_{AR} is the annual crop residue potential, C_i is the annual production of crop *i* and RPR_i is the residue to product ratio of crop *i*. Factor *n* is the total number of residue categories.

When estimating crop residue availability, an important factor that is taken into account is the removal rate (or recoverability fraction) of the residue (Lemke *et al*., 2010; Zheng *et al*., 2010). The recoverability fraction is the ratio between the residues that realistically can be collected and the total theoretical amount (Smeets *et al*., 2007). In practice, not all the biomass may be available for collection due to several inhibiting factors. In the first place, the existing technology may not be able to process all the available biomass into useful energy. Some biomass may also be left to replenish soil nutrients and prevent agricultural fields from being exposed to harsh environmental conditions, especially soil erosion. Other considerations such as economic and social conditions also prevent or render undesirable the removal of all available biomass for energy production. Most experts agree that a removal rate of 35% is ideal in order to allow for soil replenishment (Cooper and Laing, 2007; Shahbazi and Li, 2006). Factors such as the condition of the land, accessibility, and competitive uses were critical to the selection of this recovery rate. In a global assessment of bioenergy potentials, Smeets *et al*. (2004) used a recoverability fraction of 25% for rice straw, 80% for stalks, 100% for processing residue and 50% for wood process residues. In an assessment of maize residues for energy production in the Eastern region of Ghana, the Kumasi Institute for Technology, Energy and Environment (KITE, 2009) used 80% recoverability fraction, taking into consideration the fact that farming in Ghana is largely no-tillage and with no existing regulation for residue management. This thesis assumes recoverability fractions for individual residue types to estimate the technical biomass potential.

4.2.2 Assessment of Manure, Wood Residues and Municipal Solid Waste

Anaerobic digestion of livestock manure provides sanitation by reducing the pathogenic content of substrate materials (Bond and Templeton, 2011). Small-and medium-scale digesters (up to $6m^3$) can provide biogas for single-household cooking and lighting in rural communities. Large-scale digesters can supply biogas in large volumes for electricity generation, heat, steam, and transportation fuel production. The potential quantities of livestock manure resources are estimated using number of livestock, average annual manure production per livestock, recoverability fraction, and dry manure fraction (Cai *et al.*, 2008). Amount of manure per head per day depends on factors such as body size, kind of feed, physiological state (lactating, growing, etc.), and level of nutrition (Junfeng *et al.*, 2005). The manure available (P_{manure}) was estimated using equation 4.3. Data on livestock production was obtained from the Ministry of Food and Agriculture (MOFA, 2012). The recoverability fraction used in the estimation of technically available livestock manure is based on a study by KITE (2008).

$$\boldsymbol{P}_{\mathbf{manure}} = \sum_{i=1}^{n}(\boldsymbol{P}_{live} \times \boldsymbol{y}_{man} \times \boldsymbol{\eta}_{rec})_{i} \qquad \mathbf{4.3}$$

where P_{live} is the number of specific livestock population, y_{man} is manure produced by one specific livestock annually, η_{rec} is the recoverability fraction of manure for specific livestock.

Wood residue results as a co-product of logging and timber processing. Wood residue can be collected and used from in-forest cutover, log landing or wood processing sites. In Ghana, the landing and processing sites are often the same since the tree-length materials are transported straight from the forest to the processing sites. Data on wood production was obtained from the FAO (2013).

Data on MSW generation in the country was obtained from Zoomlion Ghana Ltd., covering MSW collected in all ten (10) regions in the country. In this study, waste that is not collected is ignored.

4.2.3 Estimation of Energy Potentials

The Lower Heating Value (LHV) of each resource type was used to determine the approximate energy content of bioenergy feedstock sources in the country using equation 4.4. LHVs were obtained from scientific literature (Duku *et al.*, 2011; Koopmans and Koppejan, 1997; Jekayinfa and Scholz, 2009) and laboratory analysis conducted by The Energy Centre of Kwame Nkrumah University of Science and Technology at two laboratories in Burkina Faso and Germany (Addo *et al.*, 2014).

$$\boldsymbol{E = \sum_{i=1}^{n}(B_i \times LHV_i)} \qquad \textbf{4.4}$$

where, E is the annual gross energy potential of bioenergy feedstock type, *B_i* is the dry matter content of annual production of bioenergy feedstock type i, and n is the total number of residue categories.

To estimate future bioenergy potential from the resources, regression analysis was employed, using growth rate of each biomass type over the past decade. Due to the absence of crop production growth projections from the Ghana Ministry of Food and Agriculture, this thesis used the crop production outlook data from the Organisation for Economic Co-operation and Development (OECD) and the Food and Agricultural Organisation (FAO) (OECD/FAO, 2014). The future biomass availability was estimated using equation 4.5:

$$\boldsymbol{P_n = P_o\left(1 + \frac{r}{100}\right)^n} \qquad \textbf{4.5}$$

where P_n is future biomass available, P_0 is current biomass available, r is growth rate of biomass type, and n is projected number of years.

The energy content computed is the total energy obtainable from the resource available. In principle, not all of this energy can be recovered. Chapter Five would therefore delve deeper into how these energy potentials are translated into different energy carriers for use in different sectors of the economy.

4.3 Results and Discussion

4.3.1 Residue to Product Ratio (RPR) Analysis

The average residue to product ratio obtained from field experiments conducted in sixteen (16) different communities in the country are summarised in Table 4.1. The values range from 0.25 for maize cobs to 6.37 for millet stalks. Table 4.1 also shows a comparison of the field determined RPR with those available in literature from other countries. Even though there are notable differences, the values obtained from the field fall within range of those obtained from literature. It is only in the case of millet stalks and sorghum stalks that the RPR obtained is more than twice the highest value obtained from literature. But that can be attributed to the fact that millet and sorghum in Ghana are harvested in the very fresh state with high moisture. This is reflected by the moisture content of above 60% in each case. The high moisture content results in higher weight of the residue. Moisture content of the other residues fall within range of values obtained/quoted by other studies. For example, reported RPR values for maize stalk are 1.21 at 15% moisture content (Murali *et al.*, 2008); 1.5 at 15% (OECD/IEA, 2010) and 1.0 to 2.0 at 15% (Koopmans and Koppejan, 1997). This compares closely with the average figure of 1.37 at 15.02% moisture content obtained in Ghana.

The detailed results for the various locations (Tables 4.2-4.5) show that indeed RPR values would vary for different farms, communities, districts and regions as published studies suggest. Not all the crops suitable for energy purposes were covered in the field determination of RPR. For those crops that were not covered, data from literature was used for the estimation of crop residues.

Table 4.1: Field determined RPR compared to RPR from literature

Residue type	Field determined RPR	Moisture content	RPR from literature sources		
			RPR[1]	RPR[2]	RPR[3]
Maize stalk	1.37	15.02	1.28	2	1.5
Maize husk	0.26	11.23		0.2	
Maize cob	0.25	8.01		0.273	0.3
Cassava stalk	1.24	20.00			
Cassava peel	0.34	20.00	0.3	0.25	
Rice husk	0.23	13.01		0.265	0.25
Rice straw	3.05	15.5	1.28	2.188	1.5
Cowpea straw & pod	6.37	16.45			
Sorghum stalks	4.75	61.80	2.23	1.75	
Sorghum husks	0.14	2.74			
Millet stalks	5.53	63.57	2.55	1.75	1.2
Millet husks	0.29	11.6			
Groundnut straw	1.73	18.86		2.3	2
Groundnut shells	0.35	13.82		0.447	0.3

[1] OECD/IEA, 2010; [2] Jekayinfa and Scholz, 2009; [3] Koopmans and Koppejan, 1997.

Table 4.2: Residue to Product Ratio for maize from different locations

District	Stalk	Husk	Cob
Ejisu Juaben	1.25	0.30	0.22
Sunyani West	1.25	0.28	0.25
Ga East	1.62	0.20	0.29
Asante Akyem North	1.19	0.22	0.54
Nzema East	1.92	0.18	0.32
Average	**1.49**	**0.22**	**0.35**

Table 4.3: Residue to Product Ratio for cassava

Locations	Stalk	Peels
Asante Akyem North	1.97	0.34
Sunyani West	1.05	0.3
Ga East	1.02	0.39
Average	**1.35**	**0.34**

Table 4.4: Residue to Product Ratio for rice

Locations	Husk	Straw
Asante Akyem North	0.34	2.95
Ejisu Juaben	0.10	3.50
Ejura Sekyedumasi	0.25	2.68
Average	**0.23**	**3.04**

Table 4.5: Residue to Product Ratio for other crops

Location	Crop type	Residue type	Average RPR
Ejura Sekyeredumasi	Cowpea	Straw + pods	6.37
Asante Akyem North	Cocoa	Pod	2.20
Asante Akyem North	Yam	Straw	0.029
Nzema East Municipal	Coconut	Husk	0.67
Nzema East Municipal	Coconut	Shell	0.27
Lawra	Groundnut	Straw	1.75
Lawra	Groundnut	Shell	0.35
Lawra	Sorghum	stalks	4.75
Lawra	Sorghum	Heads	0.14
Lawra	Millet	Stalks	5.53
Lawra	Millet	Heads	0.29

4.3.2 Crop Residue Availability

Crop production data and the residue generated from these crops in 2011 are listed in Table 4.6. A distinction is made between residues generated during harvesting on the field ('field based') and those generated during processing. As mentioned in the methodology, residues that are thought to end up in municipal solid waste, such as yam peels, are not considered in this results. The theoretical potential of residue assumes a 100% availability of all residues considered and was calculated using residue to product ratios (RPRs) obtained from the field measurements and literature. The technical potential of residue assumes a recoverability fraction. The recoverability fraction is based on a number of assumptions. The first assumption is that some residue will be left on farm plots for re-fertilisation, in line with global agricultural principles. The second assumption is that there will be practical challenges when collecting field residues, due to poor road condition to, especially, small-holder farms in rocky and mountainous agricultural fields. These accounts for the low recoverability of field residues. Process residues are assumed to be widely available since processing could take place in centralised locations. If economic and sustainability challenges are considered, the recoverability fractions could be lower than those used in this thesis. In essence, it is not expected that all the technically available resource will be utilised for energy purposes. This is considered in Chapter Five where practical uses of the resources are considered.

Residue availability is dominated by residues from cassava, yam, maize, plantain and groundnut, which together make up 78% of the technical potential. These crops are produced in relatively large quantities and in several districts in the country. Maize, for instance, is produced in almost every district in Ghana. Other crops such as sugarcane, coconut, cotton and sweet potato contribute very little residue as they are produced in very few districts.

Table 4.6: Crop residue generation from agricultural crops in 2011

Biomass type	Annual Production - 2011 (t)	Field based residue	Processing residue	RPR	Theoretical potential of residue (t)	Recoverability fraction	Technical potential of residue (t)
Maize	1,699,134	Stalk		1.37	2,327,814	0.35	814,735
Maize	1,699,134		Husks	0.26	441,775	0.80	353,420
Maize	1,699,134		Cobs	0.25	424,784	0.80	339,827
Rice	465,967	Straw		3.05	1,421,199	0.35	497,420
Rice	465,967		Husks	0.23	107,172	0.8	85,738
Millet	183,922	Stalk		5.53	1,017,088	0.50	508,544
Sorghum	287,069	Stalk		4.75	1,363,576	0.50	681,788
Groundnut	479,252		Husks/ Shells	0.35	167,738	0.80	134,191
Groundnut	479,252		Straw	1.73	829,106	0.35	290,187
Cowpea	240,825		Straw & pods	6.37	1,534,057	0.35	536,920
Cassava	14,368,535	Stems/ stalk		1.24	17,816,984	0.50	8,908,492
Cassava	14,368,535		Peelings	0.34	4,885,302	0.20	977,060
Plantain	3,681,078	Trunks/ Leaves		0.50	1,840,539	0.80	1,472,431
Soybean	164,511	Straw & pods		3.50	575,788	0.35	201,526
Yam	6,323,782	Straw		0.50	3,161,891	0.35	1,106,662
Cocoyam	1,345,149	Straw		0.50	672,575	0.35	235,401
Sweet Potato	43,834	Straw		0.50	21,917	0.35	7,671
Oil palm	2,196,096		EFB	0.23	505,103	0.80	404,082
Oil palm	2,196,096		Kernel shells	0.065	142,746	0.80	114,197
Oil palm	2,196,098		Fibre	0.14	307,454	0.80	245,963
Coconut	297,900		Husks	0.419	124,820	0.80	99,856
Coconut	297,900		Shells	0.12	35,748	0.80	28,598
Sugarcane	145,000	Leaves		0.113	16,313	0.80	13,050
Sugarcane	145,000		Bagasse	0.20	29,000	0.80	23,200
Cotton	26,500	Stalks		2.755	73,008	0.80	58,406
Cocoa	903,646	Pods		1.00	903,646	0.80	722,917

4.3.2.1 Residue from Cereals

Residues available from cereals include stalks from maize and millet, husks from maize and rice, straw from rice and sorghum, and cobs from maize. Among the cereal residues, maize residues are the most abundant as maize is cultivated in almost every district in Ghana and is intercropped with a range of other crops such as vegetables, cocoyam, legumes or even yam depending on the location. In terms of regional distribution, rice is the next most cultivated crop in the country. Even though rice is not found in every district, it is cultivated in all the ten regions. Millet and sorghum are available mainly in the three northern regions and the quantities produced are minimal compared to maize and rice. Next to cowpea, millet and sorghum are among the least cultivated crops considered in this analysis.

4.3.2.2 Residues from Roots, Tubers and Plantain

Residue available from roots and tuber crops include straw, peelings and stem/stalk. Cassava is the dominant crop in this category in terms of output and it is cultivated in eight of the ten regions in the country. The large production of cassava is partly the result of a cassava improvement programme – the ‘Root and Tuber Improvement and Marketing Programme’ (RTIMP) [7] – supported by the International Fund for Agricultural Development (IFAD) and the Government of Ghana (GoG) through the Ministry of Food and Agriculture. The RTIMP is seeking to develop downstream activities like processing and marketing of cassava in order to ensure that farmers reap

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[7] The programme is a follow-up of the Root and Tuber Improvement Programme (RTIP) which was implemented from 1999 to 2005. RTIMP is being sponsored for a period of 8 years (2007-2014) and was expected to be implemented across 60 districts but this has now been scaled up to 90 districts.

the full advantages of higher yields and production. The programme has encouraged *gari*[8] production in most communities in southern Ghana where medium- to large-scale production of *gari* takes place, often in centralised locations within the community. In these communities, heaps of cassava peels are piled up and readily available for energy purposes.

Yam and cocoyam are also very important crops in Ghana and are cultivated in most of the regions. Sweet potato is cultivated mainly in the northern parts of the country and is the least available tuber crop. The straw from these crops is available after harvest for collection and use for energy production. With regards to plantain, there is presently not much local use for the trunks, apart from minimal uses as erosion control material, and its use as an energy raw material could therefore be explored.

4.3.2.3 Residue from Legumes

Groundnut is the most cultivated legume in the country, followed closely by cowpea and soybean. These crops are mainly available in the three northern regions with very little cultivated in the southern parts of the country. Both straw and shells/husks may be obtained from these three leguminous crops. It is possible to obtain the shells from these crops because shelling or dehusking is done before the crops are transported to their point of sale.

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[8] *Gari* is a food obtained from the roasting of cassava flour.

4.3.2.4 Residue from Oil Crops

Oil palm is the predominant oil crop in Ghana, followed by coconut. Residues from these two crops include empty fruit bunches (EFB) for oil palm, shells, fibre and husk. Because of its importance as an industrial crop, four (4) companies in the country (Ghana Oil Palm Development Company Limited [GOPDC], Benso Oil Palm Plantation [BOPP], Twifo Oil Palm Plantation Limited [TOPP] and Norpalm Ghana Limited [NOPL]) produce more than 30% of the total oil palm in the country, based on data from the Ministry of Food and Agriculture (MOFA, 2011). Company plantations have centralised processing plants which makes it easier to have the entire residue in one central location for energy production. Coconut plantations in Ghana cover an area of about 57,800 ha, and have average yields of about 5,000 nuts per ha (Duku *et al.*, 2011). The crop is cultivated along the coastal belts of the country and in the Eastern and Ashanti regions. Close to 80% of coconut plantations are in the Western region alone.

4.3.2.5 Residue from Other Crops

Other crops for which residues are available for energy production in the country include sugarcane, cotton and cocoa. Cocoa is cultivated in much larger quantities than sugarcane and cotton. The processing of cocoa begins with the cracking of the pods to expose the beans. The cracking is done either on the farm (in gathered heaps) or within the farming communities and pods become available as residues. Cocoa pods are presently used for the production of soap on small scale and organic potash on a medium scale[9]. However, a lot more remains unused. With Ghana aiming to become the number one cocoa producer in the world, the amount of cocoa pods available are expected to keep increasing and be available for energy production.

Sugarcane is cultivated in very small plantations, mainly in the Central region and in a few districts in the Eastern region. Sugarcane production has seen very little increase in the last decade. Production levels rose slightly from 140,000 t in 2000 to 145,000 t in 2010 (FAO, 2013).

4.3.2.6 Residue uses and management

There are existing uses for most of the crop residues discussed above. This implies that not all of the residues would be available for energy purposes and it is important to take the existing uses into consideration when conducting feasibility studies for energy production purposes. The use of crop residues vary from region to region and depend on several factors such as their calorific values, lignin content, density, palatability and nutritive value. Some crop residues are often left on the farm for re-fertilisation and soil conservation purposes while others are used as cooking fuels. Removing residues such as straw from agricultural fields can decrease humus content, cause degradation of soil structure with additional negative influences on erosion of soil and plant nutrients, and reduce the natural pathways of plant nutrients, especially nitrogen mineralization (Blanco-Canqui and Lal, 2009). As a consequence, a great reduction in soil fertility occurs. In most types of soils, lack of organic matter in the soil

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[9] More information about the Organic Potash Corporation can be found on their website, http://www.organicpotash.com/opc/home/

significantly decreases earthworm population and in consequence available nitrogen and other nutrients (Blanco-Canqui and Lal, 2009). Residues of most of the cereals and peelings of tubers have fodder value.

It is difficult to estimate existing uses of residues at a national level. Considering Ghanaian households' lifestyle and production systems, it is very likely that a significant portion of the residues identified here are already in use as livestock feed, on farm applications, or for cooking and water heating. These uses are site specific and require detailed analyses for any proposed project. Residues of plantain and cassava, especially, are used to feed goats and sheep. In the northern savannah zone, the use of crop residue as cooking fuel is widespread. In Chapters Six and Seven, existing use from specific cases are discussed, based on case studies.

4.3.3 Geographical Distribution of Residues

4.3.3.1 Regional Distribution of Residues

A summary of regional residue potential is presented in Table 4.7 and the detailed results shown in Appendix 2. The Northern, Brong Ahafo and Eastern regions have the highest potential in terms of total residues. Together they account for more than 58% of the crop residues available in the country; this figure roughly corresponds to their share of Ghana's total land area, which makes residue distribution density very important.

Table 4.7 ranks the regions according to their residue densities, expressed as the total amount of residue per square kilometre. The Eastern, Central and Upper East regions have the highest crop residue densities, with levels at or above 100 t of residues per square kilometre (t/km^2). The Greater Accra, Western, Northern and Volta regions have lowest densities, with, less than 60 t/km^2. The Greater Accra region has the lowest crop residue density due to its urban characteristics. The Eastern and Brong Ahafo regions rank among the top five regions for both total residues and residue densities and therefore make interesting cases for further study and more detailed district level analysis.

Table 4.7: Summary of regional crop residue availability

Region	Residue total (t)	Residue Density (t/km^2)
Eastern	2,943,424	158
Central	1,191,286	124
Upper East	842,322	100
Brong Ahafo	3,647,669	96
Ashanti	1,952,738	81
Upper West	1,301,397	72
Volta	1,172,363	57
Northern	3,780,136	56
Western	902,252	40
Greater Accra	67,622	21

The high level of residues production and residue density in the Eastern and Brong Ahafo regions can be attributed to the high production of maize, cassava, plantain, yam and cocoyam in the regions. Together these two regions account for 47% of maize residues; 47% of cassava residues; 52% of plantain residues; 45% of yam residues and 44% of cocoyam residues production in the country. The two regions are in the forest and transitional zones with high agricultural activities which explain the high production of these crops.

4.3.3.2 District Level Analysis of Residues

Figure 4.3 shows crop residue generation by district and illustrates the spatial distribution of residues within the country. Districts with high residue potentials are located in the Eastern, Brong Ahafo and Northern regions. Districts in the Greater Accra, Western, Central and Volta regions tend to have lower potential for residues. Because districts vary with respect to sizes, residue densities were computed in each of the districts to examine which ones have higher residue densities. Districts in the Eastern and Brong Ahafo region have the highest density of residue generation, followed by the Central region (see clusters in Figure 4.4). A few districts in the Ashanti and Northern regions have higher concentration of residues even though the bulk of the districts in these regions have quite low residue levels. The same applies to the Western and Volta regions.

The greatest amount of residue is produced in the Afram Plains, which is one of the major agricultural production districts in Ghana. About 450,000 t of residue from different crops is produced annually from the Afram plains alone. This is followed by Yendi, West Gonja, Techiman, Sene, Nkwanta, Asutifi, Fanteakwa, East Gonja, Savelugu Nanton and Nkoranza, in that order. The Accra Metropolis produces the least amount of residues (just 198 t per annum).

Cape Coast district has the highest crop residue density with about 580 t/km^2. This is followed by Awutu/Efutu/Senya (402 t/ km^2), New Juaben (360 t/km^2), Fanteakwa (303 t/km^2), Techiman (296 t/km^2), West Akim (295 t/km^2), Tamale (287 t/km^2), Asunafo South (284 t/km^2), Nanumba South (251 t/km^2) and Komenda/Edna

Eguafo/Ebire (243 t/km^2). Of the top 20 districts with high residue densities, the Eastern Region alone has 10 districts. The Brong Ahafo and Central regions have 3 districts each in this category.

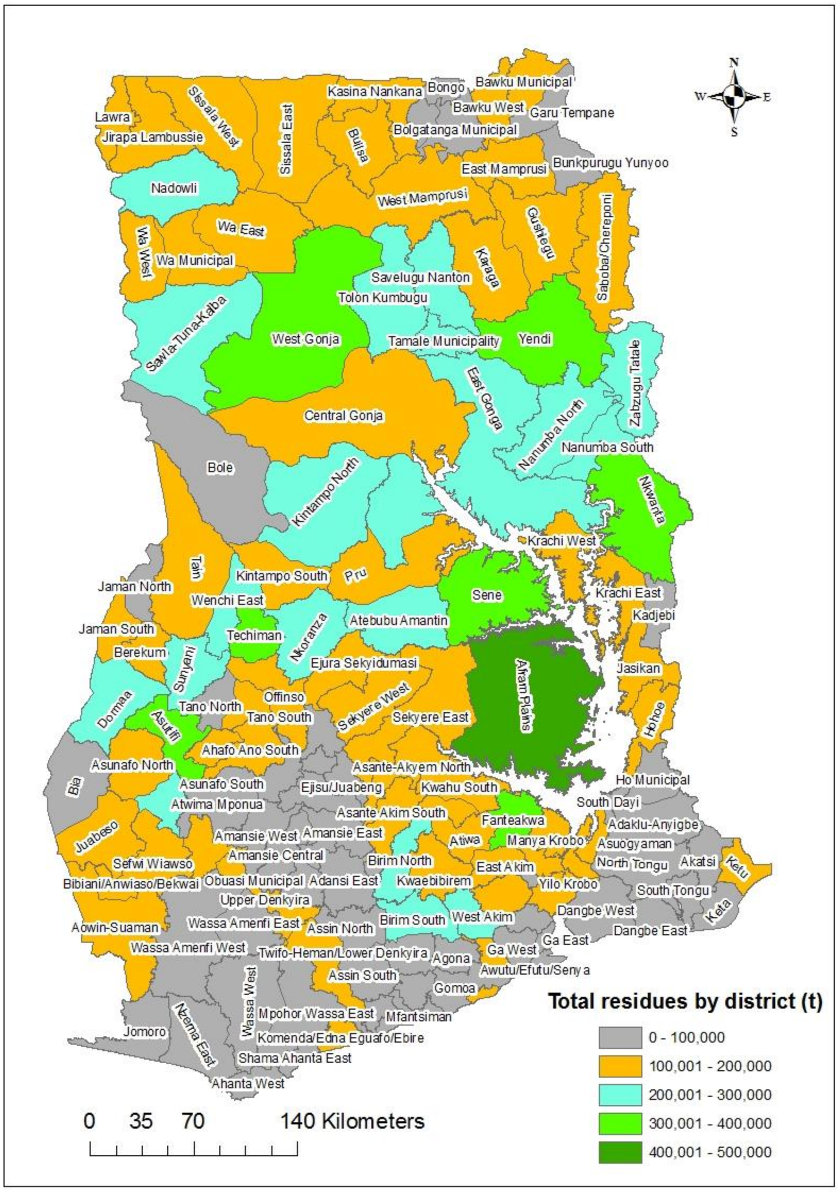

Figure 4.3: Residue generation at district level, 2011 (t)

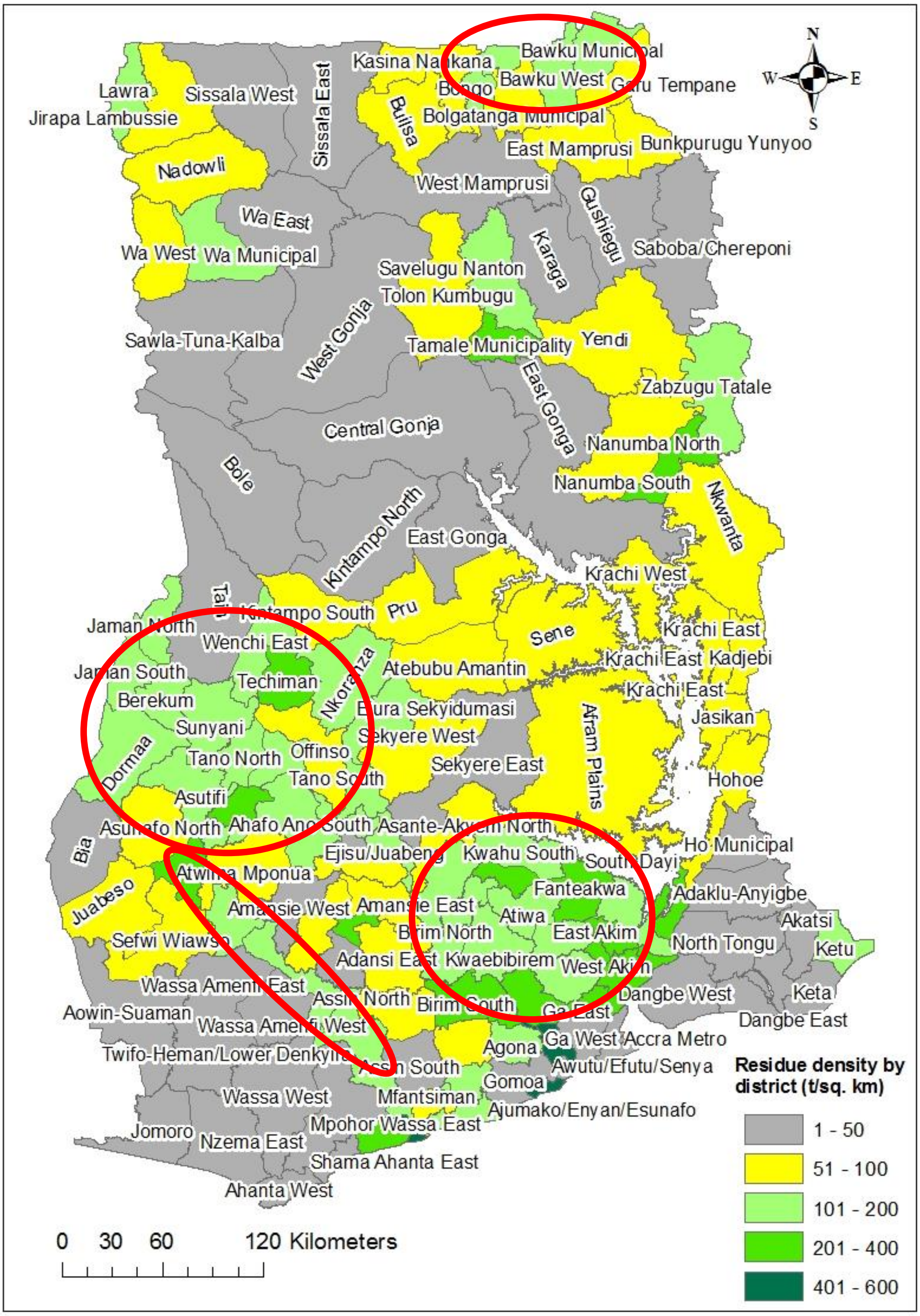

Figure 4.4: Residue generation density at district level, 2011

Expanding this to include all districts with residue densities more than 100 t/km^2 brings the total number to 57 districts (see Appendix 3). The Eastern region has 16 districts in this category followed by the Brong Ahafo region with 12 districts and Ashanti region with 9 districts. Figure 4.4 indicates that districts in the Ashanti, Brong Ahafo, Central and Eastern regions have higher residue densities. Districts in these four regions also share common boundaries and could, in the future and depending on national plans, be studied in more detail for the location of centralised plants that could use resources from these four regions.

4.3.4 Livestock Manure

The most important livestock types raised in Ghana, with regards to numbers, are cattle, sheep, goats, pigs and poultry (mainly chicken). Livestock are either reared extensively using pasture, which is suitable for small-sized farms for specific livestock or are raised in concentrated feeding, as practiced in large and medium-sized livestock farms. Just like for crop residues, not all the manure produced by livestock is available for collection and use. In most parts of Ghana, cattle are allowed to graze in open fields and hence, manure produced during grazing periods cannot be collected. Some cattle are used as draught animals for agricultural operations and their manure cannot be collected. It could therefore be assumed that for half the day, manure produced from most cattle is not recoverable. It has also been established that cattle breeds reared in Ghana and many other West African countries are small and undernourished, with less manure production as compared to better fed cattle breeds (KITE, 2008). Non-commercial sheep and goats are also mostly kept on free range and allowed to stable around farmer residences at night which implies that manure may only be available for collection at night. Chicken and pigs are, to a large extent, kept on an intensive farming system. Manure produced from poultry and pigs should be more easily recoverable as compared to the first three. Using these factors, recoverability fractions have been assumed for the five main livestock types identified. Table 4.8 presents the technical potential of livestock manure available in Ghana in 2011.

Table 4.8: Availability of livestock manure in Ghana in 2011

Type of Livestock	Population	Estimated amount of manure available per head per day (kg)	Recoverability Fraction	Manure available per annum (t)
Cattle	1,498,000	12	0.2	1,312,248
Sheep	3,887,000	1.2	0.2	340,501
Goats	5,137,000	2	0.2	750,002
Pigs	568,000	3.6	0.5	373,176
Poultry	52,575,000	0.02	0.5	191,899

Source: Livestock population data from MOFA (2012); Recoverable fraction estimated; Estimated daily manure amount is from Kartha and Larson (2000).

Although manure from all the livestock types listed in Table 4.8 is used for biogas production, cattle and pig manure have been most commonly used because of the higher manure and methane produced per livestock which implies that a family sized livestock farm is enough to produce biogas for a household. In India, it is reported that four to five cattle is enough to feed a 2 m^3 household biogas plant (Dutta *et al.*, 1997).

4.3.5 Household / Municipal Solid Waste

Municipal solid waste (MSW) is often considered a potential low cost feedstock which can be used to produce biogas and electricity. MSW streams are collected from households, industries and commercial market places. Conversion of MSW to biogas and/or electricity can be an alternative, sustainable approach to disposal of waste and reduction of the biodegradable and other important fractions of the MSW to dumpsites.

The amount of MSW collected in Ghana exceeded four million tonnes in 2011 (Table 4.9), constituting less than 80% of the waste generated by households in the country. Organic (biodegradable) fraction of MSW is usually over 60% (Asase *et al.*, 2009; Boadi and Keitunen, 2004), with moisture content of about 39-62% (Carboo and Fobil, 2004). Due to this high moisture content, the calorific value or mean gross energy of the waste is said to be as low as 16.95MJ/kg (Carboo and Fobil, 2004).

Table 4.9: MSW collected by each region of Ghana in 2011

Region	Annual MSW Collected in 2011 (t)
Greater Accra	1,126,755
Ashanti	960,425
Eastern	544,233
Brong Ahafo	515,161
Central	465,266
Volta	210,262
Western	202,502
Northern	173,229
Upper East	95,101
Upper West	93,385
TOTAL	4,386,318

Source: Unpublished data from Zoomlion Ghana Ltd., 2012.

4.4 Energy Potential of Identified Bioenergy Feedstock

A summary of the energy potential of the various bioenergy feedstock sources is presented in Table 4.10 with details in Appendix 4. Biomass waste resources generated in the country in 2011 had a total energy potential of approximately 275 PJ. Energy potential of cassava residues alone constitute about half of this potential. Energy potential from cereal residues also account for about one-seventh of the total potential. The total energy potential of biomass is slightly higher than the total final energy consumed in Ghana in 2012 which amounted to 268 PJ.

Table 4.10: Energy potential of identified residues

Biomass type	Residue amount (wet tonnes)	Residue amount (dry tonnes)	Energy potential (PJ)
Cassava residue	9,885,552	7,908,442	135.18
Cereals residue	3,281,471	2,259,308	38.94
Legumes residue	1,162,824	970,997	15.27
Cocoa residue	722,917	614,479	9.51
Oil palm residue	764,242	428,854	6.34
Other crops residue	3,045,275	1,431,519	18.15
Municipal solid waste	4,386,318	2,193,159	37.17
Livestock manure	2,967,826	519,120	9.79
Wood residue	606,000	303,000	4.80
Total energy potential			**275.16**

Table 4.11: Biomass energy potential projected to 2030

Biomass type	**2015**	**2020**	**2025**	**2030**
Cassava	148.33	192.86	234.57	267.23
Cereals	43.1	60.14	77.87	93.23
Legumes	7.41	8.16	8.99	9.92
Cocoa	27.4	30.88	34.8	39.22
Oil palm	12.65	13.35	14.1	14.88
Other crops	79.59	116.3	153.14	183.7
Municipal solid waste	44.15	52.19	60.51	70.14
Livestock manure	11.59	14.36	17.39	21.4
Wood residue	4.8	4.8	4.8	4.8
Total energy potential	**379.02**	**493.04**	**606.17**	**704.52**

However, it is lower than the total primary energy supply of 348 PJ in the same year. For planning purposes, it is also important to estimate energy potentials of feedstock sources into the future. Summary of the projection for 2015 to 2030 is shown in Table 4.11. These potentials can be made available for use as different energy carriers such as ethanol, biogas and electricity. In chapter Five, the extent to which these resources can contribute to the energy mix in Ghana is investigated.

4.5 Sustainability Challenges

Although it has been shown in the analysis that Ghana has high technical potential for residue based bioenergy, there are sustainability challenges to producing bioenergy on this scale. A transition to modern bioenergy should not be done without a thorough discussion of likely socio-economic and environmental consequences. Based on the identification of key issues related to the sustainability of bioenergy production, some general recommendations to guide sustainability assessments are presented.

The sustainability of bioenergy production is influenced by several interrelating factors as indicated in Figure 4.5. These include:

- The continued flow of feedstock to the energy conversion stage which, in turn, is dependent on the reliable supply of inputs in the biomass production, transport and/or processing stage(s);
- The emissions to the environment related to production and transport of feedstock as well as from the conversion stage;
- The resulting outputs' ability to replace fossil-based and traditional biomass energy carriers and thereby realize actual reductions in non-renewable resource use and emissions;
- The ability of the applied technology and practices to re-cycle nutrients in order to avoid soil degradation and reduce the use of non-renewable inorganic fertilizer;
- The ability of projects to make use of local resources including labour to facilitate societal support and improve resilience to changes in external support;
- The use of practices that do not undermine the social, environmental and economic foundations that the projects are based on.

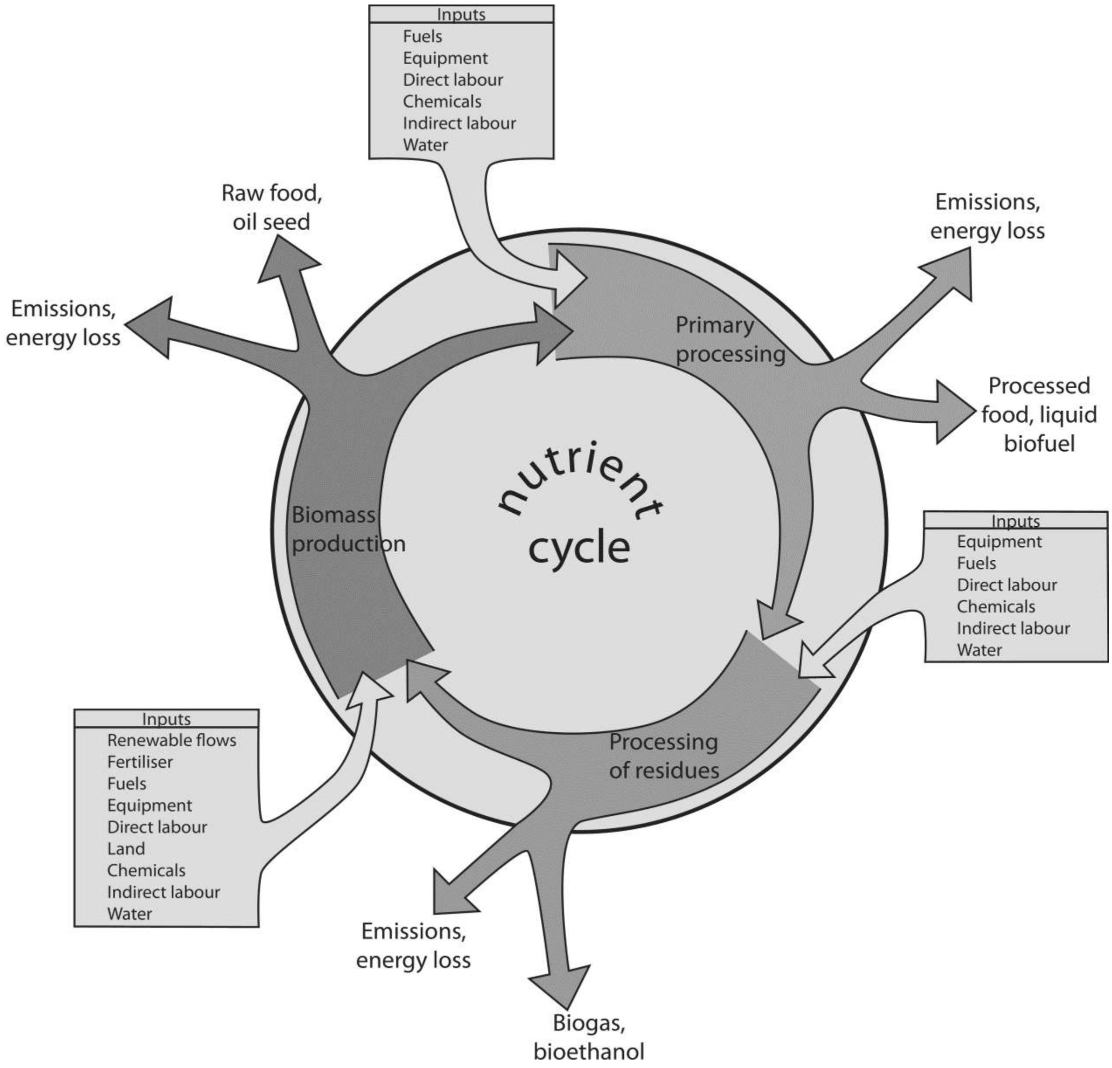

Figure 4.5: Conceptual overview of life-cycle approach to bioenergy
Source: Kemausuor et al., 2014.

The ability of bioenergy production to contribute to energy supply should be assessed through the calculation of net energy output or energy return on energy invested (Murphy *et al*., 2011, Giampietro and Mayumi, 2009). Energy inputs should be considered in a life-cycle perspective and ideally, be categorized according to origin (fossil or renewable) to highlight how dependent bioenergy production is on non-renewable energy resources. Moreover, assessing the degree to which energy inputs are from local and/or domestic sources can indicate the project's dependence on imports.

Bioenergy projects should be evaluated on their ability to create employment, generate income for local society and in general improve the livelihood of people involved in and affected by the development (EPFL, 2011). General socio-economic indicators include: expanded access to modern energy services, contribution to local economy, job creation, change in the food basket price, change in income, land use changes and effects for users, effect in changes in traditional uses of residues, and smallholder integration.

Altering agricultural practices, e.g. through the removal of residue biomass may affect agro-ecosystem functioning and could possibly increase the susceptibility of agro-ecosystems to diseases and pests, especially in large-scale plantations. Since this may undermine the sustainability of ecosystem function, bioenergy projects should be assessed to indicate the impacts on biodiversity. Assessing biodiversity is complex and no straightforward method with easily calculated indicators is available at present. Attempts to establish a common framework are made however, e.g. by the Roundtable on Sustainable Biofuels (EPFL, 2011) who provides extensive guidance on conservation measures that also encompass the maintenance of biodiversity. By carrying out sustainability assessments, the impacts of bioenergy production can be modelled and estimated, both quantitatively and qualitatively.

In order for assessments of Ghanaian bioenergy production projects to be comparable and thereby ease decision-making, a reasonable degree of consistency in methods is recommended. Choosing among the approaches and indicators, however, can be overwhelming. As a starting point in the development of a framework for carrying out systematic and compatible assessments of environmental and socio-economic consequences of bioenergy production, a compilation of guiding principles is provided. A more detailed discussion can be found in the Roundtable on Sustainable Biofuels guidelines (EPFL, 2011), Markandya and Halsnaes (2002) discussion of sustainable development assessment in Clean Development Mechanism (CDM) projects, and Giampietro and Ulgiati (2005) discussion on integrated assessment of biofuel production. Sustainability assessments of bioenergy projects should:

- Be considered in a life-cycle perspective (European Commission, 2010) and preferably with a consequential approach that takes alternative land use and likely ability of bioenergy carriers to substitute for alternatives into account;
- Focus on quantitative indicators to facilitate comparison;
- Include up- and downstream indicators from several categories to reflect the range of effects and the amount of stakeholders involved;
- Contain sensitivity analyses that emphasize the (highly) unstable economic environment of Ghana's economy and its dependence on oil, inorganic fertilizer and other non-renewable inputs; and
- Be transparent with respect to assumptions made.

Apart from addressing environmental impacts on the global scale, e.g. GHG emissions, the choice of indicators should reflect the conditions in the region where a specific bioenergy project is carried out. Site-specific problems of e.g. drought, deforestation, soil erosion, water pollution and/or potable water scarcity should be addressed with appropriate environmental sustainability indicators where those problems are present.

4.6 Summary of Findings

This chapter estimated biomass resource potential in Ghana. The estimation was limited to agricultural residue, livestock manure, municipal solid waste and wood waste, and based on assumptions and factors that relate to production statistics. The contribution of agricultural residues, livestock manure, municipal solid waste and wood waste could play a valuable role in transportation fuel provision, cooking fuels and stand-alone electricity applications and be particularly effective for households in remote rural areas.

Agricultural residues are concentrated in districts in the Brong Ahafo and Eastern regions. In these two regions, between 101 and 400 t of agricultural residue is found within every square kilometre space with maize and cassava residues being the major residue types. In contrast, districts in the Northern, Western, and Volta regions have lower residue density, with about 1-50 t of residue located within a square kilometre space.

The local production and use of biomass resources as substitute for fossil-based fuels offers many attractive benefits for Ghana. The socio-economic benefits include opportunities for attracting investment, job creation, rural development, and poverty reduction. The resources considered in this chapter have an estimated energy potential of approximately 275 PJ, compared to 268 PJ total final energy consumed in Ghana in 2012. It should be emphasised, however, that not all of this potential would be available as useful energy when conversion efficiency is considered. In the next chapter, possibilities for utilising these resources for the production of appropriate energy carriers is investigated.

CHAPTER FIVE

5.0 MODELLING ENERGY DEMAND AND SUPPLY WITH EMPHASIS ON BIOENERGY USE IN GHANA

5.1 Introduction

Although bioenergy has a lot to offer in Ghana's energy mix, existing energy plans by relevant agencies have failed to capture the extent of this support (Ministry of Energy, 2006; Energy Commission, 2006). The newly approved Renewable Energy Act, combined with increasing demand for energy has created an opportunity for dramatic changes in the way energy will be generated in Ghana. However, the impending changes and their implication remain uncertain. This chapter examines the extent to which future energy scenarios in Ghana could rely on modern biomass energy. The analysis in this chapter is based on a moderate and high use of bioenergy in the transportation, electricity generation and residential fuel use sectors in order to determine their possible impacts on Ghana's energy system. Indicators of interest in this chapter are: bioenergy substitution of fossil fuels; bioenergy substitution of traditional biomass; change in diversity of energy supply and environmental benefits (GHG emission reduction).

5.2 Methodology

A number of energy modelling tools were initially considered as possible modelling tools for this part of the study. These are: Invert, Market Allocation (MARKAL), Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) and Long-Range Energy Alternatives Planning (LEAP) model.

The analysis was conducted using the Long-Range Energy Alternatives Planning (LEAP) model.

Invert is used to simulate national energy-systems and can be run for up to a 25-year period, using one-year time-steps, and it accounts for all sectors of the energy system (Connoly *et al*., 2010). Invert is able to model most generation plants but cannot model wave and tidal energy. It is also unable to model energy storage/conversion technologies. It has a specific focus on the analysis of heating systems and its core objective is to model the effects of policies and promotional schemes such as feed-in-tariffs, subsidies and soft loans on a country's energy system.

MARKAL is a general purpose model that can be applied at the global, multi-regional, national, state/province, or community level. Each annual load duration curve, and hence each annual variable can be detailed by as many user-defined time slices as desired at three levels: seasonal (or monthly), weekdays/weekends and hour of the day (Connoly *et al*., 2010). MARKAL can model all generation, storage/conversion, and transportation technologies.

MESSAGE is a tool used for the planning of energy-systems, analysing climate change policies, and building scenarios for national or global regions (Connoly *et al*., 2010). The tool uses a 5 or 10 year time-step to simulate a maximum of 120 years. MESSAGE can model all generation, conversion, and transportation technologies as well as costs implications and carbon sequestration. MESSAGE has the capability to determine cost-effective portfolios of GHG emission limitation and reduction measures (Connoly *et al.*, 2010).

LEAP is a scenario-based energy-environment modelling tool for energy policy analysis and climate change mitigation assessment. LEAP can be used to track energy consumption, production and resource extraction in all sectors of an economy as well as account for GHG emissions from energy demand and conversion (Bautista, 2012; Shin *et al.*, 2005; McPherson and Karney, 2014). The model was developed by the Stockholm Environment Institute (SEI-US), based in Boston, Massachusetts[10]. LEAP can be applied at different scales ranging from cities and states to national, regional and global applications (Suganthi and Samuel, 2012).

For this particular study, the LEAP model was chosen because it suits the aim of this present study for the following reasons: i) it is well suited to tracking energy demand and transformation in developing countries, ii) it is scenario-based and integrated with energy-environment model building tool, so that both energy demand and its environmental implications can be tracked within the same platform, iii) it includes a Technology and Environment Database (TED), which compiles technical characteristics and environmental impacts for range of energy technologies, including both advanced technologies for developed countries and conventional technologies found in developing countries, iv) it is flexible with regards to data availability and has low initial data requirement which can be improved as detailed data becomes

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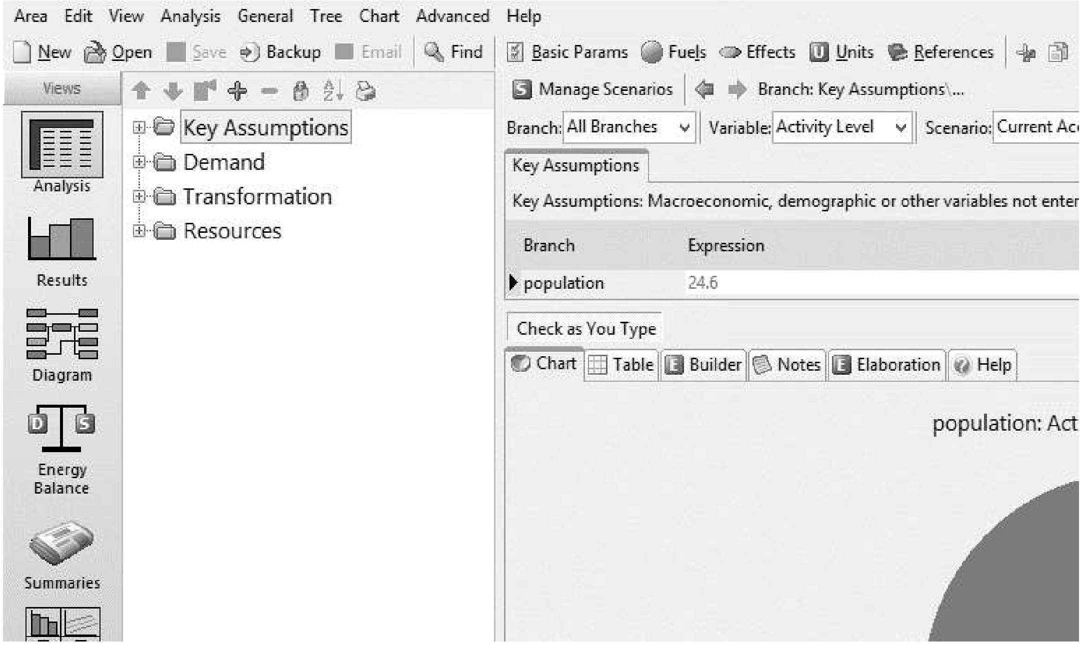
[10] Details about the LEAP software can be found in http://sei-us.org/software/leap

available for the study location, and v) it is free to use for developing country researchers and government agencies.

In order to project energy demand for the future, LEAP uses a base year, for which extensive data is available. The base year used for this thesis is 2010 – the last year in which a national population and housing census was conducted in Ghana. Energy demand is projected from 2015 to 2030. Historical data from the 2010 census and other relevant energy databases in the country were used in the 2010 base year.

5.2.1 Data Requirements

The input data for the LEAP model are grouped into four categories called modules (Figure 5.1). The four modules are the 'Key Assumptions' module, 'Demand' module, 'Transformation' module and 'Resources' module. The 'key assumptions' module entails information on demographics (such as rural and urban population, population growth rates for rural and urban communities, and rural and urban household size), macroeconomic data (GDP and GDP growth rate) and other relevant data needed for modelling. The 'demand' module requires information on sector activities and energy intensity. Energy demand of a particular sector is computed as the product of an activity level measuring the level of energy service provided (such as number of households, passenger-km of transportation, output of an industry, etc.) and an energy intensity. The demand module can be disaggregated into several 'branches' depending on the level of data disaggregation available. Because each sector is composed of subsectors with different energy consumption structures, the most important subsectors are broken down to estimate their consumption. The sectors taken into account for this modelling are: Households (or residential), Agriculture, Industry, Transport, Non-residential and Street Lighting. Each of these branches was further disaggregated into ‘sub-branches’. Household sector is disaggregated into urban households and rural households. Urban households are further disaggregated into ‘Metro Urban’ and ‘Other Urban’, in line with energy data compilation from the 2010 population and housing census and a national energy survey conducted by the Energy Commission in the same year. Rural areas were subdivided into coastal, forest and savannah rural, defined by the various agro-ecological zones in the country. Due to the different agro-ecological zones, population dynamics and affluence of these rural areas, there are different patterns in fuel consumption. Based on historical data from the Ghana Statistical Services, the coastal and forest areas of the country tend to have higher population densities than the savannah areas. Other sectors have also been disaggregated based on data availability.



Branch: All Branches
Variable: Activity Level
Scenario: Current Ac

Key Assumptions: Macroeconomic, demographic or other variables not enter

Branch	Expression
population	24.6

Figure 5.1: Leap model interface

In the 2010 base year, the ‘transformation’ module is mainly composed of electricity generation, oil refining and charcoal production, consistent with energy consumption pattern in that year. In other scenarios and where appropriate, the transformation module also includes categories for the production of biodiesel, ethanol and biogas. Data on electricity generation plants, oil refinery and charcoal production methods were obtained from the Energy Commission (Energy Commission, 2013). The ‘resource’ module builds energy resource requirements based on data input in the transformation module. In the 2010 base year, resources include crude oil for the refinery, fuels for electricity generation and wood for charcoal production. The resource module provides energy supply options and their implications for carbon emissions.

5.2.2 Scenario Analysis

To project energy demand from the 2010 base year, three energy scenarios were developed – a reference (or business-as-usual) scenario and a moderate and high bioenergy scenarios. The reference scenario projects energy demand and supply options using a business-as-usual approach. The moderate and high bioenergy scenarios were characterised primarily by increasingly aggressive infusion of bioenergy into the energy mix.

5.2.2.1 Reference Scenario

The reference scenario examines how Ghana’s energy system might evolve up to 2030 in the absence of significant new policies for bioenergy. Demand projection for energy is dependent on projected GDP and population growth. Based on the growth projections, it is expected that the number of households in Ghana will increase from 5.5 million in 2010 to about 8.4 million in 2030 (Ghana Statistical Services, 2012). Energy demand for urban areas differs from rural areas in types of fuel and amount consumed. Urban communities are defined by the Ghana Statistical Service as communities with population above 5000. In 2010, Ghana had more than half of households (56%) living in urban areas. In 2030, it is expected that 65% of the projected 8.4 million households will be urban. This will increase energy consumption and also serve as a driver for an increased use of modern fuels, such as electricity for lighting and LPG for cooking. With regards to transportation, passenger-km is expected to grow at an annual rate of 6%. Road transportation is currently the dominant transport mode. However, the share of road transportation is projected in the model to decrease from 95% in 2010 to about 80% in 2030 with rail and air transport accounting for the remaining 20%.

In the reference scenario, electricity generation is based on the ‘Generation Master Plan Study for Ghana’, a study by Tractebel Engineering for the Ghana Grid Company Limited (GRIDCO, 2011). The study developed a 15 year electricity generation plan which is aimed at guiding investment in generation for both the public and private sector. Oil refining capacity is based on the capacity of the country’s only oil refinery. Charcoal production in the reference scenario starts with existing methods of producing charcoal in Ghana, predominantly the earth mound method. Going forward, it is assumed that improved charcoal kilns will be introduced gradually and account for 20% of charcoal output by 2030.

5.2.2.2 Environmental Effect / GHG Emissions

GHG emissions for the reference scenario were estimated for energy demand and also for energy transformation or conversion. Estimation for energy demand captures all non-biogenic emissions. Non-biogenic emissions are those emissions from fuels of non-biological origin and include emissions from fossil fuels used in transportation and other sectors such as industry and agriculture. The analysis uses a straightforward accounting methodology in which emissions of different pollutants are calculated as the product of fuel combustion and an emission factor, following the methodology prescribed by the Intergovernmental Panel on Climate Change (IPCC, 2006). Estimation for energy transformation or conversion captures non-biogenic emissions from the use of fossil fuels to generate electricity, using the generation fuel sources from individual generation plants. Biogenic emissions, which are emissions emanating from fuels of biological origin (e.g. burning of firewood and charcoal) have not been computed in this study. The issue of equating biogenic emissions to emissions from fossil fuels is one that is still very much debated (Gunn *et al.*, 2012). Indeed, this study relies on the IPCC methodology for computing emissions (IPCC, 2006) which does not attribute biogenic emissions to the energy sector.

5.2.2.3 Bioenergy Scenarios

Next to the reference scenario are two bioenergy scenarios, a moderate bioenergy scenario and a high bioenergy scenario. These two scenarios assume bioenergy infusion into Ghana’s energy mix. A number of technologies could be deployed which could utilize biomass as feedstock for the production of desired energy forms for the country. Table 5.1 summarizes the technology options that could allow the substitution of bioenergy fuels for fossil fuels.

Table 5.1: Possible technology options that allow fossil fuels to be substituted with biomass based fuels

Feedstock	Energy production	Energy conversion	Substituted fuel
*Electricity generation**			
Municipal solid waste	Land fill gas capture	Gas turbine/ Internal Combustion Engine (ICE)	Natural gas/crude oil
Wood waste	Combustion / Gasification	Steam turbine/ Gas turbine	Natural gas/crude oil
Oil palm waste	Combustion / Gasification	Steam turbine/ Gas turbine	Natural gas/crude oil
Transportation			
Crop residues (cereal waste, cassava waste, etc.)	Ethanol fermentation	ICE	Gasoline
Energy crops (cassava, sugarcane, etc.)	Ethanol fermentation	ICE	Gasoline
Energy crops (jatropha, sunflower, etc.)	Biodiesel refinery	ICE	Diesel
Cooking fuel			
Animal manure and crop residue	Biogas digester	Biogas stoves	Firewood and charcoal

*Some wood and oil palm processing companies already produce electricity from residues using combustion technology. The technology is feasible in the country but some scaling up and advanced combustion technology may be needed to increase generation capacity and efficiency.

The high bioenergy scenario is an increased use of bioenergy compared to the moderate bioenergy scenario. The assumptions are based on Ghana's Strategic National Energy Plan (Energy Commission, 2006), the Draft Bioenergy Strategy Document (Energy Commission, 2010), Ghana's SE4ALL Action Plan (Government of Ghana 2012) and own assumptions. In the moderate bioenergy scenario, it is assumed that 0.1% of households in non-metro urban households would switch to biogas as one of their cooking fuels, rising to 2% by 2030. A higher number of households in rural communities would be expected to switch to biogas, reaching 10% by 2030. With regards to transport, an estimated 10% of road passenger transport would use biodiesel and ethanol by 2030 while 10% of rail transport[11] and road freight transport is to rely on biodiesel. Electricity from biomass resources is assumed to be generated from municipal solid waste, wood waste, oil palm waste and cocoa waste. The share of improved charcoal carbonisation technologies would increase in the bioenergy scenarios, contributing 35% and 60% respectively to charcoal output in the moderate and high bioenergy scenarios. There would also be a gradual uptake of improved cookstoves, beginning with just 0.1% national penetration in 2015 to 5% in the moderate bioenergy scenario and 10% in the high bioenergy scenario. Other assumptions that make up the bioenergy scenarios are summarised in Table 5.2. Apart from the production of biodiesel, all bioenergy types are assumed to be produced from lignocellulosic biomass sourced from within the country.

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[11] Even though modern rail transport relies on electricity, Ghana currently runs an intercity train on diesel. At the current pace of infrastructural development, it is not expected that Ghana would turn to electric trains anytime soon.

Table 5.2: Highlight of assumptions in the different scenarios

Feedstock	**Reference Scenario**	**Moderate bioenergy**	**High bioenergy**
Electricity generation			
Municipal solid waste Wood waste Oil palm waste Cocoa	No contribution to electricity generation	Combined 1.4 % of electricity generated by 2030	Combined 4.0 % of electricity generated by 2030
Transportation			
Crop residues (for ethanol production)	Road passenger transport (0%)	Road passenger transport (10 %)	Road passenger transport (20 %)
Energy crops (jatropha, sunflower, etc.)	Road passenger transport (0%); rail transport (0%); road freight transport (0%)	Road passenger transport (10%); rail transport (10%); road freight transport (10%)	Road passenger transport (20%); rail transport (20%); road freight transport (20%)
Cooking fuel			
Animal manure and crop residue	Non-metro urban HH (0%); coastal rural HH (0%) all other rural HH (0 %)	Non-metro urban HH (2%); rural HH (10%)	Non-metro urban HH (5%); rural HH (20%)

HH-households

5.3 Results and Discussion

5.3.1 Reference Scenario

5.3.1.1 Energy Demand

The projected final energy demand of Ghana in the reference scenario is summarised in Figure 5.2. The country’s total final energy demand would double between 2015 and 2030, an increase from 329 PJ in 2015 to 644 PJ. Diesel, electricity, woodfuels and gasoline, would dominate fuel demand in the year 2030. Diesel consumption would more than double in the planning period, rising from 89 PJ in 2015 to approximately 203 PJ in 2030. The increased diesel demand is attributed to increases in the transportation, industry and agriculture sectors. Growth in electricity demand would be boosted by increased population and urbanisation. Wood and charcoal would be needed primarily for residential cooking and heating, with the greater part of wood demand coming from rural communities. The major energy demand sectors are transportation, industry and residential sector. Minor demand sectors include street lighting, agriculture and non-residential sector. The transportation sector is expected to become the highest consumer of energy by 2030, followed by the residential sector. In 2030, the transportation sector would account for 50% of total energy demand in the reference scenario. The residential sector would account for 23% of demand. Together, the two sectors account for three-quarters of energy demand.

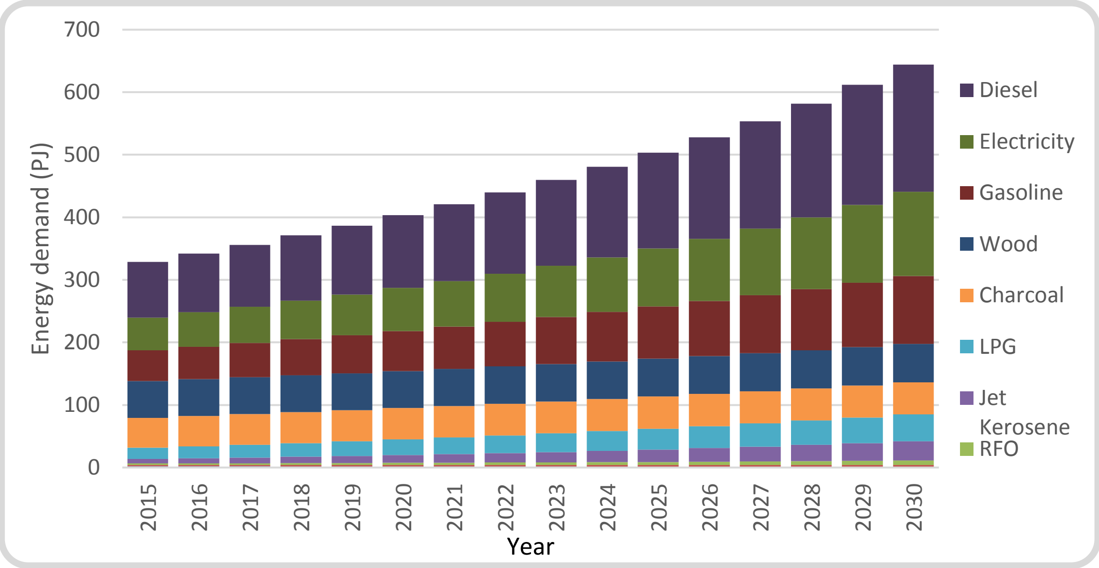

Figure 5.2: Projected energy demand by fuel type

Installed electricity generation capacity is expected to increase from about 3,500 MW in 2015 to nearly 6,000 MW in 2030, which is close to a doubling of generation capacity within the 15 year period, according to the electricity generation master plan. Electricity supply in the reference scenario is assumed to be produced by thermal, large hydro, and renewables comprising solar, wind and small hydro. Currently, fuels for thermal generation are Light Crude Oil (LCO) and natural gas. According to the electricity generation master plan, LCO was to be phased out at the end of 2014 and natural gas used entirely to run thermal plants (GRIDCO, 2011).

Natural gas is currently obtained from the West Africa Gas Pipeline[12] which has proven unreliable, with erratic supply. From 2015 onwards, gas will also be obtained from the country's own gas processing plant (Ghana National Gas Company) that will process gas from oil fields in the country. Figure 5.3 shows projected electricity generation by fuel source from 2015 to 2030. Thermal share of electricity generation will rise to about 63% in 2030, from 46% in 2012. Electricity from renewables will contribute 10% to total electricity generation. In the reference scenario, biomass will not contribute to electricity generation.

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[12] The West Africa Gas Pipeline is a natural gas pipeline that supplies gas from Nigeria to Benin, Togo and Ghana. The pipeline is owned by the West African Pipeline Company (WAGPCo), a consortium of 6 partners. The partners are: Chevron West African Gas Pipeline Ltd., Nigerian National Petroleum Corporation, Shell Overseas Holdings Ltd., Takoradi Power Company Ltd., Societe Togolaize de Gaz and Societe BenGaz S. A.

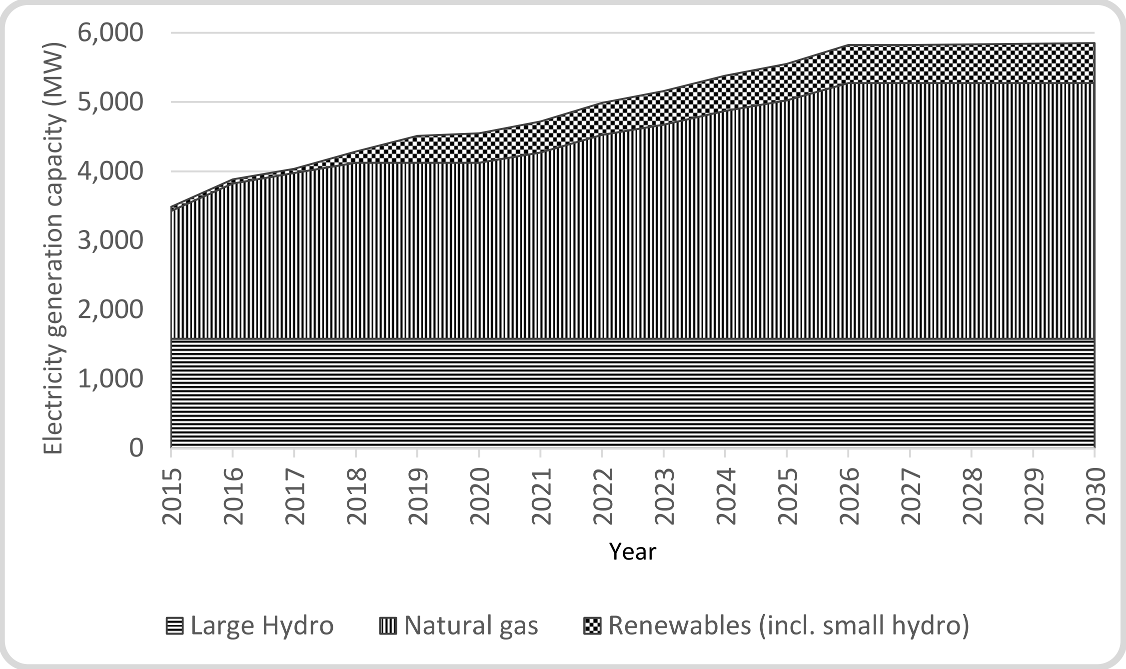

Figure 5.3: Projected electricity generation by source

Source: Modified from GRIDCo, 2011

5.3.1.2 Greenhouse Gas Emissions

Emissions from energy are subdivided into two components. The first component are those emissions that are accounted for at the point of combustion (such as in cars) and are referred to as 'demand side emissions' in this thesis. The second component of emissions are accounted for at the point of transformation (such as electricity generation) and will be referred to as 'transformation emissions'. Figure 5.4 shows GHG emissions[13] arising from demand and transformation. Demand side emissions would more than double between 2015 and 2030, rising from about 12 $MtCO_2eq$ in

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[13] 'one hundred year' global warming potential

2015 to more than 28 $MtCO_2eq$ by 2030. Gasoline and diesel account for more than 80% of demand side emissions. The high contribution from diesel and gasoline is the result of substantial increase in transportation.

Transformation emissions have their source in electricity generation. Transformation emissions would more than triple between 2015 and 2030. From 3.8 $MtCO_2eq$ in 2015, GHG emissions from transformation are projected to exceed 12.45 $MtCO_2eq$ by 2030. Transformation emissions would rise constantly due to an anticipated increase in electricity generation capacity. Electricity generation is projected to increase from 20,000 GWh in 2015 to 43,000 GWh in 2030, out of which about 80% would be delivered by thermal sources[14] compared to an estimated 62% in 2015. This is expected to increase the national electricity grid's carbon intensity from 0.18 tCO_2eq per MWh in 2015 to 0.28 tCO_2eq per MWh in 2030.

The net GHG emission from energy consumption is obtained by summing the emissions from final energy demand and emissions from energy transformation. The final emission in 2030, 40.8 $MtCO_2eq$, is more than twice the emission in 2015 of 16 $MtCO_2eq$. Throughout the planning period, emissions from energy demand would account for between 69-76% of the total emissions per year. Two very important indicators, with regards to emissions, are emissions per capita and emissions per GDP. Based on the projected population growth in the reference scenario, emissions per

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[14] It should be noted that even though thermal generation capacity will reach 63% of total capacity by 2030, actual generation from thermal sources is higher.

capita[15] would double, increasing from 0.6 tCO_2eq in 2015 to 1.2 tCO_2eq in 2030. Emissions per GDP would decrease marginally, from 0.303 tCO_2eq per 1,000 US$ in 2015 to 0.296 tCO_2eq per 1,000 US$ in 2030.

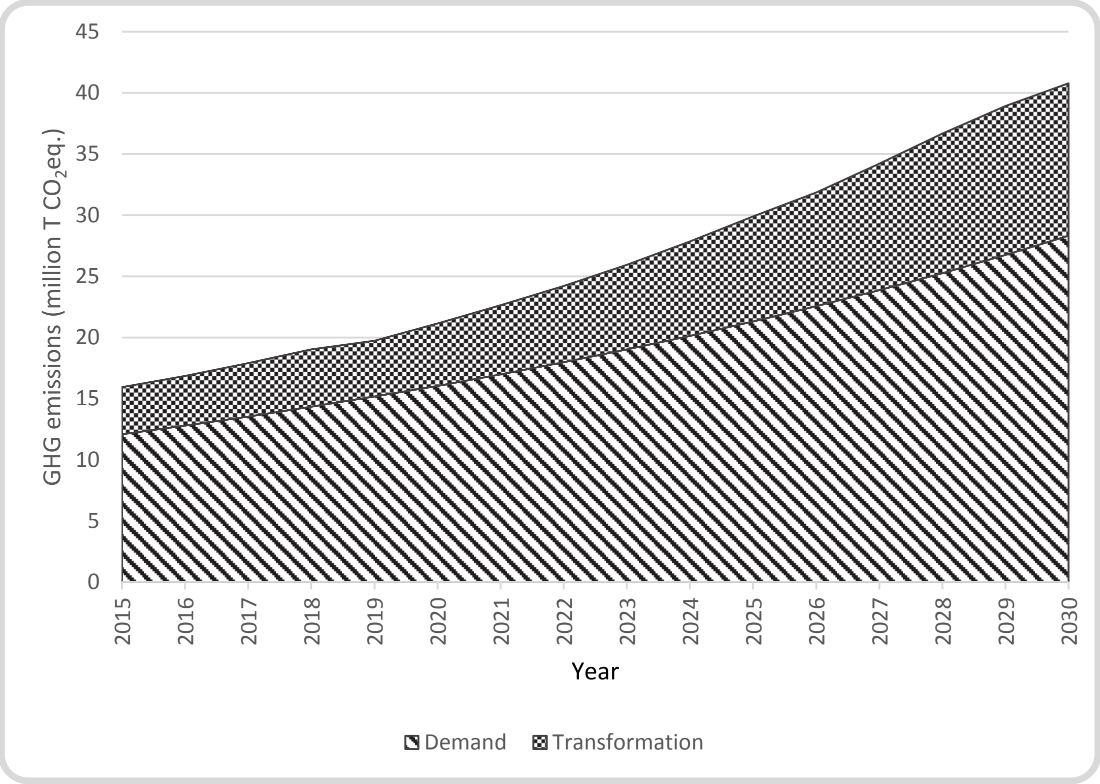

Figure 5.4: Projected net GHG emissions

5.3.2 Bioenergy Scenarios

5.3.2.1 Electricity Generation

In the reference scenario, electricity generation was assumed to follow a master plan developed for the country. Even though the master plan considered solar, wind and mini-hydro in the generation master mix, it did not make any provision for electricity

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[15] These are energy emissions alone. They do not include other sectors such as waste disposal, agriculture, forestry, land use and land use change.

generation from biomass sources. The bioenergy scenario therefore sought to analyse bioenergy contribution to electricity generation between 2015 and 2030.

In the bioenergy scenarios, biomass electricity generation sources are municipal solid waste (MSW), wood waste, oil palm waste and cocoa waste. Potential technologies to generate electricity from MSW include combustion, biogas from anaerobic digestion and landfill gas capture. This model assumed that electricity generation from MSW would rely on landfill gas technology and the other feedstock types would undergo combustion. One of the advantages of electricity generation from biomass resources is that distributed generation technologies can be easily deployed and power produced at agro-industrial plants and rural communities where feedstock is generated and in abundance. Power produced could either be used within the site/community where it is produced or it could be fed into the grid as desired.

A summary of electricity generation from biomass sources is presented in Table 5.3. In the moderate bioenergy scenario, total capacity of electricity generation from biomass could start from 50 MW in 2015 and rise to about 65 MW by 2030, with the assumption that a quarter of MSW, wood waste and oil palm waste are dedicated to electricity generation. This is expected to contribute about 2.0% of generated electricity by 2015 and 1.4% by 2030. In the high bioenergy scenario, installed electricity generation capacity from biomass resources could amount to 155 MW and rise to 200 MW by 2030, assuming the use of three-quarters of the resources mentioned in the moderate bioenergy scenario. Electricity from biomass resources in the high bioenergy scenario would contribute 4.0% to total electricity generated in 2030. In the high bioenergy scenario, electricity from all renewables (including from biomass) would contribute about 9% to total generation by 2030, compared to 6.4% in the moderate bioenergy scenario.

Table 5.3: Electricity generation in bioenergy scenarios

Power from bioenergy	Moderate bioenergy		High bioenergy	
	2015	**2030**	**2015**	**2030**
Installed Capacity (MW)	50	65	155	200
Electricity generated (GWh)	412	590	1186	1769
Biomass as percentage of total electricity	2.0%	1.4%	5.8%	4.0%
Percentage contribution from other renewables (excl. large hydro)	0.5%	5.0%	0.5%	5.0%

5.3.2.2 Transportation Sector

Ethanol and biodiesel are the principal biofuels used in the transportation sector. Only ground transportation, i.e. road and rail, was considered for bioenergy use in the bioenergy scenarios. In the moderate bioenergy scenario, biodiesel will contribute 0.3% of transportation energy requirement in 2015, rising to 5.4% in 2030 as summarised in Table 5.4. Demand for ethanol will amount to 0.2% of transportation energy in 2015 and rise to 4.8% in 2030. In the high bioenergy scenario, total biofuels demand will increase from 1.1% in 2015 to 21% in 2030. The high bioenergy scenario is therefore in agreement with the draft bioenergy policy document (Energy Commission, 2010) which called for a 10% biofuels in transportation fuels by 2020 and 20% by 2030.

Table 5.4: Percentage of transport fuels in bioenergy scenarios, by energy content

Transport fuel type	Moderate bioenergy		High bioenergy	
	2015	**2030**	**2015**	**2030**
Biodiesel	0.3%	5.4%	0.7%	11.2%
Diesel	62.4%	58.2%	62.2%	53.2%
Ethanol	0.2%	4.8%	0.4%	9.9%
Gasoline	37.0%	31.5%	36.8%	25.8%
Total biofuels	0.5%	10.2%	1.1%	21.1%

In terms of actual biofuel requirements, Table 5.5 shows biodiesel and ethanol required to meet the percentages shown in Table 5.4. In the moderate bioenergy scenario, about 0.44 PJ of biofuels would be required in 2015, increasing to over 15.53 PJ in 2030. In the high bioenergy scenario, approximately 0.88 PJ of biofuels would be needed in 2015, and increase to over 31 PJ in 2030. In 2020, about 12.77 PJ (or approximately 480 million litres) of biofuels would be needed in the transportation sector for the high bioenergy scenario. This is close to the 336 million litres estimated by Antwi *et al.* (2010) to meet 2020 requirements for biofuels in order to satisfy the draft bioenergy policy.

Table 5.5: Bioenergy requirement in the bioenergy scenarios

Bioenergy	Moderate bioenergy			High bioenergy		
	2015	**2020**	**2030**	**2015**	**2020**	**2030**
Biodiesel (PJ)	0.44	3.44	15.53	0.88	6.88	31.06
Ethanol (PJ)	0.27	2.94	13.73	0.54	5.88	27.46
Total biofuels (PJ)	0.71	6.38	29.26	1.42	12.77	58.52

5.3.2.3 Residential Sector

The policy of the government of Ghana is to have 50% of households in the country using LPG as cooking fuel by 2020, from about 18.2% in 2010. While this is ambitious, an analysis by Mensah *et al.* (2014) has shown that rural dwellers may not have access to LPG for a long time yet. This is because the LPG marketing model in the country, where consumers must convey LPG cylinders to the nearest LPG retail stations to have them filled, has made it difficult for rural communities to access LPG. This difficulty is attributed to the fact that LPG retail stations are located far from most rural communities, with poor transportation infrastructure. For such rural communities, the short to medium term solution is the provision of other more accessible modern cooking fuels. Efforts to enable rural communities switch to modern cooking fuels is one of the central themes of Ghana's Renewable Energy Act (Ministry of Energy, 2011) which aims to promote and support the increased use of improved biomass technologies through legislation, fiscal incentives and attractive packages. In the short to medium term, bio-digesters may be the most appropriate rural improved biomass technology, producing methane for cooking and heating[16].

The switch to methane gas is intended to reduce woodfuels use intensity in the Ghanaian economy. Under the Sustainable Energy for All (SE4ALL) programme, the Government of Ghana has also targeted improved cookstoves as one of the mediums

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[16] It must be mentioned here that under Ghana's SE4ALL Action Plan, improved cookstoves are to be widely promoted in the country, including rural communities, to reduce traditional biomass consumption.

to reduce woodfuels usage. Improved cookstoves marketed in Ghana are the residential charcoal types and it is expected that, going forward, the bulk of these stoves would continue to be the residential improved cookstoves. Since charcoal consumption is higher in urban areas and also because of the cookstove marketing models adopted, penetration of improved cookstoves is expected to be higher in urban communities than in rural communities.

In the reference scenario, demand for woodfuels is about 374 PJ in 2015, rising to 386 PJ in 2030. Switching to biogas in the alternative scenarios would enable a replacement of some woodfuels with biogas. In the moderate bioenergy scenario, biogas would displace 0.10 PJ of woodfuels in 2015, increasing to 6.21 PJ in 2030. In the high bioenergy scenario, displacement of woodfuels by biogas would start at 0.55 PJ in 2015 and reach 13.15 PJ in 2030. In addition to biogas, the increased use of improved charcoal carbonisation technologies and improved cookstoves in the alternative scenarios would further reduce the demand for woodfuels. In the moderate bioenergy scenario, improved carbonisation technologies would contribute 35% of total charcoal production by 2030, compared to just 20% in the reference scenario. In the high bioenergy scenario, the fraction of total charcoal produced by improved technologies reaches 60%. The resultant displacement of woodfuels, from a combined biogas demand, increased use of improved cookstoves, and use of improved carbonisation technologies, is summarised in Figure 5.5. In the moderate bioenergy scenario, about 71 PJ of woodfuels would be saved in 2030, rising to 138 PJ in the high bioenergy scenario. This is in line with the country's strategic national energy plan of 2006 in which the Ghana Energy Commission is hoping for a reduction in woodfuels intensity in Ghana's energy sector. Achieving this feat would require a lot of investment, especially in the rural biogas sector. It would also be prudent to introduce improved carbonisation technologies and to make appropriate laws that require a certain percentage of charcoal is produced using these improved technologies, especially for large-scale and frequent charcoal producers. The Forestry Commission and the Environmental Protection Agency could be empowered to enforce these laws and lead the effort towards reduced woodfuels use in the energy sector.

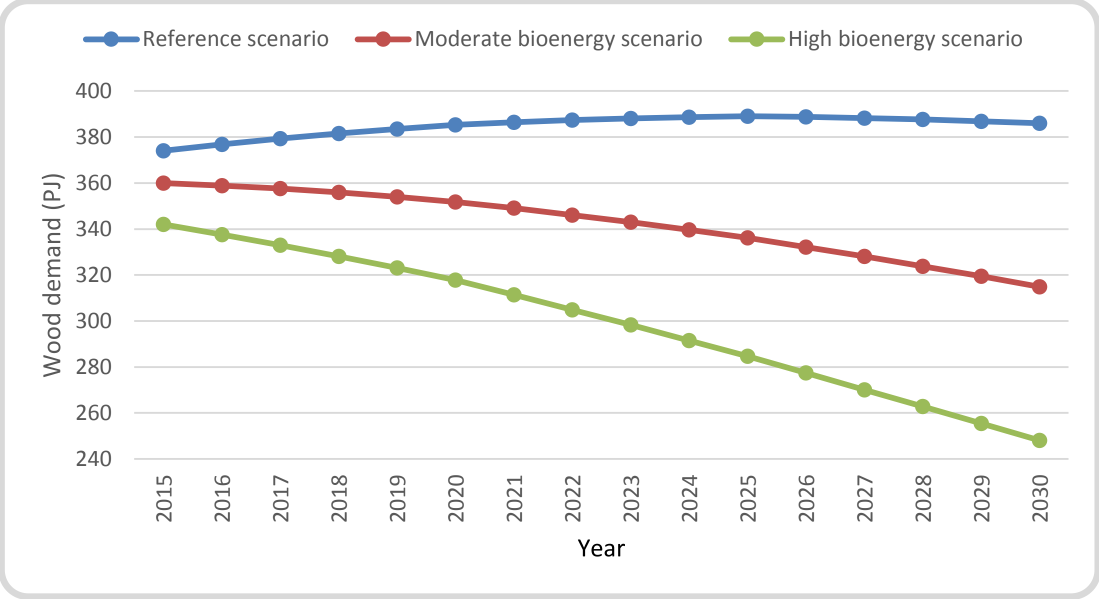

Figure 5.5: Woodfuels demand in all three scenarios

5.3.2.4 Resource Requirement in Bioenergy Scenario

Table 5.6 presents details of resource availability and their contribution towards the production of the different energy carriers. Biogas for residential cooking is assumed to be produced from livestock manure in the first instance. Depending on technology improvement, crop residues could supplement livestock manure in the production of biogas. Presently, research is ongoing on the co-digestion of livestock manure and crop residues with some success reported (Chandra *et al.*, 2012; Muhammad *et al.*, 2012; Brown *et al.*, 2012; Liew *et al.*, 2012; Cui *et al.*, 2011; Li *et al.*, 2011; Wu *et al.*, 2010) and it is hoped that the technology could be commercially available in the not too distant future. In the year 2015, close to 12 PJ of livestock manure could be available, rising to more than 21 PJ by 2030. This would be enough to meet resource requirement for biogas in the high bioenergy scenario by 2030, of 13.15 PJ. If the projected future resource becomes available, there might be no need to co-digest manure with crop residues, except when co-digestion could increase biogas yields, a situation that is dependent on ongoing research.

Table 5.6: Assumptions of biomass resource requirement in the bioenergy scenarios

Feedstock	**Resource potential (PJ)**		**Moderate bioenergy (PJ)**		**High bioenergy (PJ)**	
	2015	**2030**	**2015**	**2030**	**2015**	**2030**
Electricity generation						
Municipal solid waste	44.2	70.1	9.3	14.3	27.9	44.7
Wood waste	4.8	4.8	1.2	1.2	3.6	3.6
Oil palm waste	12.7	14.9	3.2	4.1	9.5	12.7
Cocoa waste	27.4	39.2	6.9	10.6	20.6	33.0
Transportation						
Ethanol (cereal waste, cassava waste, other crop wastes)	306.6	554.1	0.8	39.2	1.6	78.5
Biodiesel (sunflower and jatropha)*	NA	NA	0.4	15.5	0.9	31.1
Cooking fuels						
Animal manure	11.6	21.4	0.1	6.2	0.6	13.2

*Figures shown indicate actual biodiesel demand

With regard to transportation fuels, it is assumed that a combination of cereal waste, cassava waste and the other waste types not considered for electricity are available for fermentation, subject to technology availability. Producing ethanol from lignocellulosic feedstock avoids the 'food vs fuel' challenge which has become a contentious issue in the global discourse on biofuels. However, notwithstanding the fact that the social and environmental gains of producing biofuels from lignocellulosic biomass are many, it is unclear to what extent second generation biofuel technologies can compete favourably with first generation technologies with respect to costs. Second generation technologies are known to have higher costs as alluded to by a number of studies (Meihui *et al.*, 2015; Ramamurthi *et al.*, 2014; Pourhashem *et al.*, 2013; Manatt *et al.*, 2013; Haarlemmer *et al.*, 2012; Stephen *et al.*, 2012). Presently, there is no commercial scale second generation bioenergy technology in Ghana.

This implies that further research is needed to reduce costs in order to make second generation biofuels attractive for upscaling in developing countries such as Ghana. Higher costs would not encourage second generation technologies adoption and this would have consequences for land resource use. As an example, if all of the ethanol needed in the high bioenergy scenario were to be produced from first generation technologies using conventional energy crops, this would entail the use of over 583,000 ha of land by 2030, or approximately 9.6% of arable unused agricultural land in Ghana as at 2012. Details of this land requirement is summarised in Table 5.7. The computation is based on the assumption that ethanol would be produced from a combination of cassava and sweet sorghum, in a 50:50 ratio at presently conservative yields. The ratio is based on the assumption that cassava would be cultivated in the southern parts of the country while sweet sorghum is cultivated in the northern parts. Yield improvements could decrease land use for first generation biofuels but agricultural yields in Ghana and indeed most of sub-Saharan Africa have been poor and gives little room for optimism.

Table 5.7: Resource requirement for ethanol demand assuming first generation technology

Parameter	Moderate bioenergy			High bioenergy		
	2015	2020	2030	2015	2020	2030
Ethanol demand (million litres)	**12.73**	**138.10**	**644.66**	**25.45**	**138.10**	**1289.31**
Ethanol from Cassava (million litres)	6.36	69.05	322.33	12.73	69.05	644.66
Land required for cassava (ha)	2,121	23,016	107,443	4,242	23,016	214,885
Ethanol from sweet sorghum (litres)	6.36	69.05	322.33	12.73	69.05	644.66
Land required for sweet sorghum (ha)	3,636	39,456	184,188	7,273	39,456	368,375
Total land for ethanol (ha)	**5,758**	**62,472**	**291,630**	**11,515**	**62,472**	**583,260**

Conversion factor: 21.3 MJ per litre.

Yield factors assumed: cassava – 3,000 l/ha; sweet sorghum – 1,750 l/ha.

Source document for conversion factors: European Commission (2007); ethanol yield data was obtained from Afrane (2012) and Sielhorst *et al.* (2008).

Biodiesel could also be produced from crop residues using second generation technologies, but this technology is even less mature. To produce biodiesel from crop residue, the residue would undergo gasification to form syngas which can then be converted to biodiesel in a Fischer-Tropsch reactor with appropriate catalysts (Sims *et al.*, 2010; IEA, 2010). Again, if first generation technology were used, details of land requirements for biodiesel crops are presented in Table 5.8 with an assumed 50:50 combination of sunflower and jatropha. This ratio follows a similar assumption as that for ethanol crops, with sunflower cultivated in southern Ghana and jatropha in northern Ghana. In the moderate bioenergy scenario, an estimated 513,000 ha of land would be required to cultivate these crops to meet demand for biodiesel for transportation in 2030. This would rise to about 1 million ha in the high bioenergy scenario. Clearly, this calls for urgent measures globally and also in Ghana to continue to promote research into second generation technologies to decrease costs and make biofuels attractive socially, environmentally and economically.

Table 5.8: Resource requirement for biodiesel

Parameter	**Moderate bioenergy**			**High bioenergy**		
	2015	**2020**	**2030**	**2015**	**2020**	**2030**
Biodiesel demand (million litres)	**13.08**	**102.44**	**462.16**	**26.16**	**102.44**	**924.31**
Sunflower oil required (million litres)	6.54	51.22	231.08	13.08	51.22	462.16
Land required for Sunflower (ha)	9,479	74,230	334,896	18,958	148,459	669,793
Jatropha oil required (million litres)	6.54	51.22	231.08	13.08	51.22	462.16
Land required for jatropha (ha)	5,031	39,399	177,753	10,062	39,399	355,505
Total land for biodiesel (ha)	**14,510**	**113,628**	**512,649**	**29,020**	**227,257**	**1,025,298**

Conversion factor: 33.6 MJ per litre.

Yield factors assumed: Sunflower oil – 690 l/ha; jatropha oil – 1,300 l/ha.

Source document for conversion factors: European Commission (2007); biodiesel yield data was obtained from Afrane (2012) and Sielhorst *et al.* (2008).

5.3.2.5 Emissions Savings in Bioenergy Scenarios

In the bioenergy scenario, GHG emissions savings would accrue from reduced petroleum fuel consumption due to the introduction of bioenergy into the energy mix. In the moderate bioenergy scenario, about 8 PJ of petroleum fuels would be saved from transportation and electricity generation, rising to 58 PJ in 2030. In the high bioenergy scenario, petroleum fuel savings would begin at 10 PJ, and increase to 96 PJ in 2030.

The potential reduction in greenhouse gases is 3 million tonnes of CO_2e in the moderate scenario and close to 6 million in the high bioenergy scenario in 2030 (Figure 5.6), equivalent to 14% reduction relative to total projected emissions in the reference scenario. Close to 96% of the reductions in 2030 would accrue from the petroleum demand sector. The transformation sector savings are lower because of the assumption that natural gas is the primary electricity generation fuel for electricity in the reference scenario. Also, the roadmap for electricity generation already stipulates a 10% generation capacity from renewables by 2020, which results in lower emissions from electricity generation. GHG reduction in the transformation sector would be higher if LCO, which has a higher emission factor, is used in the electricity generation mix from 2015 onward.

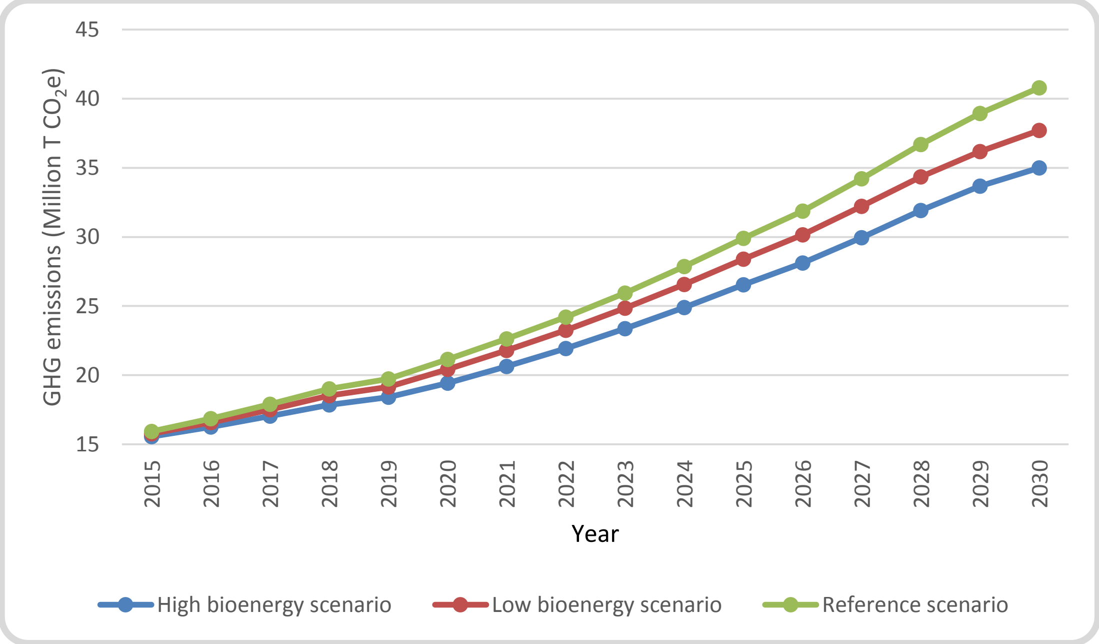

Figure 5.6: GHG emissions in the various scenarios

5.4 Summary of Findings

This chapter analysed the effects of bioenergy consumption on Ghana's energy mix from 2015 to 2030 using the LEAP model. Three possible energy scenarios were analysed to study the effects of bioenergy on the energy mix and also on GHG emissions. The first scenario, referred to as the reference scenario, considered a business-as-usual approach to current energy demand and supply. The two bioenergy scenarios examined the effects of injecting moderate and high bioenergy into the energy mix. In a high bioenergy scenario, electricity from biomass resources would contribute 5.8% to total electricity generated in 2015, reducing to 4.0% by 2030. Total biofuel demand in the high bioenergy scenario would increase from 1.1% in 2015 to 21% in 2030 which is in line with the country's draft bioenergy document which is calling for a 20% biofuel share in transportation fuels by 2030. In the high bioenergy scenario, the consumption of biofuels would result in the displacement of petroleum, starting from 10 PJ in 2015, and rising to a possible 96 PJ in 2030. Again in the high bioenergy scenario, up to 138 PJ of woodfuels could be saved in 2030 through increased consumption of biogas and increased use of improved cookstoves and charcoal carbonisation technologies. The potential reduction in greenhouse gases for modern bioenergy consumption in all sectors is 3 million tonnes of CO_2e in the moderate scenario and close to 6 million in the high bioenergy scenario in 2030, equivalent to 14% reduction relative to total projected emissions in the reference scenario. Ideally, feedstock for all bioenergy types could come from lignocellulosic biomass but there are practical challenges with biodiesel and to some extent ethanol production using the technology available. If ethanol is not produced from lignocellulosic biomass due to higher production costs, an extra 583,000 ha of land would have to be dedicated to the cultivation of starch and sugar crops for ethanol production. Producing biodiesel from lignocellulosic biomass is also possible, but the technology is even less mature, compared to ethanol. Research support is needed to quicken the pace of commercializing biofuels from lignocellulosic biomass to make the cost attractive for developing countries and thereby free-up land space for agriculture. Sustainability assessments are needed to ensure that projects meet their expected goals. Chapters Six and Seven will examine socio-economic impacts for biogas production using small-scale staple food systems and agro-industrial case study.

CHAPTER SIX

6.0 MODELLING SOCIO-ECONOMIC IMPACT OF BIOGAS OPTIONS IN SMALL SCALE STAPLE FOOD SYSTEMS

6.1 Background

Efforts to enable rural communities switch to modern fuels is one of the central themes of Ghana's RE Act. In the short to medium term, rural communities could be better served with biogas from bio-digesters. Traditionally, livestock manure, especially from cattle, is promoted as the feedstock of choice for rural bio-digesters in Ghana. But in most rural communities, cattle numbers are so few that they are hardly kept in housing structures (KITE, 2008). In Southern Ghana, manure may not be available in several rural communities due to the low level of livestock population (KITE, 2008). It is therefore worth investigating to what extent bio-digesters can rely on other feedstock sources or a mix of livestock manure and other feedstock.

Lately, researchers have been exploring the feasibility of using crop residues in bio-digesters in addition to manure, because of their abundance (Montoneri *et al.*, 2009). The possibility to use crop residues as feedstock for bio-digesters will complement manure in communities where manure is not adequate for widespread dissemination of bio-digesters. However, using crop residues as feedstock for bio-digesters has challenges with respect to the yield of methane. Methane yield is affected by the composition and biodegradability of lignocelluose due to the recalcitrant nature of lignin (Frigon and Guiot, 2010; Chandra *et al.*, 2012). These issues are the subject of ongoing technical research (Brown and Li, 2013; Chandra *et al.*, 2012; Muhammad *et* *al*., 2012; Appels *et al*., 2011; Wu *et al*., 2010; Schievano *et al*., 2009; Xu and Li, 2012; Brown *et al*., 2012; Liew *et al*., 2012; Cui *et al*., 2011; Li *et al*., 2011).

In addition to the technical challenges, producing bioenergy from crop residues also present sustainability challenges. Issues regarding economic performance as well as environmental and social effects of using crop residues for bioenergy, especially in rural contexts, are not well established (Schwietzke *et al.*, 2008). Socio-economic impacts are diverse and will differ according to such factors as the nature of the technology, local economic structures, social profiles and production processes (Krajnc and Domac, 2007). Existing socio-economic studies have targeted energy crops cultivated on agricultural lands (first generation biofuels) or impacts at the wider national/regional level (Brose *et al*., 2010; Dam *et al*., 2009; Domac *et al*., 2004; Duer and Christensen, 2010; Lehtonen and Okkonen, 2013; Sathe and Bhosale, 2013; Silalertruksa *et al*., 2012; Stanojevic *et al*., 2006; Suthar, 2011; Dale *et al*., 2013b). Socio-economic impacts of modern bioenergy from crop residue and at a rural community scale have not been the subject of much research. This chapter therefore analysed the socio-economic impacts of biogas production from a mix of crop residues and livestock manure at the rural community level. To achieve this, the specific objectives were to:

1. estimate recoverable crop residue and manure at the community level for bioenergy,
2. develop a model for determining selected relevant socio-economic indicators of modern bioenergy, and to,

3. test the reliability of the model on a case study.

The socio-economic modelling considered the 16 bioenergy social and economic sustainability indicators developed by the Global Bioenergy Partnership (2011) and selected the five (5) indicators applicable to the system being considered. The five (5) indicators selected are: financial indicators (Net Present Value, Internal Rate of Return and Payback); job creation; income effects; bioenergy to expand access to modern energy services; and change in unpaid time spent by women and children collecting biomass. The other eleven (11) indicators were not studied because they were either applicable to first generation biofuels that rely on agricultural land or they could only be measured ex-post.

6.2 Methodology

6.2.1 Model Description

A model was designed, using Microsoft Excel spreadsheet, for bio-digester systems that rely on a combination of crop residue and livestock manure for the production of methane for cooking and heating. The model was designed to analyse the socio-economic impacts from the point of collecting crop residues and livestock manure to delivery of methane for cooking and heating. The stages considered in the model are shown in Figure 6.1.

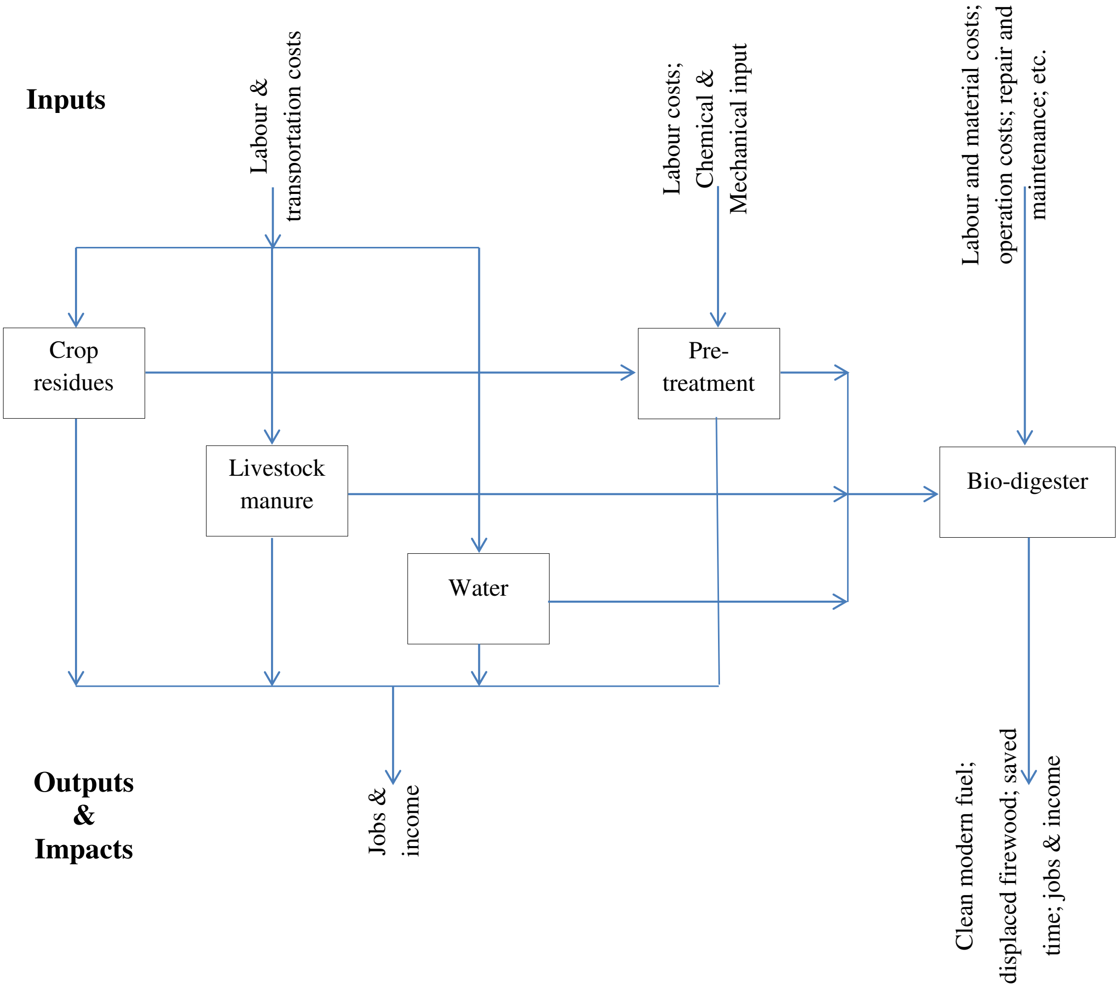

Figure 6.1: Flow diagram of residue biogas system

The bio-methane potential ($P_{methane}$) was estimated using equation 6.1, modified from Kemausuor *et al.* (2014).

$$\boldsymbol{P_{methane}} = \sum_{i=1}^{n} \boldsymbol{P_{AR}}\left(\left[\boldsymbol{y_{Buswel.glu}} * \boldsymbol{C_{glu}}\right] + \left[\boldsymbol{y_{Buswel.hem}} * \boldsymbol{C_{hem}}\right] * \boldsymbol{\eta_{scale}}\right)_{i} + \sum_{i=1}^{n}\left(\boldsymbol{P_{live}} * \boldsymbol{y_{man}} * \boldsymbol{\eta_{rec}} * \boldsymbol{C_{TS}} * \boldsymbol{y_{BMP}}\right)_{i} \qquad 6.1$$

where, P_{AR} is amount of crop residue available, y_{Buswel} is the methane potential calculated with Buswel's formula, C_{glu} is the concentration of glucan (cellulose or starch) in a specific residue, C_{hem} is the concentration of hemicellulose in a specific residue, η_{scale} is the average efficiency of continuous biogas production, P_{live} is the number of specific livestock population, y_{man} is manure produced by one specific livestock annually, η_{rec} is the recoverability of manure for specific livestock, C_{TS} is the total solids concentration of manure and y_{BMP} is the bio-methane potential of specific livestock manure. Factors i and n represent the specific residue/manure and total number of residue/manure types, respectively, for which methane potentials are computed. The efficiency of biogas production is dependent on the inoculum, which in this case is livestock manure.

Estimated energy that can be supplied by available methane is given by equation 6.2.

$$\boldsymbol{Energy_{methane}} = [\boldsymbol{V_{methane}} \times \boldsymbol{\rho_{methane}} \times \boldsymbol{CV_{methane}}] \times \boldsymbol{\eta_{stove}} \qquad \textbf{6.2}$$

where, $E_{methane}$ is the estimated energy supplied by methane (kWh), $V_{methane}$ is the amount of methane generated (m^3), $\rho_{methane}$ is the density of methane (kg/m^3), $CV_{methane}$ is the calorific value of methane (kWh/kg) and η_{stove} is the efficiency of biogas stove.

The equivalent amount of firewood that can be displaced by methane is computed using equation 6.3.

$$\boldsymbol{F_{displaced}} = \frac{\boldsymbol{E_{methane}}}{\boldsymbol{CV_{firewood}} \times \boldsymbol{\eta_{firewood\ stove}}} \qquad \textbf{6.3}$$

where, $F_{displaced}$ is the amount of firewood displaced (kg), $CV_{firewood}$ is the average calorific value of firewood used in the community (kWh/kg) and $\eta_{firewood}$ stove is the average efficiency of three stone firewood stoves.

Estimated time savings accrued as a result of households shifting to methane for cooking is computed using equation 6.4.

$$\boldsymbol{Time\ savings} = \frac{T_{unit\ of\ firewood} \times A_{firewood}}{A_{unit\ of\ firewood}} \qquad \mathbf{6.4}$$

where $T_{unit\ of\ firewood}$ is the average time to collect a defined unit of firewood (hours), $N_{firewood}$ is the amount of firewood displaced (kg) and $A_{unit\ of\ firewood}$ is the amount of firewood in a defined unit (kg)

To determine the economic feasibility of the bio-digester, Net Present Value (NPV), Internal Rate of Return (IRR) and payback period were used. NPV is the sum of the present value of individual cash flows over the project lifetime. The IRR is the discount rate at which the incremental net benefit stream or incremental cash flow equal zero (Gittinger, 1982).

NPV is computed using equation 6.5:

$$\boldsymbol{NPV} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \qquad \mathbf{6.5}$$

IRR is computed using equation 6.6 and is the discount rate 'i' such that:

$$\mathbf{0} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \qquad \mathbf{6.6}$$

where B_t is the benefit in each year, C_t are the costs in each year, i is the interest (discount) rate, t are numbers from 1, 2, 3,…, n where n is the number of years (life of biogas plant).

General input variables into the model include amount of specific crops harvested, number of cattle available within and outside the community, bio-digester component and accessories costs, biomass storage costs, land and labour costs, transport costs and methane sales. Key variables for digester inputs (crop residues, livestock manure[17] and water) include the cost of acquisition and transportation to the storage site or digester. The maximum size of the digester is estimated based on the annual supply of crop residues and livestock manure. Capital costs and maintenance costs are considered for a 30 year project implementation period. Revenues are analysed from the sales of methane to households/small businesses in the community. Net Present Value (NPV), Internal Rate of Return (IRR) and payback period were used as economic performance indicators. Social indicators determined by the model are job creation, income effects, displacement of firewood from the use of methane and time saved by women and children collecting biomass in the community

6.2.2 Model Application – *Zambrama* Community

The base case is modelled ex-ante, on a potential 300 m^3 bio-digester for *Zambrama*, a rural community in the Ashanti region of Ghana (Figure 6.2). *Zambrama* was chosen for the case study due to previous experience working in the community on other

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[17] The combination of crop residue and livestock manure are referred to as feedstock in this chapter.

bioenergy related issues and also because it is located in one of the most influential agricultural districts in the country, the Ejura-Sekyedumasi District. The base case scenario uses data collected from the study community and other relevant sources and is assumed to be the most likely outcome. The *Zambrama* community lies in the transitional agro-ecological zone in Ghana and is accessible by a 16 km feeder road from the main Ejura-Atebubu road. The digester design is based on the seasonal availability of corn stover in the community, and cattle manure.

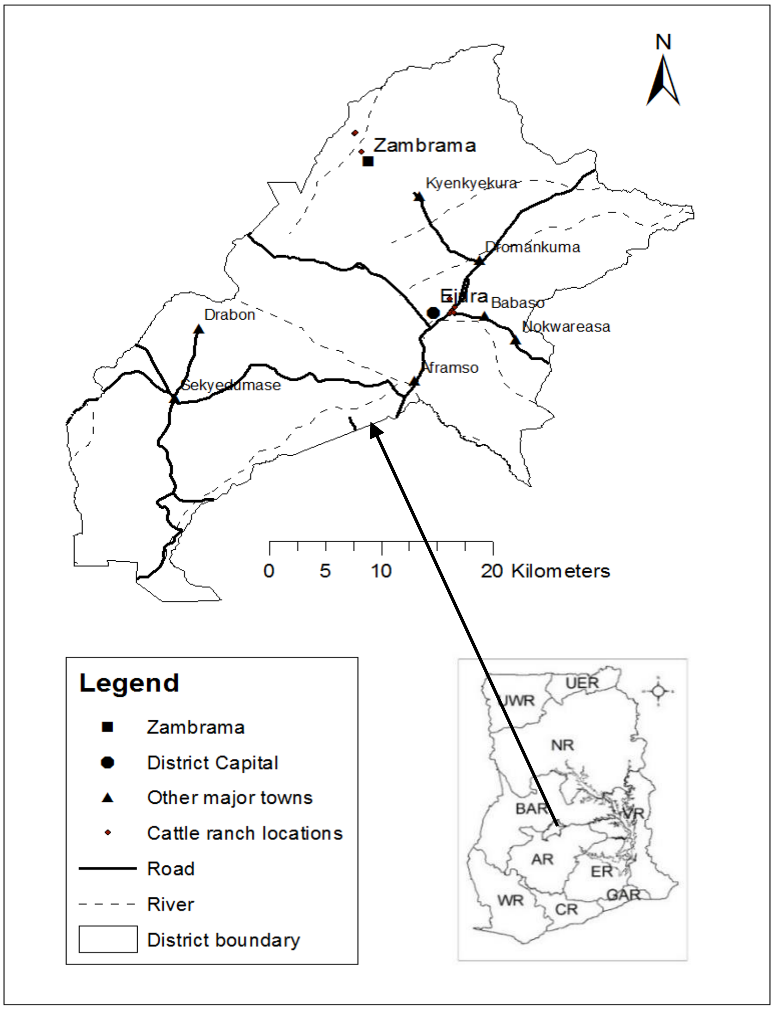

Figure 6.2: A map of Ghana showing location of *Zambrama*

Based on the experience of Ghanaian digester construction companies, it is assumed that the community will employ six fixed dome digesters, each of size 50 m^3.The fixed dome plant (Figure 6.3) comprises a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit, also known as 'compensation tank' (Arthur *et al.*, 2011). The gas is stored in the upper part of the digester, which replaces the need for a gas storage balloon. The slurry (or digestate) is displaced into the compensating tank when gas production starts.

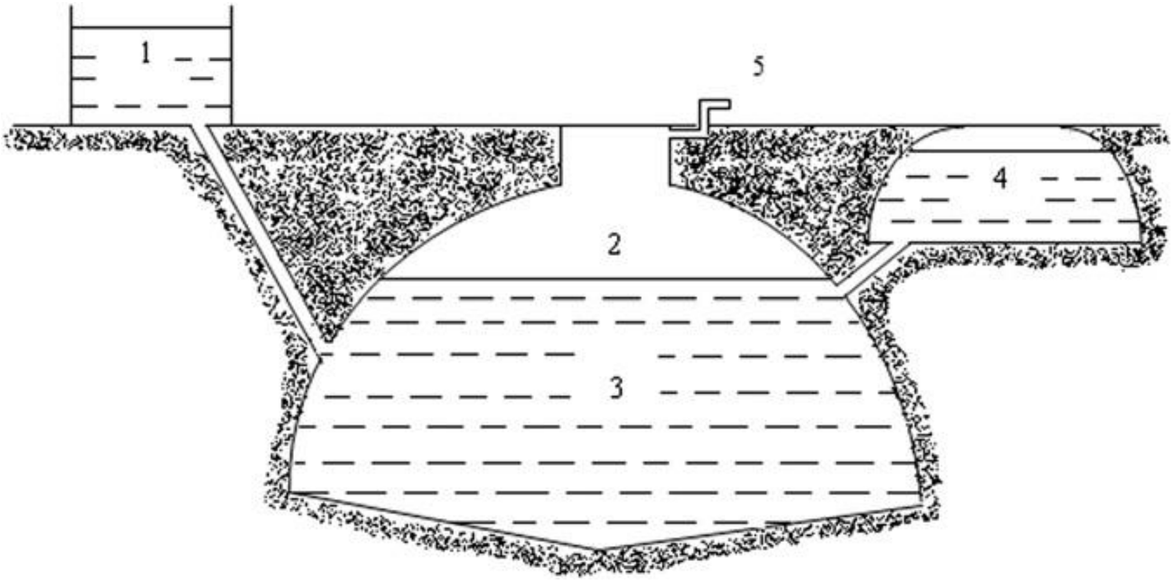

Figure 6.3: Fixed dome digester

1. Mixing tank with inlet pipe. 2. Gasholder. 3. Digester. 4. Compensation tank. 5. Gas pipe.
Source: (Arthur *et al.*, 2011)

6.2.2.1 Input variables and Data Acquisition

Table 6.1 lists selected input variables that were used for the base scenario. Data in Table 6.1 and other data for the base scenario were obtained using primary data from the following sources: (1) a questionnaire survey and focus-group discussion with farmers and household heads in the *Zambrama* community; (2) a questionnaire survey of cattle ranch owners in and around the *Zambrama* community; (3) field experiments conducted on farm plots and households in the *Zambrama* community; (4) personal interviews with two bio-digester construction companies in Ghana; and (5) personal interviews with managers of two bio-digesters, an 8 m^3 plant using human faecal waste as feedstock and an 800 m^3 plant that is fed with fruit wastes generated from a fruit processing company in Adeiso, a community in the Eastern Region of Ghana. The surveys and field experiments, details of which are presented next, were conducted between June and August 2013.

Table 6.1: Selected input variables for base scenario

Variable type	Variable description	Values	Unit
General	Engineer	10	US$ /man-hour
	Supervisor	4	US$ /man-hour
	Other Skilled labour	2	US$ /man-hour
	Unskilled labour	1	US$ /man-hour
	Government subsidy	0	US$
Investment	Cost of land	500	US$
	Cost of storage structure	600	US$
	Cost of biomass mill	300	US$
	Cost of digester& accessories	91,700	US$
Feedstock	Manual harvest of straw	10	US$ /tonne
	Collection of manure	2	US$ /tonne
	Crop residue transport	10	US$ /tonne
	Manure transport	20	US$ /tonne
Biogas production	Methane output	16,700	m^3 /year
	Methane sales	0.726	US$ /m^3

6.2.2.1.1 Farmer Household and Cattle Ranch Survey

The survey conducted in *Zambrama* was done to obtain information on types of crops grown, size of farm plots, historical harvest patterns, existing uses of crop residue, distance of farm plots from community, labour availability and costs for harvesting and transporting various residue types, household fuel demand, perception and acceptability of methane as cooking fuel, willingness to pay for the methane and the use of digestate as organic fertilizer on farm plots. A total of 32 farmer households (out of 40 in total), with farm plots totalling approximately 80 ha were interviewed in the survey. Willingness-to-pay questions were deliberately targeted at heads of households and household members who were decision makers on fuel use and other household items. These respondents were asked how much they were willing to pay for methane on a monthly basis and their willingness to invest in gas stoves. Respondents who were not household heads and/or were not decision makers on household fuel use were exempted from answering willingness to pay questions. Because they did not have the decision making power, it was thought that their response will distort the survey.

Due to the absence of cattle ranches within the *Zambrama* community itself, a survey was conducted in surrounding communities to determine the availability of manure. The distance of the cattle ranches from the community ranged from 2 km to 20 km. The majority of cattle ranches were located in Ejura, the district capital which is about 20 km away from the *Zambrama* community. Ejura is one of the dominant cattle rearing communities in the country (KITE, 2008). The survey was structured to solicit information on cattle housing systems and existing uses of manure. The questions ranged from numbers of cattle raised, housing conditions, uses of manure and cost of manure in case the owners place any price value on it. In the base case scenario, it is assumed that crop residue and cattle manure comes at no cost, a direct result from the survey conducted in the community.

6.2.2.1.2 Field/Fuel Use Experiments

Field/fuel use experiments were performed to determine parameters for specific activities relating to the consumption of fuel and operation of bio-digesters. The field experiments, described below, involved residue-to-product ratio determination of crops in the community, labour requirements for harvesting crop residues, labour requirements for fetching water from the community water source, and time taken for women to harvest firewood for household use. The household experiment was conducted to determine household fuel use in the community.

6.2.2.1.3 Residue-to-Product Ratios

To determine how much residue could be available from harvested crops, field experiments were performed in the harvest period to determine residue-to-product ratio (RPRs) using the methodology stated in Chapter four for the feedstock assessment. The RPR fieldwork was done using twenty farm plots in total (ten each for maize and cowpea), randomly selected from different locations of the community, to roughly represent an east, west, north and south direction from the community. RPR experiments were performed for two harvest seasons: January 2013 and August 2013.

6.2.2.1.4 Field Labour Requirements

To estimate labour requirements to harvest straw, ten farmers in the community were made to harvest straw and their work rate timed during the process. The farmers were asked to work at their usual pace in order to determine the optimum levels of straw harvest for analysis. The elapsed time and amount of straw harvested were recorded and averaged for all the participating farmers. The harvesting was done from 1st to 4th August 2013 when farmers were still harvesting maize and preparing the field for the second farming season in the year. Personal interviews were conducted among transport owners to sample views on the cost of conveying straw from the fields.

6.2.2.1.5 Firewood Harvest Labour Requirements

Firewood harvesting in the community is often done by the women. Although women were asked during questionnaire survey how long it took to fetch firewood, field experiments were performed to ascertain these figures in a real life situation. Ten women from ten different households were monitored as they walked from their home to their usual firewood harvest sites. The time it took to perform the activity and travel as well as the amount of firewood conveyed home were recorded. Average figures were computed and used in the model.

6.2.2.1.6 Woodfuels Consumption Estimation

Amount of firewood displaced by biogas depends on household sizes, fuelwood characteristics, combination of fuels used and types of foods cooked (Chakrabarty *et al.*, 2013). To establish fuel demand in the community, a Kitchen Performance Test (KPT) was conducted. KPT is a field test used to assess qualitative aspects of stove performance, compare the impact of different stoves or determine quantities of household fuel consumption in real-world settings (Harvey and Tomas, 2011). KPT can be simple or complex depending on the intended purpose and the size of the community. The KPT was performed between June 16 and 23, 2013, over seven full days, requiring daily household visits for eight days. Firewood and charcoal, where applicable were weighed daily using Salter Brecknell Electro Samson digital hand-held scales (45 kg x 0.01 kg). A KPT survey was also administered daily to record information on the number and type of meals prepared, and the number of people cooked for. Since the KPT required that the respondent must be present each day for fuel measurement and interview, ten households were purposely selected based on consent and availability. Mean value for the ten households over the eight day period was used to represent average and per capita woodfuels consumption in the community.

6.3 Results and Discussion

6.3.1 Resource Availability

Maize and cowpea are the most cultivated food crops in *Zambrama*. Figure 6.4 illustrates the quantity of maize and cowpea harvested in *Zambrama* over the 2011 and 2012 farming seasons. There are two farming seasons in each calendar year (shown as S1 and S2 in Figure 6.4). Season one begins in March/April – after a long dry spell that spans 3 to 4 months – and ends in August. Season two begins in August/September and crops are harvested between December and January. The estimation of crop residues in this study takes into account: a) annual grain (product) yields for different types of crops; b) crop residue-to-product ratios; c) residue removal rates; and d) competitive use of crop residues.

Results from the farm plot survey indicated that farmers had no competing uses for maize residues. Maize residues are often burnt at the end of the farming season. Farmers opined that leaving maize straw on the field poses challenges when planting seeds for the following season, as residues impede the manual planting process, especially if tractor ploughing is not well done. For this reason, the majority of farmers in the community prefer to burn their maize fields before tractor ploughing. Husks and cobs are also burnt at shelling points. For cowpea however, farmers deliberately leave residues on the field (if they are not burnt by wild fires) to serve as soil nutrient when the field is ploughed. The period between the first and second season is short as harvesting of crops and planting for the next season is done almost simultaneously, often separated by days to a couple of weeks for field preparation, depending on weather patterns. For this period, farmers may choose to burn maize residues or leave them on the field before ploughing. The period between the second harvest of the year and the first harvest of the subsequent year is a three to four month dry spell (also known as 'harmattan' season) during which wild fires consume almost every residue left on farm plots.

The assessment of residues was therefore done for maize residues only as it is not expected that cowpea residue will be available in abundant quantities for energy purposes. Using the last four seasons' average for crops harvested in the community, it is estimated that about 50 t of maize and 4 t of cowpea are harvested each season by farmers surveyed in the community. Based on these figures, Table 6.2 shows an estimation of unused residue availability in the community. Even though maize residue is unused in the community, only a 30% recoverability is estimated for energy purposes to account for any environmental and economic uncertainties. Maize cobs were left out of the analysis because of the difficulty of digestion, due to their hardy nature.

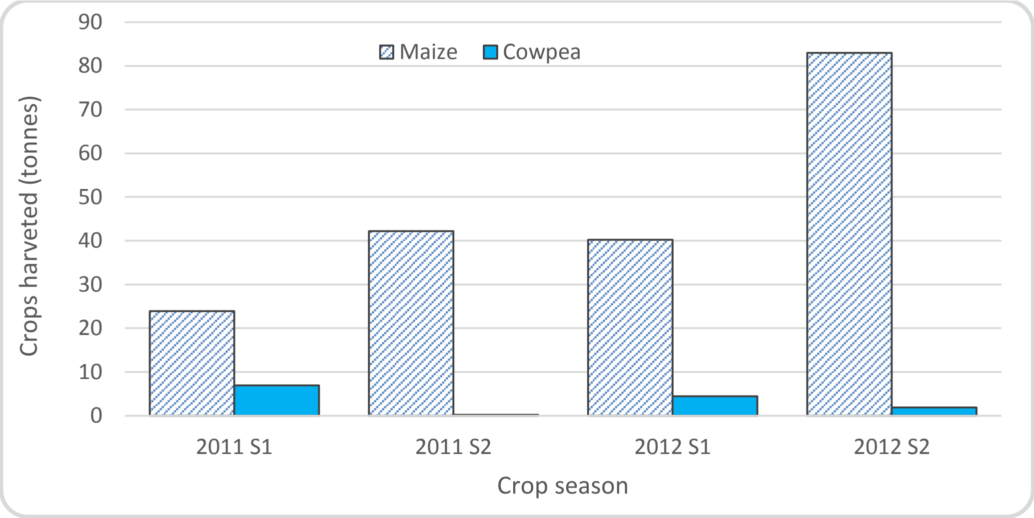

Figure 6.4: Crop harvest pattern in *Zambrama*. S1 – Season 1; S2 – Season 2

Table 6.2: Residue availability in *Zambrama* community

Crop type	Residue type	Crop amount harvested (t)	RPR	Residue available (t)	Recoverability fraction	Net residue (t)
Maize	Straw	200	1.61	322	0.3	96.6
	Husks	200	0.31	62	0.3	18.6
Beans	Straw + pods	16	7.99	127.84	0	0
Total						**115.2**

With regards to manure, the survey covered 10 ranches that had a total cattle population of 360 or on the average 36 cattle per ranch. All the ranch managers interviewed had no competing uses for manure. Manure is kept in the ranch and not discarded because it is expensive to do so (See Figure 6.5). In some ranches, herds of cattle spend the night outside of the ranch during rainy season because of the depth of wet manure which makes sleeping uncomfortable. All the surveyed ranches were willing to give out manure at no cost.

Figure 6.5: Cattle manure in a ranch in Ejura

For a 300 m^3 digester, an estimated 160 t of maize production per year (with 30% recoverable residue) and manure from 90 cattle is the approximate feedstock needed per year for operation. Daily manure production from cattle is estimated at about 12 kg/head with a recoverability fraction of 60% (Junfeng *et al.*, 2005). But cattle in the Ejura community spend half the day feeding outside the ranch. For this reason, this study assumes just 6kg of manure per day from each cattle and a moderate recoverability fraction of 20%.

6.3.2 Social Benefits

The important social benefits of a rural bioenergy programme are its ability to create employment and therefore provide income for rural households, displace the use of traditional fuels and reduce the time women spend harvesting firewood. The model assessed the employment possibilities for households in the *Zambrama* community, possible income for the community, firewood displaced per year from the use of modern bioenergy and time saved by women for not harvesting firewood as they switch to the use of methane gas for cooking.

6.3.2.1 Job Creation and Income[18]

Table 6.3 provides details of direct jobs available in terms of man-hours per year. In the investment year, more skilled labour will be required for the construction of the bio-digester. The skilled labour category is made up of an excavator operator, supervisors and brick layers. It is expected that all unskilled labour will be sourced from the *Zambrama* community, to the extent that there is adequate human resource. The unskilled labour requirement in the investment year is equivalent to 4 people working full time for all business days in the year. In the operating years, the project would create 3 permanent full-time unskilled jobs and part time management position for regular monitoring of technical performance. Labour services in the operating years

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[18] All currency figures are presented in US$ using an exchange rate of 1 US$ to 2.08 GHC as at August 2013 when the fieldwork was completed.

include those for loading of feedstock and monitoring of digester performance, harvesting of crop residues and the collection and bagging of manure for transport to the project site. The direct unskilled job creation is nearly one job per 100 m^3 digester. This compares with the calculated direct employment of around one job for 11.7 family sized (ranging between 4 and 15 m^3) digesters built (Buysman, 2009). Other indirect jobs include the regular transportation of feedstock to project site and the provision of water.

Table 6.3: Annual socio-economic benefits of project

Socio-economic indicator	Value	Unit
Skilled jobs – investment year	9,811	man-hours
Unskilled jobs – investment year	7,866	man-hours
Skilled jobs – annual over 30 year period	104	man hours
Unskilled jobs – annual over 30 year period	5,398	man-hours
Biogas available per year	28,000	m^3
Amount of firewood displaced per year	170	t
Time saved from harvesting firewood per year	3,400	hours

Income effects are directly related to the number of jobs created on the project. Unskilled labour man-hour rate is estimated at between US$ 0.8 to US$ 1, translating to a daily wage of between US$ 6 and US$ 8, compared to Ghana's 2013 daily minimum wage of approximately US$ 2.5 (GHC 5.24) per day. The hourly wage is also higher than labour rate in the study community which is approximately US$ 0.5 per hour. In the investment year, nearly US$ 8,000 will remain in the community from the use of unskilled labour for various activities relating to construction of the bio-digester and the biomass storage structure. In the first year of operation, regular unskilled labour will attract nearly US$ 5,500 of income into the local economy, increasing at 5% per year for the subsequent years. Other incomes will accrue from unskilled labour requirements for maintenance services and assistance with transportation of biomass to the project site.

6.3.2.2 Displacement of Woodfuels and Time Savings

All households in the *Zambrama* community use woodfuels for cooking and do not have access to any form of modern fuel. The closest LPG retail station to the community is about 50 km away making it difficult for households to obtain and use LPG. Results from the KPT indicate that the average household in *Zambrama* consumes about 25 kg of woodfuels per day. The average household size for the surveyed households is 8, which implies that the average person in *Zambrama* consumes approximately 3 kg of woodfuels per day. All the households rely on firewood, using the three-stone stove with an assumed efficiency of 12% (Arthur and Baidoo, 2011). There is occasional additional charcoal use in a few households. The 300 m^3 digester will produce on the average about 28,000 m^3 of biogas per year. Using biogas stoves with an assumed burning efficiency of 55%, this amount of biogas will produce energy of over 92,000 kWh. The available energy will substitute about 170 t of firewood per year. Displacing this amount of firewood will have positive health implications for women who would hitherto cook in smoky kitchens (Smith *et al.*, 2014; Perez-Padilla *et al.*, 2010).

The firewood collection field experiment conducted in *Zambrama* has shown that it takes approximately 30mins for women in the community to collect the average daily firewood requirement of 25 kg from fields around the community. The time taken to fetch firewood is relatively shorter compared to similar studies by Baniya (2007), World Bank (2006) and United Nations (1995) with estimates of between 1.2 to 2.5 hours. This may be explained by the remoteness of the *Zambrama* community, which means that wood is available within walking distance from the community and women do not have to travel far to fetch firewood. The average round-trip distance covered by women collecting daily firewood requirement in *Zambrama* is approximately 600 m but could be longer if women collected firewood from around their farm plots, many of which are farther away. In the base scenario, using all the methane available will save time amounting to approximately 3,400 hours per year not collecting firewood. This is more than 9 hours saved per day in total by women in the community. Using the higher literature average of 2 hours per day collecting firewood, the time saved by women in the community could increase to 36 hours per day.

Besides woodfuels savings, households that switch to methane gas for cooking could also save cooking time. A study in Nepal shows that households with family sized biogas plants of approximately 2.4 m^3 make savings of between 11-100 kg of woodfuels per month, 0-2.4 litres of kerosene per month and daily cooking time savings of between 1.5-5 hours (Chakrabarty *et al.*, 2013). Another study found that family sized biogas plants in Cambodia displace between 1-2 kg per day per m^3 of plant capacity and households saved around US$14.4/month on energy with an extra incentive of US$ 52 per year on chemical fertilizers (Buysman and Mol, 2013).

Households using methane gas for cooking also saved on average around 1.5 h daily on fuel wood collection and cooking time. Another potential benefit, which is not the focus of this thesis, is the use of the slurry on farm plots which could serve as an income generating source for the project and displace the use of inorganic fertiliser.

6.3.3 Financial analysis of base scenario

The investment cost for the 300 m^3 biogas digester, land and other accessories is approximately US$ 93,000. Construction will take place in year 'zero' and then other indicators are modelled for a 30 year period, assumed to be the lifetime of the digester (Labutong *et al.*, 2012). Even though the digester is assumed to have a 30 year lifespan, other accessories such as storage structure and pre-treatment facilities are expected to be replaced every 5-10 years. The base scenario's NPV over the 30 year project lifetime of the project is US$ 21,820 with an IRR of 11% as summarized in Table 6.4. The payback is reached in the 15 year as illustrated by the cash flow analysis in Figure 6.6. As shown in Table 6.4, discontinuing the project after 10 years results in a negative NPV and IRR, rendering the project unprofitable for a commercial enterprise. Discontinuing after 20 years also results in an IRR that is less than the discount rate and an NPV that is still negative. Within the 30 year period of the project, the base scenario will deliver a total energy of about 5 million kWh at a total cost of US$ 990,000, resulting in a levelised cost of approximately US$ 0.20 per kWh of energy delivered to a household.

Over the lifetime of the project, transportation of feedstock and water constitute 55% or more than half of total project costs as summarised in Figure 6.7. Transport costs are high because in the base scenario, manure is transported to the project site through a 20 km distance. The base scenario also assumes that water will be transported by hired labour. These factors increase the cost of transportation considerably. Labour costs for feedstock collection and digester operation constitute approximately 24% of total project costs. Digester establishment and maintenance costs play a less significant role, accounting for less than 10% of expenses. In the base scenario, revenues are obtained exclusively from the sales of methane.

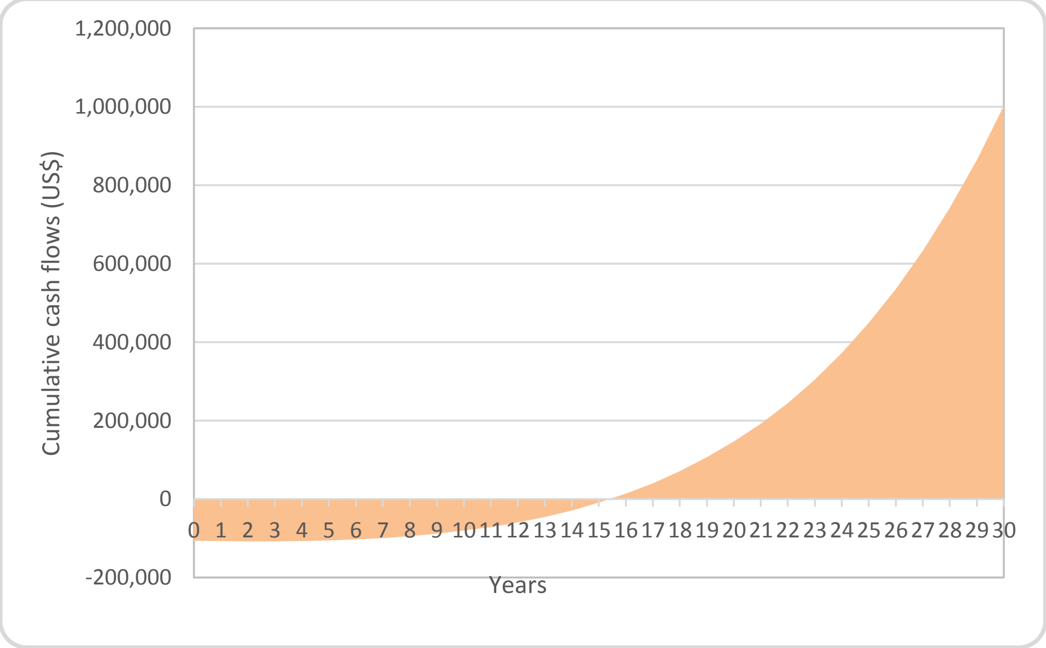

Figure 6.6: Cumulative cash flow of base scenario

Table 6.4: Key output variables of the base scenario

Output variable	Project life				unit
	10 years	**20 years**	**25 years**	**30 years**	
NPV	-86,070	-42,760	-12,654	21,820	US$
IRR	-15	6	9	11	%
Digester size	300	300	300	300	m^3
Capital cost	93,110	93,110	93,110	93,110	US$
Average revenue per year	19,370	34,800	47,800	66,630	US$

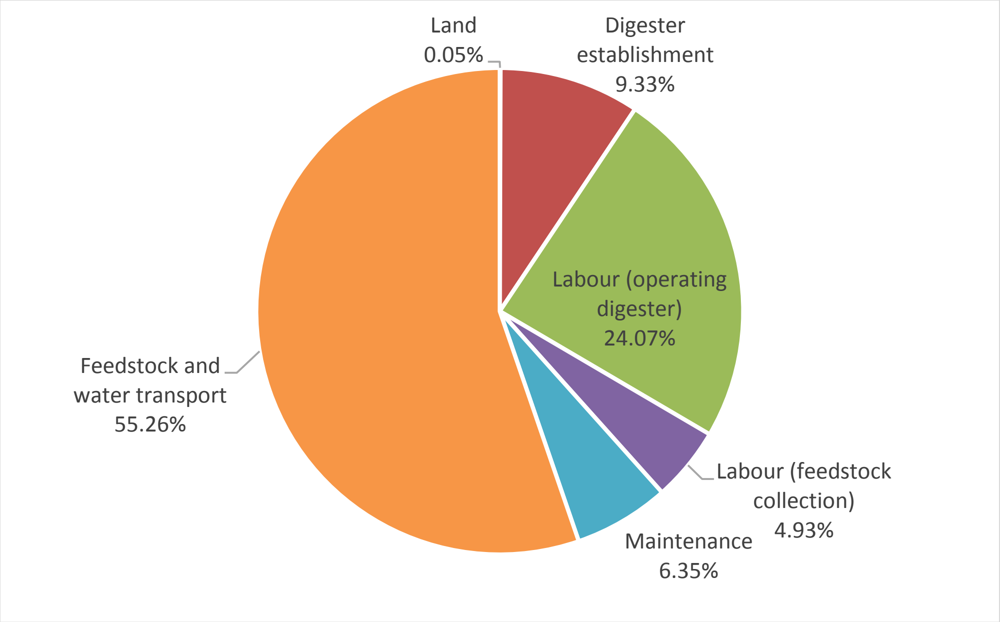

Figure 6.7: Distribution of total production costs over project lifetime

6.3.4 Willingness to Pay

In the *Zambrama* community, firewood is freely obtained from nearby trees at no monetary cost to households. Households also use three-stone stoves which come at no financial cost. The introduction of biomass digesters will necessitate the purchase of methane gas and gas stoves, using appropriate financial models or tariffs. One of the best tariff options for gas purchases is a monthly payment plan as the case is for electricity and water tariffs in Ghana. The financial indicators were modelled with an average methane tariff of US$ 30 per household. The retail price of stoves were estimated using price quotations from the open market and ranged between US$ 15 to US$ 25 for 2 cooking space to 4 cooking spaces respectively. Of the respondents to whom willingness-to-pay questions were posed, all of them were able to state a price they were willing to pay per month for methane gas.

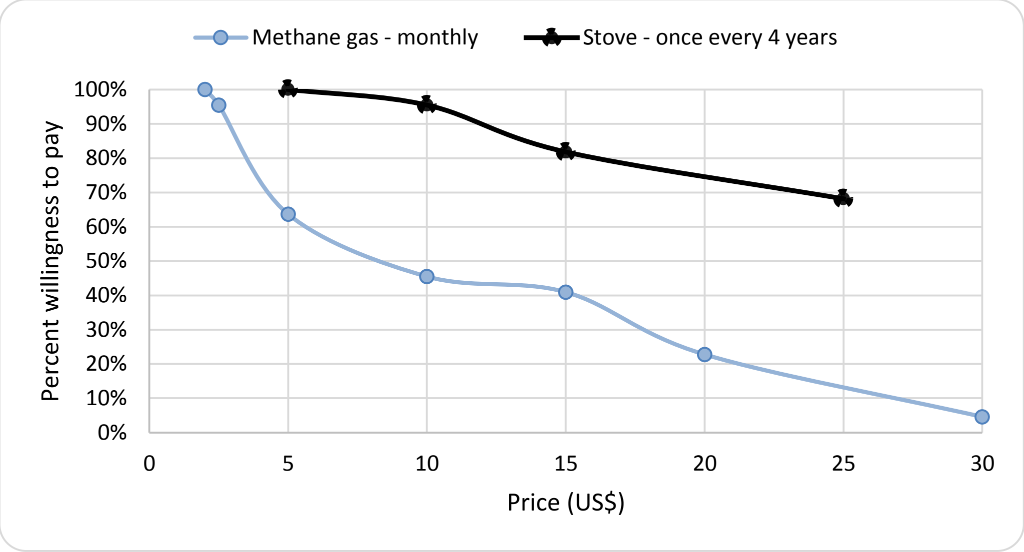

Figure 6.8: Willingness-to-pay for methane gas and stove

As presented in Figure 6.8, only 5% of respondents were willing to pay the highest price asked. Forty percent are able to pay up to half of the maximum amount. In effect, up to 60% of household decision makers are only willing to pay less than half of the maximum price stated. Willingness-to-pay for gas stoves were higher with close to

70% willing to pay the highest price of US$ 25. Willingness-to-pay for stove may be higher because it occurs once every 3-5 years as opposed to monthly for methane gas. The results of this analysis raises subsidy issues which are important if rural community households would switch to modern fuels.

Because households in the community collect their own firewood and do not pay physical cash for it, methane may not be able to compete unless subsidised, as also confirmed from the willingness to pay analysis. To make this attractive to rural communities, suitable financial schemes such as investment subsidy may be required. Subsidy schemes for biogas systems already exist in several developing countries which make it possible for rural households to switch to cleaner fuels. Household biogas systems in Ethiopia enjoy subsidies of between 34-36% of the investment cost from the National Biogas Programme Ethiopia, depending on the size of the digester (Gwavuya *et al.*, 2012). Prior to the year 2000, Chinese states subsidized biogas production through the provision of more land for farming, free technical and labour services, or supplied all the cement needed for construction which often accounted for 30% of the total cost (Ghimire, 2013). Since 2003, China has also provided direct funding for the construction of biogas plants of different scales in rural communities (Chen *et al.*, 2010). In the height of India's biogas programmes in the early 90s, construction of biogas plants were supported with subsidies of between 32-40% (Bhat *et al.*, 2001). The aforementioned subsidy programmes have promoted biogas systems in developing countries and Ghana could adopt some best practices. Government could also explore possibilities for carbon financing from appropriate carbon markets. The sensitivity analyses that follow explore the effect of government subsidy, as well as other key parameters on the profitability of the project.

6.3.5 Sensitivity Analysis

6.3.5.1 Effect of Government Subsidy with Reduced Methane Tariff

In most countries, the production of renewable fuels, including bioenergy attract incentives from governments in the form of subsidies and tax breaks (Bandyopadhyay *et al.*, 2013; Devadoss and Bayham, 2010; Grafton *et al.*, 2010; Josling, 2011; Kruse *et al.*, 2007). As part of Ghana's Renewable Energy Act, a renewable energy fund (RE Fund) is proposed to be established. The objectives of the RE Fund are to provide financial resources for the promotion, development, sustainable management and utilization of renewable energy resources. Benefits from the fund include financial incentives to project developers, and equity based participation for almost all renewable energy forms. In the base scenario, there is no government subsidy to the project and the cost of methane is estimated to be equivalent to the retail cost of LPG in Ghana. The sensitivity analysis considers a government subsidy in the form of contribution to the capital cost of the digester and with a reduced methane tariff. The analysis considers a 20% reduction in the base methane tariff, making the cost equivalent to natural gas delivered to US residential consumers in August 2013 (US Energy Information Administration, 2013). The analysis also considers subsidy contributions from government rising from 15% to 50% of the capital cost. Figure 6.9 shows the effect of changes in these two parameters on NPV and IRR. With the reduction in methane tariff, the NPV of the project remains negative until government subsidy reaches 50% of the bio-digester capital cost. IRR also remains less than the discount rate until the 50% government subsidy is applied. Government subsidies of 15% and 30% will render the project unprofitable as the NPV is negative.

Another form for government subsidy could be a direct subsidy to the price of methane purchased by households. For example, government could pay 50% of the methane tariff and credit it to appropriate funding budgets, such as an environmental fund or some form of carbon financing source. Direct government subsidy is already applied on LPG and electricity as well as transportation fuels in Ghana (Mensah *et al.*, 2014; Broni-Bediako and Dankwa, 2013; Arze del Granado and Coady, 2012). Of critical importance is the appropriate targeting of the subsidy scheme, to ensure that it is used for its intended purpose.

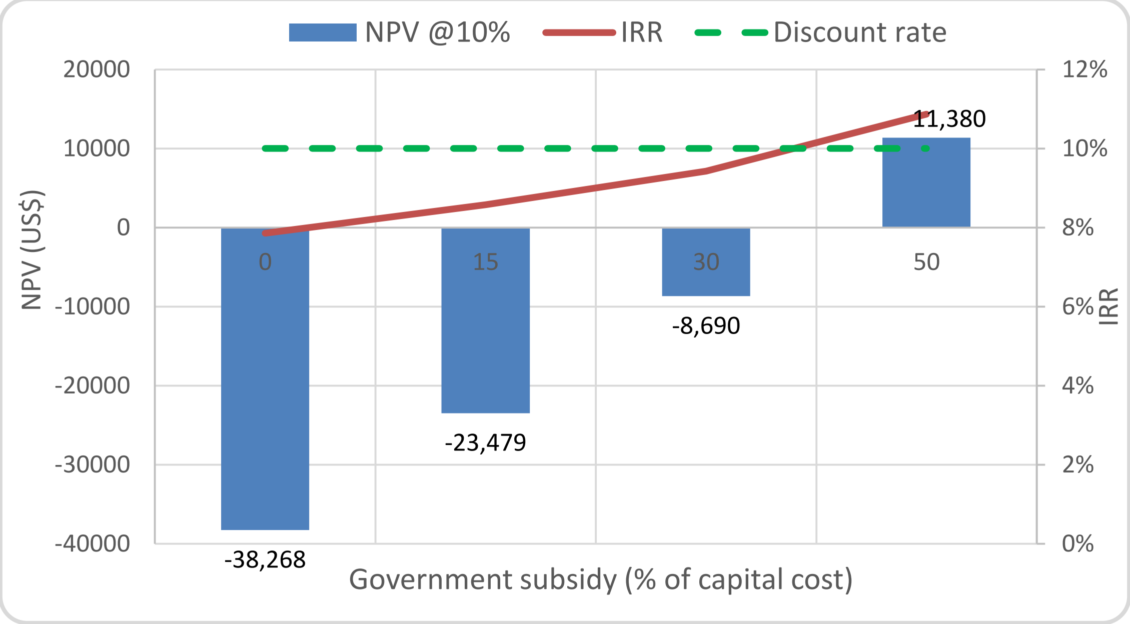

Figure 6.9: Effect of government subsidy with reduced tariff

6.3.5.2 Effect of Government Subsidy with Reduced Methane Tariff and 'Zero' Manure Transport Cost

In most bioenergy projects, feedstock costs form the major cost component (Miao *et al.*, 2012). In the base scenario, it is assumed that feedstocks are obtained at no cost, making transportation the major cost component. Transportation of feedstock and water constitute more than 57% of the total project cost over the 30 year period. Manure transport alone constitute a third of transportation costs. The high cost of manure transport is explained by the fact that in the base scenario, manure is sourced from outside the community from about 20 km away. It is therefore important to establish the impact of manure transport cost on project financial indicators in order to determine the profitability of this project in communities that have adequate manure. This section of the sensitivity analysis considers subsidy requirement from government to ensure project profitability, still with the same reduction in methane tariff as before, but this time also with no transport cost for manure. Figure 6.10 illustrates the effect of changes in these parameters on the NPV and IRR. Project becomes profitable from 10% government subsidy or higher. At 20% tariff reduction and 30% government subsidy, NPV is just slightly higher than the base scenario NPV (at US$ 23,700 compared to US$ 21,820 in the base scenario) with an IRR of 12%, compared to 11% in the base scenario.

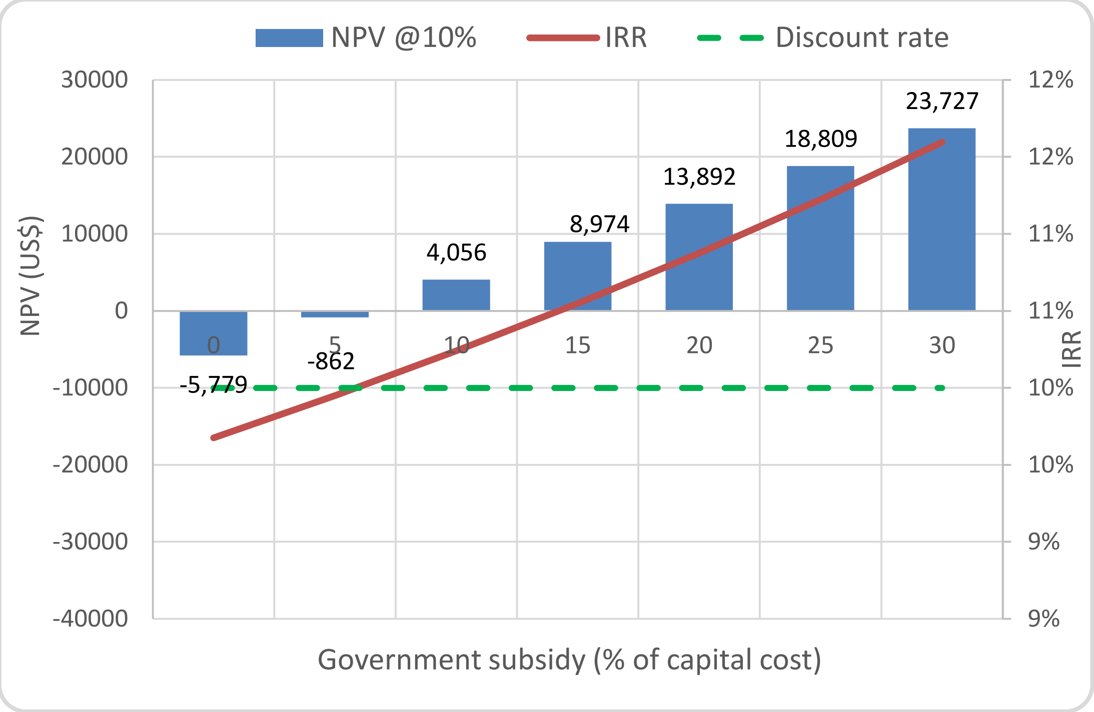

Figure 6.10: Effect of government subsidy with reduced tariff and manure transport cost

6.4 Summary of Findings

This chapter examined the socio-economic impacts of introducing crop residue bio-digesters in Ghanaian rural communities. A model was developed and used as a case study for *Zambrama*, a rural community in the Ashanti Region of Ghana. The study found that maize residues in the community have no competing uses and would be available for energy purposes.

Using a discount rate of 10% for a 30 year project lifetime, the NPV and IRR of the base scenario were US$ 22,000 and 11% respectively for a 300 m^3 bio-digester. The project will create 4 full time unskilled labour positions for community residents in the investment year and 3 full time positions for the subsequent 30 years of the project lifetime. The energy available can substitute up to 170 t of firewood and save the women 3,400 hours per year not collecting firewood considering an average daily woodfuels collecting time of 30 minutes. If the higher literature average of 2 hours per day collecting firewood is applied, the time saved by women in the community could increase to 36 hours per day or over 13,000 hours per year. Apart from the time savings, using a more modern fuel results in less smoke emissions from cooking, which translates into better heath for women.

However, households in the community are not willing to pay the tariff for methane gas which calls for some government subsidy in the form of capital cost contribution to the project and/or subsidy towards tariff. Sensitivity analysis shows that with a 20% decrease in methane tariff, project only becomes profitable when a 50% government subsidy is applied. If manure transport costs were ignored, a 10% government subsidy is just enough to make NPV positive.

CHAPTER SEVEN

7.0 MODELLING SOCIO-ECONOMIC IMPACT OF BIOGAS OPTIONS IN AGRO-INDUSTRIAL SYSTEMS

7.1 Background

Ghana is the sixth largest producer of cassava, contributing 5.5% of global production in 2012, amounting to about 14.5 million tonnes (FAO, 2014). Cassava is one of the critical staple foods in the country and is processed into/used to prepare several foods, many of which can be stored for up to several months. The more common foods made from cassava are *fufu*, *agbeli kaklo*, *gari* and *kokonte*. *Gari* is produced on commercial basis, for both local consumption and export. Processing cassava into *gari* is an agro-industrial activity that takes place on small- to medium-scale basis. Small-scale processing, often up to a few tonnes of cassava per year, is done at the household level. Medium scale production is done in agro-processing plants that process up to a few thousand tonnes per year. It is estimated that about 25% of cassava harvested in Ghana is processed into *gari* (Food Research Institute, 2013) in communities in the southern parts of the country. In most cassava processing communities, several tonnes of cassava peels are generated as a waste product from the processing activity. Even though cassava peels can be used as feed for livestock, the quantities generated and the remoteness of many of the communities where processing takes place leaves behind a lot of waste, which is left to rot or is burnt, with environmental consequences. There is therefore the need to explore other measures to manage cassava waste. This chapter examines the impacts of using cassava wastes as biogas feedstock in cassava processing communities.

Currently, communities processing cassava use firewood as main heating source, as is the case with many rural community agro-process activities. Government's policy objective is to ensure that agro-industries shift from the use of firewood to more environmentally friendly fuels such as biogas for heating. The country's Strategic National Energy Plan (Energy Commission, 2006) has proposed an increase in renewable and modern biomass energy in the final energy supply to achieve at least 10% penetration by 2020. This is also corroborated by the Renewable Energy Law of Ghana (Ministry of Energy, 2011). However, the extent to which residues from processing plants could serve as feedstock for energy has not been the subject of much research. This study therefore examines the technical and socio-economic potential of generating methane from cassava waste to replace firewood, which is increasingly becoming scarce. The specific objectives of this chapter were to:

1. Examine the availability of cassava waste from cassava processing and its potential for biogas production
2. Perform financial assessment of producing biogas from cassava waste; and
3. Assess job creation potential and other social benefits of biogas production from cassava process waste

7.2 Methodology

7.2.1 Model Description

The model developed in chapter 6 was applied for this purpose with little modifications where necessary. However, the input parameters were different and will be discussed in the next section.

7.2.2 Model Application – Agro-industrial Systems

7.2.2.1 Study Area

The study was conducted in two agro-industrial processing sites in *Asueyi* and *Akrofrom*, both located in the Techiman Municipality of the Brong Ahafo Region (See Figure 7.1). The Techiman Municipality is a major cassava production district in the country. The two communities selected are also major cassava processing areas within the district. Both communities receive assistance from the 'Root and Tuber Improvement and Marketing Programme' (RTIMP), implemented by the Ministry of Food and Agriculture. Under an ongoing project, RTIMP has selected these two communities to benefit from a pilot modern bioenergy conversion plant due to the huge quantities of waste generated[19].

Both communities have similar socio-economic characteristics. As at the last census in 2010, the *Asueyi* community had a population of 2,402 and the *Akrofrom* community had 1,505 people. Both communities are agrarian with the majority of residents

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[19] Details of the project, *Promoting a Value Chain Approach to Climate Change Adaptation in Agriculture in Ghana (ProVACCA)*, can be found at http://operations.ifad.org/documents/654016/17060381-148f-4291-b04a-24511050954e

engaged in farming activities. Farmers cultivate cassava, cocoa and cashew, in addition to other staple crops and vegetables. Cassava is a major crop because of its commercial value as raw material for *gari* production. Cassava processing is a vibrant economic activity in both communities.

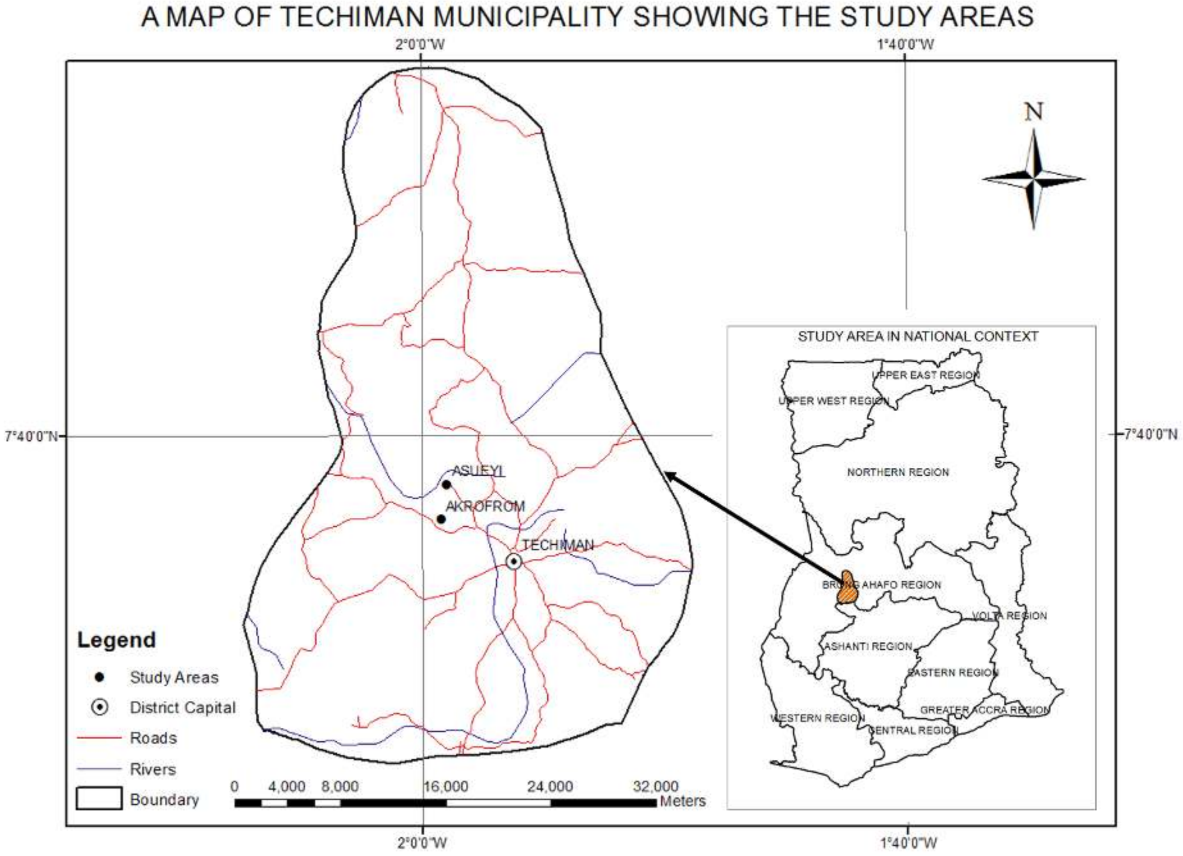

Figure 7.1: Map showing study locations

The *Asueyi* community processes about 8,000 t of cassava per year, producing about 1,500 t of *gari*. The *Akrofrom* community has two processing sites. However, data for this work was obtained from only one site, which processes in excess of 7,000 t of cassava per year. Between five and ten different cassava varieties are processed in both communities. Cassava is generally available all year round due to a planned cultivation and harvesting schedule. Occasional shortages may occur due to transportation or logistical challenges but not from shortage of the produce. Firewood is the only fuel for roasting and is purchased from suppliers. The study site in *Asueyi* had forty roasting points and the *Akrofrom* community site had thirty five. Each roasting point consists of a stove and roasting pan and is manned by one person.

7.2.2.2 Description of Cassava Processing Activity

The stages in cassava processing into *gari* is summarized in Figure 7.2. The first stage is peeling and washing of the cassava root. The peeled cassava is then grated using a motrized cassava grater. The next stage is fermentation where the grated cassava is left to ferment for 24 hours at room temperature. The fermented paste is bagged and pressed to remove moisture using hydraulic screw presses. The coarse flour material is pulverized, and then sieved to make it finer for roasting. The roasting is done manually in large, shallow stainless steel pans over a fire, with constant stirring. The stirring takes place for 20-30 minutes and is done with a piece of broken calabash or wooden paddle carefully designed for the purpose. The roasted *gari* is sieved to obtain granules of uniform size and bagged for marketing.

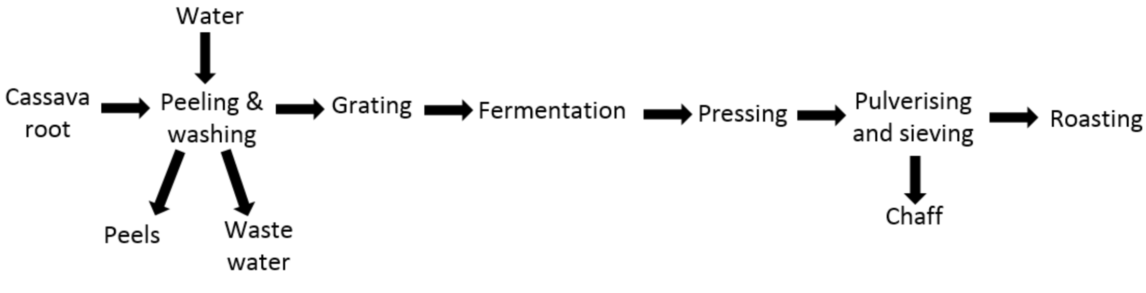

Figure 7.2: Flowchart for **processing cassava into *gari***

7.2.2.3 Assessment of Peels and Manure

The first stage in the analysis of energy potential from cassava waste is the assessment of quantities of waste generated. An experiment was performed to assess the availability of peels from each of the processing plants. The experiment was performed between April and June 2014. The assessment was performed for four varieties of cassava which were processed during the period of the study. For each variety of cassava, thirty randomly selected samples from three different truck deliveries (thus ten samples from each truck delivery to the plant) were weighed and peeled. The weight of the peels were then recorded. Peelers used in the experiment were randomly selected from among the existing peelers at the processing plants. As part of the assessment, observations were made of the existing uses of cassava peels continuously for one month to estimate how much of the peels were collected from site and how much was thrown away. Peels from each of the cassava varieties were collected for moisture content determination. The procedure for determining moisture content is as follows:

i. A sample of fresh peel (W_w) from each variety was weighed.
ii. The fresh residues were dried in a hot box oven at 103ºC for 24 hours
iii. The weight of the dried residues (W_d) were recorded.
iv. The moisture content (MC) was determined using equation 7.1.

$$\boldsymbol{MC} = \frac{(\boldsymbol{W_w} - \boldsymbol{W_d})}{\boldsymbol{W_w}} \times \mathbf{100\%} \qquad \mathbf{7.1}$$

A survey was conducted in the two communities to determine the availability of manure to serve as inoculum for biogas production. The survey was structured to solicit information on cattle housing systems and existing uses of manure. The questions ranged from numbers of cattle raised, housing conditions, uses of manure and cost of manure.

7.2.2.4 Measurement of Firewood Use

In order to assess the amount of firewood used for *gari* processing, a fuel use experiment was conducted. Ten roasting points were purposively selected from each site based on consent to participate and agreement to observe the rules of the experimentation. Fuel use experiment was performed between June 16 and 23, and June 25 to July 2, 2014, for *Asueyi* and *Akrofrom* respectively. Experiment at each roasting point took seven full days, requiring daily visits for eight days. For each roasting point, an amount of firewood (more than often required for a day) was weighed daily and the leftover at the end of the working day weighed again to determine how much was used. For each roasting point, the amount of *gari* roasted for the day is also weighed. The amount of firewood used and the corresponding *gari* roasted are used to determine the amount of firewood per a unit of *gari* roasted. Data was analysed and the mean of the firewood recorded.

7.3 Results and Discussion

7.3.1 Cassava Peel and Biogas Potential

The ratio of peels to cassava roots, based on the experiment conducted in the two communities is shown in Table 7.1. The average peel to whole cassava ratio obtained for the four cassava varieties is 0.303 with a standard deviation of 0.016. This means that for every tonne of cassava processed, approximately 300 kg of peels are obtained, ranging from 290 kg for the *Esam* variety to 321 kg for the *Dakwari* variety. The data obtained corroborates findings by the FAO (2001) which states that between 250 to 300 kg of cassava peels is produced per tonne of fresh cassava root processed. However, the figure obtained is slightly higher than the 0.25 peel to cassava root ratio quoted by Jekayinfa and Scholz (2009).

Table 7.1: Field determined ratio of peels to cassava

Variety	**Peel to cassava root ratio**	**Moisture content**
Bensere	0.312	19.9
Nkruwa	0.288	20.09
Dakwari	0.321	20.22
Esam	0.29	19.8
Average	**0.303**	**20.00**
Standard deviation	*0.016*	*0.188*

Table 7.2: Cassava peel and biogas production details

Parameter	**Unit**	***Asueyi***	***Akrofrom***
Annual cassava consumption	tonnes	8,000	7,000
Peels generated	tonnes	2,424	2,121
Estimated peels collected for livestock feeding	tonnes	727	1,414
Peels discarded	tonnes	1,697	707
Peels considered for biogas production	tonnes	97	148
Firewood used for *gari* production	w/w	0.85	0.85
Estimated annual biogas production	m^3	27,463	45,744
Amount of firewood displaced per annum	tonnes	119	198

The *Asueyi* community processing site processes approximately 8,000 t of cassava per annum. The *Akrofrom* community processes a little over 7,000 t of cassava. Using the ratio of peels to cassava roots ratio shown in Table 7.1, the peels generated in the two communities are shown in Table 7.2. Based on a month of monitoring and interaction with the managers of the processing sites, it was estimated that about two-thirds of peels in *Akrofrom* are collected for livestock feeding and only one-third collected in *Asueyi*. The lower collection rate in *Asueyi* can be attributed to the remoteness of the *Asueyi* community with poor road connection. This makes it difficult and expensive for livestock farmers to assess the area regularly for collection of peels, resulting in the creation of a huge pile of cassava peel within the community. The processing site has attempted to manage the waste by resorting to open combustion (see Figure 7.3) which has health implications for residents and workers.

Figure 7.3: Pile of cassava peels undergoing open combustion

Based on the livestock survey, only 20 cattle and 20 pigs are kept in the *Asueyi* community. In the *Akrofrom* community, there are 45 cattle and 12 pigs. The cattle in both communities are housed only at night and allowed to open-graze during the day. The pigs are however, housed 24 hours a day. The analysis for biogas production therefore estimated manure production from cattle for only half the day and a full day for pigs. Also for the period when manure generation is considered, only 60% recoverability is estimated. Based on this analysis, only 46 t of manure is available from *Asueyi* and 75 t from the *Akrofrom* community.

The biogas production is based on 2:1 peel to manure ratio following experiments conducted by Adelekan and Bamgboye (2009), Adelekan (2012) and Oparaku *et al.* (2013). Even though there is abundant cassava peels, the availability of livestock manure restricts the size of digester. Based on the 2:1 peel to manure ratio, only 4% of the peel generated in *Asueyi* and 7% from *Akrofrom* is used for biogas generation. This is very little, compared to an estimated 65% discarded cassava peels in *Asueyi* and 33% in *Akrofrom*. The combined feedstock availability in *Asueyi* can only support a 300 m^3 plant whereas the feedstock in *Akrofrom* can support a 500 m^3 plant. The annual potential of biogas from both communities is approximately 75,000 m^3 of gas with an estimated 60% methane content. The ultimate aim for producing biogas is to replace the use of firewood for *gari* processing. The potential for firewood replacement at the *gari* processing factories is shown in Table 7.2.

As mentioned earlier, it is estimated that a quarter of the cassava produced in Ghana is used for the production of *gari*. Meanwhile all *gari* production factories rely on firewood which means that approximately 580,000t of firewood was used for the production of roughly 682,000t of *gari* in 2012 alone. Exploring the use of cassava waste to produce fuel for the production of *gari* could be socially and environmentally beneficial. Table 7.3 shows a projection of cassava production for Ghana with corresponding amount that could be used for *gari* production. Table 7.3 also shows the estimated firewood that could be used to process the potential *gari* using an average of the firewood amount used in the two communities. It is expected that close to 1.3 million tonnes of firewood could be needed for *gari* production by 2030 under a business-as-usual scenario. This figure is only indicative because there might be differences in communities due to social practices, efficiency of roasting stoves, and other factors. However, it depicts the extent to which demand for firewood could rise in the *gari* production industry, with alarming consequences for the country's wood resources. Clearly, this could compete with rural households for scarce wood resources. This calls for urgent attention and efforts must be made to explore the use of agro-process residues for processing.

Table 7.3: Estimates of firewood needed for *gari* production

Parameter	**2015**	**2020**	**2025**	**2030**
Projected cassava production (t)	17,149,547	21,066,444	25,877,948	31,788,382
Estimated cassava for *gari* production – 25% of total produced (t)	4,287,387	5,266,611	6,469,487	7,947,096
Estimated *gari* (t)	803,885	987,490	1,213,029	1,490,080
Estimated firewood needed (t)	683,302	839,366	1,031,074	1,266,568

7.3.2 Financial Assessment of Biogas Development

There are two options for using the gas: (1) internally for cassava processing, and (2) sale to households in the community to be used as cooking fuel. In large plants, both options could be pursued. The financial analysis is therefore performed from two perspectives. The first one investigates the extent to which gas produced could be used within the plant and its cost implications (compared to using firewood for roasting *gari*). The second one examines the profitability of generating the gas for sale within the community.

The capital cost for the biogas digester, and other key financial indicators are summarised in Table 7.4. Capital cost for the 300 m^3 plant in *Asueyi* is approximately US$ 91,000, rising to about US$ 151,000 for *Akrofrom*, where a 500 m^3 plant is envisaged. The financial analysis is performed for a 30 year period, assumed to be the lifetime of the digester.

At the time of conducting fieldwork for this study, *gari* roasting is done entirely with firewood. The analysis from the fuel use experiment shows that it takes approximately 0.85 kg of wood to produce 1 kg of *gari*. Firewood is purchased at US$ 14.5 per tonne. Thus at present value, it takes approximately US$ 12.325 of firewood to produce a tonne of *gari*. Taking *Akrofrom* as an example, within the 30 year assumed lifetime of the bio-digester, the project will deliver useful thermal energy[20] of about 3.5 million kWh at a total cost of US$ 300,000, resulting in a levelised cost of approximately US$

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[20] This is the effective energy used, taking into account stove efficiency.

0.081 per kWh. Delivering the same amount of energy (3.5 million kWh useful energy) with firewood will cost US$ 472,800 over the 30 year period, resulting in a levelised energy cost of approximately US$ 0.135 per kWh. Thus the levelised cost of firewood is 40% more than biogas, on an energy equivalent basis. The situation is similar for *Asueyi*.

Table 7.4: Key financial variables of the analysis

Output variable	Project life			Unit
	10 years	20 years	30 years	
Asueyi				
NPV	-7,004	78,697	169,302	US$
IRR	8.3	17.7	19.6	%
Digester size	300	300	300	m^3
Capital cost	90,690	90,690	90,690	US$
Average revenue per year	19,066	34,259	65,595	US$
Akrofrom				
NPV	-832	147,905	302,579	US$
IRR	9.9	18.7	20.5	%
Digester size	500	500	500	m^3
Capital cost	150,791	150,791	150,791	US$
Average revenue per year	31,757	57,063	109,257	US$

If the gas produced were sold to the community, the NPV over the 30 year lifetime of the project is US$ 169,000 with an IRR of 19.6% in the case of *Asueyi*. The payback is reached in the 8th year. As shown in Table 7.4, discontinuing the project after 10 years results in a negative NPV, rendering the project unprofitable for a commercial enterprise. However, discontinuing after 20 years makes the project profitable with an NPV of US$ 79,000 and an IRR of 17.7%. Also for the *Akrofrom* community, the project is profitable for the 30 year and 20 year project duration periods but unprofitable for a 10 year duration. Payback is in the 7th year.

The financial analysis shows that, to the extent that households are available and willing to purchase the gas for cooking, a larger plant is more profitable than a smaller plant, which agrees with general economic principles. This however, is dependent on the availability of manure in close proximity to the locations where agro-process waste are generated. Even though cassava peels are abundant in most cassava processing locations, transporting manure from other locations will increase the project costs.

The combined production cost for both plants is summarised in Figure 7.4. Over the lifetime of the project, labour costs constitute 40% of total project costs. This is followed by the cost of digester establishment. Transportations costs are low because feedstock and water are available within the premises of the processing sites which reduces the need for transportation over longer distances. The analysis also assumes manure availability from within the community which avoids the need for higher manure transportation costs.

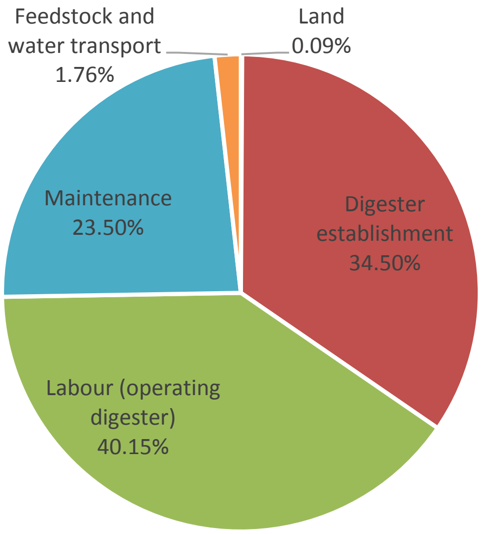

Figure 7.4: Distribution of total production costs over project lifetime

The introduction of environmental taxes could encourage companies to shift to cleaner fuels for agro-processing. At the same time, the state could examine financial avenues to assist agro-processing plants to explore options of generating biogas from their waste resources, using resources such as the RE Fund, when it becomes operational. This could then make way for the introduction of a gradual ban on the use of firewood for agro-industrial processing while granting tax breaks for modern energy interventions. Government and the Environmental Protection Agency (EPA) could lump these projects together and trade for carbon credits to defray the cost of such subsidies.

One of the models that could be used to obtain manure for bigger biogas plants is a peel-manure exchange programme where processing plants livestock farmers will come to some arrangement with livestock farmers to convey manure to cassava processing sites in exchange for cassava peels to feed livestock. This could make cheap manure available in large quantities for the production of biogas. As indicated previously, only a little fraction of the peels is used for cassava production due to lack of manure.

7.3.3 Job Creation and Income Generation Potential

Summary of job creation potential and firewood displacement from the two plants are shown in Table 7.5. Similar to the analysis in Chapter Six, it is expected that unskilled jobs will be sourced from within the locality. Details of direct jobs are presented in terms of man-hours per year. The unskilled labour requirement for both projects, in the investment year, is equivalent to 10 people engaged full time for all business days in the year. In the operating years, the projects would create approximately 4 permanent full-time unskilled jobs and part time management position for regular monitoring of technical performance. Labour services in the operating years include those for loading of feedstock and monitoring of digester performance, and the collection of manure to the project site. The direct unskilled job creation stands at one job per 200 m^3 digester. This is slightly lower than that calculated for the bio-digester in Chapter Six. The low unskilled job creation is attributable to the fact that feedstock meant for the digesters are produced on site and will not have to be transported over longer distances.

Income effects are directly related to the number of jobs created on the project. Unskilled labour man-hour rate is estimated at US$ 0.5. For an 8-h working day, this exceeds Ghana's minimum wage for the year 2014 which is GHC 6 or approximately US$ 2.14 per day (using exchange rate of 1 US$ to GHC 2.81 on May 1, 2014 when new minimum wage was announced)[21]. The hourly wage is also higher than current labour rate in the study communities which is less than US$ 0.3 per hour.

Another important benefit of biogas production is the effluent, which can be returned to cassava fields as organic fertiliser after appropriate treatment. This extra activity could be considered in order to create a near zero waste system.

Table 7.5: Annual socio-economic benefits of project

Socio-economic indicator	Unit	*Akrofrom*	*Asueyi*
Skilled jobs – investment year	man-hours	16,088	9,659
Unskilled jobs – investment year	man-hours	12,873	7,745
Skilled jobs – annual over 30 year period	man hours	1,560	1,560
Unskilled jobs – annual over 30 year period	man-hours	113,843	103,398
Biogas available per year	m^3	45,744	27,463
Amount of firewood displaced per year	t	198	119

7.4 Summary of Findings

Agro-process industries continuously generate waste throughout the year which can be used for the generation of biogas or other energy carriers. This chapter analysed the possibility of using cassava peels from *gari* production industries for the production of biogas. The study was conducted in two communities in the Techiman Municipality in Ghana, which is a major cassava cultivation and processing hub in the country. The

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[21] Exchange rate information from http://www.oanda.com/currency/converter/

two case study agro-processing plants in the two communities each process between 7,000 and 8,000 t of cassava per annum, generating in excess of 4,500 t of waste. The availability and proximity of manure is critical to the successful and cost effective production of biogas from cassava waste. A lot more peels are generated than manure could be available to ensure maximum utilisation. It is estimated that a combined total 800 m^3 plant in both processing plants could displace a little over 300 t of firewood per year. In a business-as-usual scenario, this chapter has shown that approximately 1.3 million tonnes of firewood will be needed by 2030 to produce *gari* in Ghana. Based on the amount of firewood currently used for *gari* production, it has been shown that over a 30 year period, utilising firewood will cost 40% more than using biogas, on an energy equivalent basis. Job creation is lower compared to the analysis for community farm wastes. This is because feedstocks in agro-industrial systems are produced onsite and its gathering will not generate extra employment.

CHAPTER EIGHT

8.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The aim of this chapter is to draw conclusions and make recommendations based on the original research objectives. The significance and impact of the results obtained from the various chapters are presented. The socio-economic impact case studies are also discussed, which focus on the key indicators that were put forward in the methodology.

8.1 Conclusions

This thesis set out to achieve three principal objectives as follows:

1. Analyse technical potential of bioenergy feedstock in Ghana;
2. Analyse possible contribution of bioenergy feedstock to energy mix in Ghana and its impact at the national level; and
3. Study the socio-economic impacts of implementing bioenergy programmes, using biogas as a case study.

8.1.1 Assessment of Bioenergy Feedstock Potential

The assessment of bioenergy feedstock was done with established methodology and has estimated that in 2011, the technical potential of bioenergy in Ghana amounts to approximately 275 PJ. This is slightly higher than 268 PJ total final energy consumed in the 2012. The potential is estimated from four principal sources: agricultural residue (both crop residue and agro-industrial residue), livestock manure, municipal solid waste, and wood waste. Agricultural residue is the principal feedstock source, constituting more than 80% of the estimated energy potential. Of the total agricultural residue potentials, cassava residues alone account for 60%, with cereals contributing 17%. Residues from notable agro-industrial activities like *gari* production, starch production, palm oil production and rice milling offer higher opportunities for energy generation since they are often generated in centralised locations where conversion plants could be built and resulting energy used on site, with excess exported. Indeed, some oil palm milling companies already generate electricity from oil palm residue but the potential is higher, compared to the existing generation. Wood waste also offer potentials for electricity generation due to its concentration at wood felling and timber production sites. In addition to agro-industrial and wood residues, organic component of municipal solid waste from urban centres are also potential electricity generation sources using technologies such as landfill gas recovery from engineered landfill sites. Residues from cereals, the rest of the crops, and livestock are scattered and could be more suited for biogas production within communities where they are generated. However, cereal residues from large scale plantations could be explored for electricity generation and ethanol production. It is also possible to collect residues from clusters of communities for same purpose.

It must be emphasised, however, that project feasibility studies often go beyond the technical potential by considering the economic potential of biomass, which would be lower than the technical potential. In view of this, it is expected that the economic potential will be slightly lower than the technical potential as it is dependent on conditions in localities where projects will be sited. It is therefore recommended that project developers consider projects on a case-by-case basis before going ahead with project implementation.

8.1.2 Perspectives of Bioenergy Contribution to National Energy Mix

The potential contribution of the identified resources to Ghana's energy mix was examined using the LEAP model. The analysis considered bioenergy contribution to transportation, electricity generation and residential fuel use. The thesis has shown that the use of bioenergy as alternative fuel for transportation and electricity generation can reduce the GHG intensity in the country. Also, its use as cooking fuel source, such as biogas, will reduce dependence on woodfuels for rural communities.

In a business-as-usual scenario, Ghana's thermal electricity generation will reach 80% of total electricity generation by 2030, increasing the national electricity grid's carbon intensity from 0.18 tCO_2eq per MWh in 2015 to 0.28 tCO_2eq per MWh in 2030. Increasing demand for petroleum fuels will result in demand side emissions increasing from 12 $MtCO_2eq$ in 2015 to more than 28 $MtCO_2eq$ by 2030. The final emission in 2030 is expected to reach 40.8 $MtCO_2eq$ under a business-as-usual scenario.

The analysis points out that the use of bioenergy in electricity generation may represent 4 % of all electricity generated by 2030. Likewise, the use of bioenergy in the transport sector may account for 21% of fuels used. These possible changes in the two sectors would result in the reduction of the nation's energy greenhouse gas emissions by about 6 million tonnes of CO_2eq by 2030, which represents a reduction of close to 14% over the business-as-usual emissions. In the residential sector, increased consumption of biogas and increased use of improved cookstoves and charcoal carbonisation technologies could replace up to 138 PJ of woodfuels in 2030.

The results obtained from this analysis point out that it is important for Ghana's current energy system to advance towards a greater use of modern bioenergy to substitute fossil fuels and ensure environmental sustainability. If bioenergy feedstock resources in Ghana are not developed in a timely manner, Ghana may lose the opportunity to diversity its energy system. Developing bioenergy has the opportunity to create jobs in especially rural areas where the bulk of agricultural residue potentials are located. A move to bioenergy use would allow Ghana to embrace the three pillars of sustainable development in its energy sector.

8.1.3 Socio-economic Assessment of Biogas Production

The study examined the socio-economics of the production and use of biogas in staple food and agro-industrial systems which has highlighted the possible financial and social benefits of adopting medium scale bio-digesters in Ghana. The assessment was based on five (5) socio-economic indicators selected from those developed by the Global Bioenergy Partnership. The analysis points out that biogas production could create jobs for rural communities and provide income for households. The study concludes that medium sized bio-digesters in remote rural communities could contribute towards about 5,500 man-hours of jobs per year, displace 170 t of firewood and save women within the community some 3,400 h/y not collecting firewood. For communities that commute for up to two hours per day collecting firewood, close to 14,000 h will be saved per annum not collecting firewood. The study has also shown that costs would be lower in agro-industrial systems because feedstock are produced on site, which results in practically insignificant collection and transportation costs.

The analysis points out that larger sized plants will deliver energy at a cheaper cost. In agro-industrial systems, it is possible to build larger sized bio-digesters due to the availability of abundant process residue, but the ultimate size is dependent on manure availability rather than process residue. This is because methane yield is dependent on the presence of manure in the substrate to serve as an inoculum for the production process. One proposed solution to this problem is a manure for cassava waste exchange programme proposed for cassava processing firms.

The development of bio-digesters to provide modern cooking fuels in rural communities has been a success in Asia with notable success stories in China, India and Nepal. These success stories were supported by government legislation and were aimed at reducing forest degradation and introducing environmentally friendly fuel to rural households. Fortunately, recent legislation in Ghana is supportive of such schemes. The Renewable Energy Act encourages the use of biomass to generate energy, especially for rural applications. A Draft Bioenergy Policy Document which is being finalised has also reiterated that an effective strategy to address the energy needs of majority of the rural population is to promote the climbing of the energy ladder. The policy document lay emphasis on the need to move rural households from traditional biomass fuels to more convenient, efficient forms of energy – liquid or gaseous fuels for cooking and heating and electricity for lighting. To move from the present to the stage envisaged will require substantial funding and it is hoped that government will establish the necessary funding scheme to make this a reality. Government must expedite action on the establishment of the RE Fund and pilot some of these rural energy intervention projects in order to examine their feasibility for widespread dissemination in rural communities. This will ensure that communities that cannot access other alternative modern fuels can take advantage of modern biomass technologies to improve their livelihood.

8.1.4 Contribution from Research Findings

This thesis has conducted an extensive and detailed study of bioenergy for Ghana. Based on the methodology used in this thesis, it has been identified that Ghana has strong technical potential for bioenergy. Previous studies have not covered this depth, and have only ended at the theoretical potential which is far higher, compared to the recoverable potential. Again, no known study has moved beyond what resources are available to how they could actually contribute to the energy mix in Ghana. Therefore the bioenergy feedstock assessment makes a contribution towards Ghana's appraisal of bioenergy. The highlight of the feedstock assessment is that bioenergy can be produced and used in Ghana without recourse to agricultural lands, a situation that could potentially create direct conflict with farmers and food production in the country. In the process of conducting the bioenergy feedstock availability, this study has for the first time in Ghana, established RPR values for important bioenergy crops in Ghana.

Developing the bioenergy potential established has environmental and socio-economic impacts. At the national level, this thesis used the LEAP model to show environmental benefits that the use of biomass for electricity generation, transportation fuel production and cooking fuel production could have with respect to GHG emission reduction and woodfuels savings. Direct GHG emissions savings will result from petroleum fuel savings. Indirectly, reduced woodfuels consumption could result in the creation of carbon sinks by trees that could hitherto had been harvested for firewood and charcoal production. The thesis has also shown the approximate amount of biofuels needed between 2015 to 2030 to satisfy Ghana's target for transportation and the benefits that could accrue with respect to land displacement if second generation biofuels were used.

At the local level, this thesis has shown the socio-economic benefits of developing second generation bioenergy using internationally accepted indicators proposed by the Global Bioenergy Partnership (GBEP). No known previous study has been done in Ghana in this regard. Overall, information has been provided on seven (7) out of the sixteen (16) bioenergy sustainability indicators developed by GBEP. This information could assist decision making process on bioenergy development in Ghana.

8.2 Recommendations for Further Research

The following recommendations are made:

1. Future studies should consider the use of appropriate GIS tools to determine location of possible biomass conversion plants.
2. This study only considered socio-economics of biogas production from residues. Future studies should also consider the economic and environmental impacts of

replacing petroleum fuels with second generation ethanol from lignocellulosic materials.

3. Future studies should consider communities who are not on the electricity grid and perform analysis for electrification technologies, similar to the biogas systems study.

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APPENDICES

Appendix 1: Details of Bioenergy Certification Initiatives

Certification Initiative	Summary	Secretariat	Geographical scope	Source (website)
Roundtable on Sustainable Palm Oil (RSPO)	Established in 2004, the principles and criteria for certification are generic, and that is because countries differ in their laws for the same criteria, such as minimum wages for workers for example, and there are cultural and other differences. The principles and criteria are further adapted for use by each country through National Interpretation (NI). The methodology to develop National and Local Interpretation are described in the RSPO Certification Systems document.	Kuala Lumpur, Malaysia	International	http://www.rspo.org/

Roundtable for Responsible Soy Production (RTRS)	RTRS Standard for Responsible Soy Production was created to discuss and reach consensus on a series of Principles and Criteria for certifying soy as a responsible crop. The pillars of the RTRS Standard of Production are: legal compliance and good business practices, responsible labour conditions, responsible community relations, environmental sustainability and good agricultural practices.	Buenos Aires, Argentina	International	http://www.responsiblesoy.org/?lang=en
International Sustainability and Carbon Certification (ISCC)	Certification for sustainability and GHG emissions. In 2010, it received first official state recognition by the German authorities. In July 2011, the European Commission recognized ISCC as one of the first certification schemes to demonstrate compliance with the EU Renewable Energy Directive's (RED) requirements. The ISCC standard comprises six principles and corresponding criteria (1) biomass shall not be	Köln, Germany	First Germany, then EU	http://www.iscc-system.org/en/ Scarlat and Dallemand, 2011

	produced on land with high biodiversity value or high carbon stock; (2) biomass shall be produced in an environmentally responsible way, including protection of soil, water and air and application of Good Agricultural Practices; (3) Safe working conditions through training and education; (4) biomass production shall not violate human rights, labour rights or land rights; promote responsible labour conditions and workers' health, safety and welfare; (5) biomass production shall take place in compliance with regional and national laws and relevant international treaties; (6) good management practices.			
The Council on Sustainable Biomass Production (CSBP)	CSBP is a diverse, multi-stakeholder group developing voluntary biomass-to-bioenergy sustainability standards for the production of feedstocks for second-generation (cellulosic) bioenergy facilities. It is made up of growers,	Washington DC, United States	United States	www.csbp.org

	environmental and social interests, and all sectors of the industry. The intent is to create a sustainable production system from the very outset for the emergent biomass-to-bioenergy industry, with an initial focus on dedicated fuel crops, crop residues, and native vegetation in the United States.			
Roundtable on Sustainable Biofuels (RSB)	Created in 2007 as an international multi-stakeholder initiative that brings together farmers, companies, non-governmental organizations, experts, governments, and inter-governmental agencies concerned with ensuring the sustainability of biomass and biomaterial production and processing. The RSPO criteria cover major economic, social and environmental aspects, including the establishment and management of plantations and processing: (1) transparency, (2) legality, (3) commitment to long-term economic and financial viability, (4)	Geneva, Switzerland	International	http://rsb.org/ Scarlat and Dallemand, 2011

	use of best practices by growers and millers, (5) environmental responsibility and conservation of natural resources and biodiversity, (6) responsible consideration of employees, individuals and communities, (7) responsible development of new plantings and (8) commitment to continuous improvement in key areas			
Global Bioenergy Partnership (GBEP)	GBEP Task Force on Sustainability established in June 2008 and has since developed the GBEP Sustainability Indicators for Bioenergy. The indicators are intended to guide any analysis undertaken of bioenergy at the domestic level with a view to informing decision making and facilitating the sustainable development of bioenergy in a manner consistent with multilateral trade obligations. Details discussed in section 2.6.3	Rome, Italy	International	http://www.globalbioenergy.org/

Appendix 2: Regional distribution of crop residue in order of residue density

	Residue from crop type (t)														
Region	**Maize**	**Rice**	**Millet**	**Sorghum**	**Groundnut**	**Cowpea**	**Cassava**	**Plantain**	**Soybean**	**Yam**	**Cocoyam**	**Sweet Potato**	**Coconut**	**Total (t)**	**Residue Density (t/km^2)**
Eastern	757,404	42,710	-	-	35,707	4,490	1,203,742	427,120	-	341,497	126,721	-	4,034	2,943,424	158
Central	420,879	10,269	-	-	-	-	616,807	80,193	-	7,897	47,174	-	8,068	1,191,286	124
Upper East	156,556	209,442	92,622	138,394	142,638	27,843	-	-	52,911	-	-	21,917	-	842,322	100
Brong Ahafo	904,188	11,615	-	1,409	34,558	12,741	899,606	531,945	-	1,085,671	165,936	-	-	3,647,669	96
Ashanti	361,339	52,860	-	-	20,548	4,177	592,938	488,716	-	235,407	192,719	-	4,034	1,952,738	81
Upper West	171,900	12,489	99,599	160,864	409,475	148,744	-	-	62,076	236,250	-	-	-	1,301,397	72
Volta	203,527	144,257	-	10,637	-	5,189	517,922	31,278	17,504	213,375	24,639	-	4,034	1,172,363	57
Northern	400,584	327,770	144,969	259,962	566,466	218,261	416,023	-	443,296	1,002,804	-	-	-	3,780,136	56
Western	148,261	44,294	-	-	-	-	213,523	281,288	-	38,991	115,387	-	60,510	902,252	40
Greater Accra	9,279	35,922	-	-	-	-	22,421	-	-	-	-	-	-	67,622	21

Appendix 3: District level biomass availability

Region	DISTRICT	Maize	Rice	Cassava	Plantain	G/NUTS	Soybean	Sorghum	Millet	Cowpea	Yam	Cocoyam	Sweet Potato	Sugarcane
Ashanti	Sekyere West	45475	386	66908	21942	1754	0	0	0	0	54910	6757	0	0
	Ejura Sekyidumasi	49479	14728	12730	3605	15187	0	0	0	3394	79815	68	0	0
	Ahafo Ano South	25655	4672	54717	37648	0	0	0	0	0	2759	29555	0	0
	Offinso	39844	1534	38323	32292	1458	0	0	0	131	7387	4500	0	0
	Ahafo Ano North	26092	2106	29419	38160	0	0	0	0	76	5103	21665	0	0
	Sekyere East	28514	896	31440	21735	1955	0	0	0	495	23861	10758	0	0
	Asante Akim South	12093	1632	36129	45329	0	0	0	0	0	1680	21463	0	0
	Asante-Akyem North	28021	1774	25891	44589	0	0	0	0	44	5163	4158	0	0
	Atwima Mponua	9050	3716	24273	40158	0	0	0	0	0	3402	17640	0	0
	Afigya Sekyere	19059	797	28949	20260	166	0	0	0	0	14918	10832	0	0
	Atwima Nwabiagya	14430	2299	30571	22822	0	0	0	0	0	7590	14300	0	0
	Amansie East	10184	1799	28496	34414	0	0	0	0	0	2096	7700	0	0
	Adansi East	7481	8180	35208	15105	0	0	0	0	0	4435	7800	0	0
	Adansi North	8518	1493	34158	22170	0	0	0	0	0	3328	3025	0	0
	Amansie Central	10334	136	25444	20038	0	0	0	0	0	4412	5416	0	0
	Ejisu/Juabeng	7413	3129	25891	17243	0	0	0	0	0	2322	8042	0	0
	Bosumtwe/Atwima/ Kwanwoma	8319	1634	20656	15722	0	0	0	0	37	4196	3396	0	0
	Kwabre	2492	620	23844	10868	0	0	0	0	0	1040	9176	0	0
	Amansie West	6197	969	12812	15649	0	0	0	0	0	4797	5100	0	0
	Obuasi Municipal	1931	189	1623	4052	0	0	0	0	0	2142	1350	0	0

	Kumasi Metro	786	74	1655	4916	0	0	0	0	0	51	20	0	0
Brong Ahafo	Techiman	65973		56946	40968	1478	0	0	0	1869	137397	7569	0	0
	Sene	30162	5750	89043		7838	0	0	0	0	176895		0	0
	Asutifi	23516	635	72554	156275	0	0	0	0	0	868	51447	0	0
	Nkoranza	133605		42236	1854	4321	0	189	0	3762	95013	1205	0	0
	Dormaa	112320	2321	78303	23246	0	0	0	0	0	4760	12397	0	0
	Sunyani	138229	0	43476	33617	0	0	0	0	0	3323	3678	0	0
	Asunafo South	18277	246	64376	102966	0	0	0	0	0	740	33157	0	0
	Kintampo North	105472	149	20068	0	6353	0	339	0	1785	73251	533	0	0
	Wenchi East	59964		51885	0	1522	0	254	0	3351	87302	0	0	0
	Atebubu Amantin	7280	887	102927		5454	0	276	0	1028	83737		0	0
	Pru	10926	340	46653		5744	0	0	0	0	106916		0	0
	Kintampo South	43095		23810	173	0	0	0	0	0	85141	963	0	0
	Asunafo North	20999	328	20117	94783	0	0	0	0	0	679	14119	0	0
	Jaman South	22808		22194	5189	0	0	0	0	0	87496	8795	0	0
	Berekum	48593		42090	16543	0	0	0	0	0	7657	15961	0	0
	Tain	8955		37661		1799	0	351	0	945	67575		0	0
	Tano South	22595	421	50073	24641	0	0	0	0	0	4245	7484	0	0
	Jaman North	10271		9410	2345	0	0	0	0	0	60795	3077	0	0
	Tano North	21218	688	20018	25315	0	0	0	0	0	1882	5552	0	0
Central	Awutu/Efutu/Senya	64005		131947		0	0	0	0	0	572		0	0
	Twifo-Herman/ Lower Denkyira	40529	1393	100603	13952	0	0	0	0	0	878	4714	0	0
	Upper Denkyira	51683	1782	58070	27298	0	0	0	0	0	1305	19087	0	0
	Komenda/Edna Eguafo/Ebire	44965		68790	1481	0	0	0	0	0			0	348

	Agona	27283		35824	16679	0	0	0	0	0	2193	8749	0	832
	Assin North	30009	4940	39823	5202	0	0	0	0	0	564	5105	0	0
	Ajumako/Enyan/ Esunafo	24854		39759	2852	0	0	0	0	0	1773	3989	0	0
	Mfantsiman	31472		29260	600	0	0	0	0	0			0	442
	Cape Coast	20676		38134	508	0	0	0	0	0		894	0	510
	Assin South	21390	1426	19336	6115	0	0	0	0	0	238	2853	0	1804
	Gomoa	26722	222	16648	211	0	0	0	0	0	31		0	2036
	Asikuma/Odoben/ Brakwa	21533	112	20142	1858	0	0	0	0	0	41	38	0	0
	Abura/Asebu/ Kwamankese	15791	376	14516	2875	0	0	0	0	0	301	1744	0	816
Eastern	Afram Plains	83653	439	110050	546	29000	0	0	0	2669	226125	115	0	0
	Fanteakwa	61335	0	127159	71531	0	0	0	0	1401	13913	28846	0	0
	Birim South	75660	19125	87215	47058	0	0	0	0	0	6970	20107	0	0
	West Akim	72280	96	91335	51516	0	0	0	0	0	11250	13626	0	0
	Birim North	49243	9814	75998	47045	0	0	0	0	0	13235	9962	0	0
	Suhum/Kraboa/ Coaltar	40903	0	85870	33887	0	0	0	0	0	1760	2357	0	0
	Atiwa	33130	722	54808	44033	0	0	0	0	0	3488	16525	0	0
	Manya Krobo	59623	6418	66774	3014	0	0	0	0	223	13158	434	0	0
	Akwapim North	45458	0	86244	7105	0	0	0	0	0	1043	1300	0	0
	Kwahu South	26732	0	57032	32870	6657	0	0	0	0	10350	4368	0	0
	Kwaebibirem	35204	5637	49394	28709	0	0	0	0	0	1950	12082	0	0
	Asuogyaman	33453	0	68665	3825	0	0	0	0	0	11921	95	0	0

	East Akim	26976	160	47263	26882	0	0	0	0	0	3536	10158	0	0
	Yilo Krobo	39146	0	52888	2827	0	0	0	0	63	11600	2338	0	0
	Kwahu West	19219	221	61225	14235	0	0	0	0	0	8760	2444	0	0
	Akwapim South	30888	0	51130	7374	0	0	0	0	0	1600	853	0	0
	New Juabeng	24561	0	22977	4664	0	0	0	0	135	840	1112	0	0
Greater Accra	Dangbe West	4867	34762	10044	0	0	0	0	0	0	0	0	0	0
	Dangbe East	796	0	5694	0	0	0	0	0	0	0	0	0	0
	Ga West	1360	952	2728	0	0	0	0	0	0	0	0	0	0
	Ga East	1250	46	2483	0	0	0	0	0	0	0	0	0	0
	Tema Municipal Area	818	97	1318	0	0	0	0	0	0	0	0	0	0
	Accra Metro	188	0	11	0	0	0	0	0	0	0	0	0	0
Northern	Yendi	29619	13580	13076	0	49805	113435	6400	15784	36604	72828	0	0	0
	West Gonja	22090	3994	129580	0	41463	5442	19056	10380	19852	88802	0	0	0
	East Gonga	26716	18186	29218	0	49594	10128	9779	30	24514	129980	0	0	0
	Savelugu Nanton	25688	56367	6603	0	66528	45225	10642	7430	28274	45695	0	0	0
	Nanumba North	14414	2019	51894	0	29950	30573	16107	5495	3802	121044	0	0	0
	Tolon Kumbugu	46725	69098	22952	0	46385	14261	27488	7778	11204	27414	0	0	0
	Nanumba South	13416	3586	35712	0	17572	47816	19820	2654	5371	122208	0	0	0
	Zabzugu Tatale	32248	5656	26784	0	37498	4074	28395	21790	2108	73341	0	0	0
	Tamale Municipality	27113	86213	5208	0	40903	12189	7721	3967	11123	33248	0	0	0
	Sawla-Tuna-Kalba	63866	4991	5642	0	23342	3123	23912	9926	6202	81003	0	0	0
	West Mamprusi	17684	26174	7310	0	42031	19950	15963	17927	12470	25355	0	0	0
	Gushiegu	16594	13489	19251	0	21022	34869	10655	6670	8882	14342	0	0	0
	Saboba/Chereponi	9317	6449	3515	0	26090	12149	24358	8198	8663	46107	0	0	0
	East Mamprusi	6515	3141	4534	0	25553	21280	7880	10344	13139	38735	0	0	0

	Karaga	15474	7563	10416	0	12685	35558	13880	5707	7265	12971	0	0	0
	Central Gonja	11291	3989	30272	0	17916	5806	3383	2174	3701	33963	0	0	0
	Bole	16542	1932	9219	0	5971	5082	7415	3651	3362	28139	0	0	0
	Bunkpurugu Yunyoo	5304	744	2171	0	11376	22335	7108	4802	11725	7633	0	0	0
Upper East	Bawku Municipal	59417	24830	0	0	28242	30223	13834	21503	3612	0	0	5562	0
	Kasina Nankana	16707	63320	0	0	18005	980	42557	16104	1754	0	0	660	0
	Builsa	10686	48705	0	0	27821	735	18467	14414	2408	0	0	3600	0
	Bawku West	18522	32180	0	0	21455	6105	22661	14032	8015	0	0	1612	0
	Garu Tempane	22776	11605	0	0	5160	4256	14746	8948	5005	0	0	2040	0
	Bolgatanga Municipal	12384	7481	0	0	20605	1481	8884	8059	2576	0	0	2375	0
	Talensi-Nabdam	14510	5877	0	0	10912	8292	9313	5001	1743	0	0	2684	0
	Bongo	1565	15060	0	0	10241	840	7932	4393	2730	0	0	3384	0
Upper West	Nadowli	37565	602	0	0	67632	2257	30516	14964	49669	55591	0	0	0
	Wa Municipal	19708	1147	0	0	46328	19866	10939	12603	9773	55233	0	0	0
	Lawra	7833	287	0	0	55708	526	69165	26770	10647	0	0	0	0
	Wa West	13578	4653	0	0	67138	20293	9001	5005	8064	27646	0	0	0
	Wa East	21790	2256	0	0	34636	16520	6241	8889	8335	52936	0	0	0
	Jirapa Lambussie	15434	2091	0	0	69844	838	19130	10068	20929	8925	0	0	0
	Sissala East	30751	708	0	0	35970	824	2352	13511	19958	16569	0	0	0
	Sissala West	25255	722	0	0	31651	952	13520	7608	21368	19350	0	0	0
Volta	Nkwanta	14787	14368	184959	1746	0	2700	1356	0	2423	82933	2311	0	0
	Ketu	53172	22590	59327		0	0		0	0			0	0
	Krachi West	5547	5428	59138	347	0	9842	6389	0	0	44749	122	0	0
	Hohoe	34874	45357	31140	1804	0	0		0	0	8385	326	0	0
	Krachi East	4268	6525	49654	653	0	4962	2891	0	0	49804	227	0	0

	Jasikan	16449	13902	35990	14766	0	0		0	0	8061	11170	0	0
	Kadjebi	15555	13944	21826	9179	0	0		0	0	6795	9002	0	0
	Ho Municipal	9053	2075	19552	1486	0	0		0	0	5404	809	0	0
	North Tongu	5616	14039	8913		0	0		0	171			0	0
	Akatsi	11690		13423		0	0		0	2596			0	0
	North Dayi	8518	2548	7585	619	0	0		0	0	6422	313	0	0
	Adaklu-Anyigbe	9063	1280	6639	54	0	0		0	0	582	50	0	0
	South Tongu	5634	706	9492		0	0		0	0			0	0
	South Dayi	6432	1232	6965	624	0	0	0	0	0	239	310	0	0
	Keta	2885		0		0	0		0	0			0	0
Western	Sefwi Wiawso	21713	7243	31874	59520	0	0	0	0	0	7565	32300	0	0
	Aowin-Suaman	23991	4998	27849	45235	0	0	0	0	0	2924	12240	0	0
	Juabeso	22152	8812	19418	35136	0	0	0	0	0	9013	21080	0	0
	Bibiani/Anwiaso/ Bekwai	13882	3700	22653	40095	0	0	0	0	0	9945	18688	0	0
	Bia	16640	5038	9052	34475	0	0	0	0	0	4250	19095	0	0
	Wassa Amenfi East	13204	2772	13308	25463	0	0	0	0	0	1975	3492	0	0
	Wassa Amenfi West	12813	3687	10199	23040	0	0	0	0	0	2040	2280	0	0
	Mpohor Wassa East	5766	280	18895	7866	0	0	0	0	0	492	3720	0	0
	Wassa West	5400	3159	10664	4485	0	0	0	0	0	522	1425	0	0
	Nzema East	4482	1631	17047	1724	0	0	0	0	0	72	245	0	0
	Jomoro	2434	2318	14133	1620	0	0	0	0	0	48	195	0	0
	Ahanta West	3468	250	11408	1058	0	0	0	0	0	72	480	0	0
	Shama Ahanta East	2330	324	5654	1572	0	0	0	0	0	74	147	0	0

Appendix 4: Details of energy potentials from identified biomass resources in 2011

Crop type	Residue type	Residue amount (wet tonnes)	Moisture content (%)	Residue amount (dry tonnes)	Lower Heating Value (MJ/kg)	Energy potential (PJ)
CEREALS						
Maize	Stalk	814735	15.02	692362	17.71	12.26
Maize	Husks	353420	11.23	313731	17.22	5.40
Maize	Cobs	339827	8.01	312607	19.32	6.04
Rice	Straw	497420	15.50	420319	15.56	6.54
Rice	Husks	85738	13.01	74583	13.04	0.97
Millet	Stalk	508544	63.57	185263	17.78	3.29
Sorghum	Stalk	681788	61.80	260443	17.00	4.43
Total cereals		**3,281,471**		**2,259,308**		**38.94**
LEGUMES						
Groundnut	Shells	134191	13.82	115645	17.43	2.02
Groundnut	Straw	290187	18.86	235458	17.58	4.14
Cowpea	Straw & pods	536920	16.45	448597	15.60	7.00
Soybean	Straw & pods	201526	15.00	171297	12.38	2.12
Total legumes		**1,162,824**		**970,997**		**15.27**
CASSAVA						
Cassava	Stems	8908492	20.00	7126794	17.50	124.72
Cassava	Peelings	977060	20.00	781648	13.38	10.46
Total cassava		**9,885,552**		**7,908,442**		**135.18**

OTHER CROPS						
Plantain	Trunks/Leaves	1472431	93.00	103070	15.48	1.60
Yam	Straw	1106662	15.00	940663	10.61	9.98
Cocoyam	Straw	235401	15.00	200091	17.70	3.54
Sweet Potato	Straw	7671	15.00	6520	10.61	0.07
Coconut	Husks	99856	10.30	89571	18.82	1.69
Coconut	Shells	28598	13.00	24881	10.61	0.26
Sugarcane	Leaves	13050	75.00	3263	16.5	0.05
Sugarcane	Bagasse	23200	48.00	12064	13.38	0.16
Cotton	Stalks	58406	12.00	51397	15.5	0.80
Total other crops		**3,045,275**		**1,431,519**		**18.15**
Cocoa	Pods	**722,917**	15.00	**614,479**	15.48	**9.51**
Oil palm						
Oil palm	EFB	404082	60.00	161633	15.51	2.51
Oil palm	Kernel shells	114197	6.00	107345	18.83	2.02
Oil palm	Fibre	245963	35.00	159876	11.34	1.81
Total oil palm		**764,242**		**428,854**		**6.34**

Wood

Wood residues	**Recoverable amount (wet tonnes)**	**Moisture content (%)**	**Residue amount (dry tonnes)**	**LHV (MJ/kg)**	**Energy potential (PJ)**
Logging residues	216000	50	108000	15.83	1.71
Wood process residues	390000	50	195000	15.83	3.09
Total wood residues	**606,000**		**303,000**		**4.80**

Livestock Manure

Type of Livestock	Manure available per annum (t)	Solid content (%)	Total Solids (t)	LHV (MJ/kg)	Energy potential
Cattle	1,312,248	12	157469.76	19.25	3.03
Sheep	340,501	25	85125.3	18.85	1.60
Goats	750,002	25	187500.5	18.85	3.53
Pigs	373,176	11	41049.36	19.86	0.82
Poultry	191,899	25	47974.688	16.87	0.81
TOTAL	**2,967,826**		**519,120**		**9.79**

Municipal Solid Waste

Region	Annual MSW Collected in 2011 (t)	Moisture content (%)	MSW dry matter (t)	LHV (MJ/kg)	Energy potential (PJ)
Greater Accra	1,126,755	50	563,378	16.95	9.55
Ashanti	960,425	50	480,213	16.95	8.14
Eastern	544,233	50	272,117	16.95	4.61
Brong Ahafo	515,161	50	257,581	16.95	4.37
Central	465,266	50	232,633	16.95	3.94
Volta	210,262	50	105,131	16.95	1.78
Western	202,502	50	101,251	16.95	1.72
Northern	173,229	50	86,615	16.95	1.47
Upper East	95,101	50	47,551	16.95	0.81
Upper West	93,385	50	46,693	16.95	0.79
TOTAL	**4,386,318**	**50**	**2,193,159**	**16.95**	**37.17**