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Electricity generation prospects from clustered smallholder and irrigated rice farms in Ghana

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ABSTRACT

In farming communities in Ghana and the West African region, crop residues are often unused and remain available for valorisation. This study has analysed the prospects of electricity generation using crop residues from smallholder farms within defined clusters. Data was collected from 14 administrative districts in Ghana, where surveys were conducted and residue-to-product ratios determined in farmer fields. Thermochemical characterisation of residues was performed in the laboratory. The number of clustered farms, reference residue yields and residue densities were determined to assess the distances within which it would be feasible to supply feedstock to CHP plants. The findings show that in most districts, a minimum of 22–54 larger (10 ha) farms would need to be clustered to enable an economically viable biomass supply to a 1000 kWe plant. A 600 kWe plant would require 13 to 30 farms. Financial analysis for a 1000 kWe CHP plant case indicate that such investment would not be viable under the current renewable feed-in-tariff rates in Ghana; increased tariff by 25% or subsidies from a minimum 30% of investment cost are needed to ensure viability using internal rate of return as an indicator. Carbon finance options are also discussed.

1. Introduction

Rising fossil fuel prices and increasing concerns about climate change are creating a growing demand for new sources of raw material for sustainable electricity and heat production [13,18,30]. For countries with poor access to electricity and modern fuels, biomass provides an alternative raw material source that can be explored for the production of modern energy to meet rising energy demand and spur socio-economic development [4,8,19,21,25]. Home grown biomass resources offer significant potential for increasing the quantity and controlling the rising costs of raw material to produce energy. Many of these biomass resources are usually underutilized and, in theory, there are considerable opportunities to use them as an energy source [38,42,44].

Already, biomass plays a very important role in global energy provision. In 2014, biomass contributed 14% to global final energy consumption [36]. The so-called 'modern biomass', in the form of heat and power, contributed approximately 5.1%, while traditional biomass contributed 8.9%. Total primary energy supplied from biomass reached approximately 60 EJ [36] and is the main cooking fuel source for about 2.6 billion people in developing countries. It has been predicted that biomass is likely to remain an important global source in developing countries well into the next century [19]. Presently however and as presented from the statistics above, the use of biomass has principally been in traditional forms, as charcoal and firewood, with very low efficiencies. The inefficiencies associated with the use of biomass in traditional forms, as well as associated harmful environmental, health and social effects has enhanced the growing interest in the search for better application of biomass globally [17,47].

The task facing technology developers and policy makers is to move beyond the use of biomass in traditional forms and to introduce technologies that utilize biomass to produce modern fuels such as electricity and heat at both small and large-scale levels [15]. Current research and analysis is therefore geared towards shifting away from the use of biomass in traditional cook stoves and other inefficient conversion systems to its use as raw material for the production of energy carriers using more efficient conversion processes [16,20,40,44]. The use of biomass in modern forms can contribute to increasing the share of renewable energy and decrease the reliance on fossil fuels. In addition, the use of biomass

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in modern forms can have important environmental benefits [5,10,14,26]. Biomass is also an indigenous energy source available in most countries and its deployment on a larger scale may help diversify the fuel-supply in many situations, which in turn may lead to a more secure energy supply [3,41].

The successes of any new form of biomass energy will most probably depend upon the use of advanced technology at a reasonable cost. Among the important drawbacks of modern bioenergy is the complexity of the supply chain (from biomass sourcing to energy consumption) and the economic costs associated with the conversion of the resource. For this reason, the integration of biomass in the energy planning of a community/country requires the development of advanced planning and economic tools that allow for assessing and optimizing costs in order to identify the optimal location for biomass investments [9,14]. Indeed, if bioenergy is to have a long-term future, it must be able to provide affordable, clean and efficient energy forms. A number of studies have been conducted into the potential of biomass to provide modern fuels (see for example [6,28,29,32,37,39,44]).

Like many other developing countries, biomass is a dominant energy source in Ghana [24]. In 2014, traditional biomass contributed 39% to primary energy supply. In rural communities, a little below 90% of households use woodfuel as their main cooking fuel. Because of the agrarian nature of Ghana's rural economy, there are opportunities to use biomass resources for the production of modern fuels such as biogas, to complement traditional biomass use in rural communities [7]. In urban communities, residues from oil palm mills and timber processing, as well as waste from fruit processing and crop residue, offer interesting possibilities for the production of electricity and heat for internal applications and also for export into the grid. One of the aims of Ghana's Renewable Energy Act (RE Act), which was enacted by parliament in 2011, is to promote the utilisation of biomass for the generation of electricity and heat. In line with this, a number of scientific studies have been conducted which indicate a high potential for modern biomass fuels in Ghana. Notable studies include those by Duku et al. [12], Mohammed et al. [31] and Kemausuor et al. [24]. However, these studies have focused on aggregated feedstocks at the national level. There is limited study on potentials of feedstock at the community level, where crop residues could be used in small and medium scale technologies for distributed generation. The aim of this study was therefore to analyse small farm typologies and irrigated rice farms in selected districts in Ghana to determine prospects of using crop residues within defined clusters to generate electricity, with a high replication potential across the country.

2. Methodology

2.1. Crop residue assessment methodology

The first stage in the analysis of biomass for electricity generation is the assessment of biomass resource availability. The resource assessment is important as it goes hand-in-hand with technical feasibility study, and provides the baseline for financial pre-feasibility studies. For this study, the prospects of using crop residues from small-scale aggregated farms and irrigated large rice farms were investigated in a fieldwork that principally considered types of crops cultivated, farm sizes, and potential residue yield from fourteen (14) districts in Ghana. A summary of the methodology is presented in Fig. 1. The districts were selected to reflect the different agro-ecological zones in the country, from the forest zone, through the transitional zone, to the savannah zone. The selection was also based on districts that have relatively high crop production figures within each agro-ecological zone, based on earlier studies by Kemausuor et al. [22]. Crop residue available was estimated using the Residue-to-Product Ratio (RPR). Fieldwork to determine RPR was conducted in twenty-eight (28) farming communities, two (2) each from the fourteen selected districts (see Table 1). Maize is cultivated in all the selected districts and is also the commonest crop cultivated in the country by area. Every district

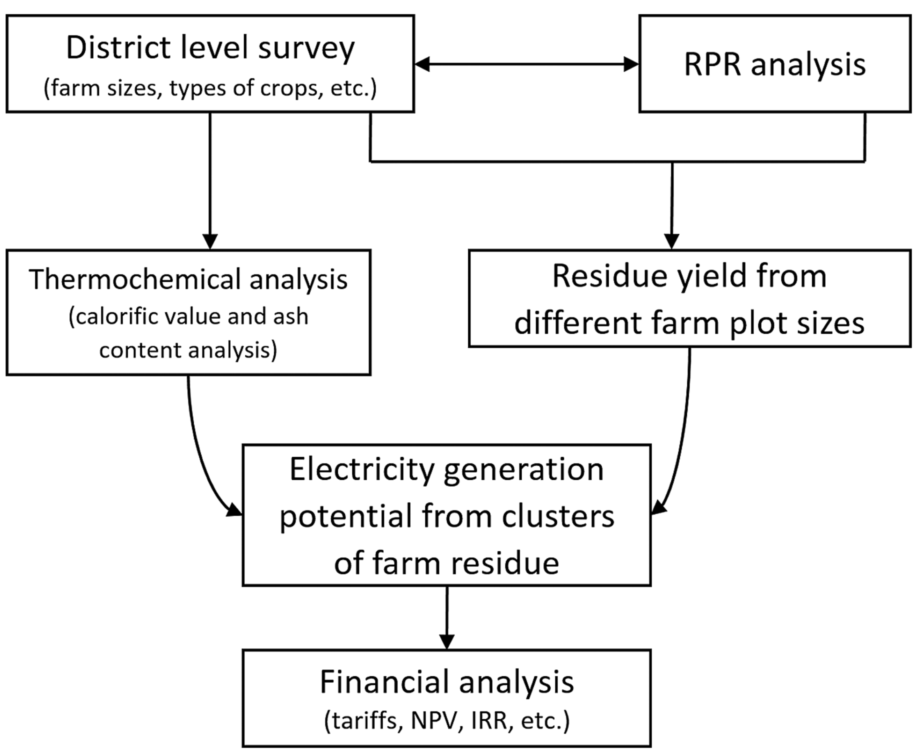

Fig. 1. Summary of methodology.

Table 1
Districts where small/medium holder farms were visited.

District	Agro-ecological zone	Main crops
Ejisu Juaben	Deciduous forest	Maize, rice, cassava
Asante Akyem north	Deciduous forest	Maize, rice, cassava, cocoa
Sunyani west	Guinea Savanna	Maize, yam and cassava
Nzema East municipal	Rainforest	Maize and coconut
Ejura Sekyedumasi	Transitional zone	Maize
Lawra district	Guinea Savanna	Millet, sorghum, maize and groundnut
Ga East Municipality	Coastal Savannah	Maize and cassava
Nkoranza	Transitional zone	Maize and cassava
Techiman	Transitional zone	Maize and cassava
Kintampo North	Guinea Savana	Maize and cassava
Dormaa	Transitional zone	maize and cassava
Sekyere West	Deciduous forest	Maize and cassava
Kintampo south	Transitional zone	Maize and cassava
Wenchi	Transitional zone	Maize and cassava

Table 2
Major irrigated rice production sites in Ghana.

Irrigation scheme	Area (hectares)	Rice production (tonnes/year)
Kpong irrigation	1896	9482
Tono	1050	5250
Afife/Whetta	870	4350
Bolgatanga	310	1550
Aveyime	53	268
Okyereko	50	250
Anum valleys	50	250
Colinga	40	200

in the country cultivates maize as one of the main crops. Cassava was the next most common crop, cultivated in the forest and transition agro-ecological zones in the country. Other crops, including yam, sorghum and millet are the least common, restricted to the savannah zone. In all, ten (10) farms were randomly selected from each farming community, bringing the total number of farms to two hundred and eighty (280). RPR was determined using methods described by Ayamga et al. [2] and Kemausuor et al. [23]. Data on major crops, farm sizes as well as crop yields in the selected districts were obtained from the district offices of the Ministry of Food and Agriculture. Data on medium and large-scale irrigated rice fields was also obtained from the Ghana Irrigation Development Authority (GIDA) in order to assess husks and straw from larger scale farms (See Table 2).

The RPR obtained from the field experiments in the various districts, as well as the production amounts and yield per ha of the crops under consideration were used to determine the various residue potentials for 1 ha, 5 ha and 10 ha small holder farms.

Equation (1) was used to determine the amount of crop residues available.

$$P_{AR} = \sum_{i=1}^{n} (C_i \times RPR_i) \tag{1}$$

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.

2.2. Thermochemical characteristics of crop residues

Thermochemical characteristics of crop residues were determined based on laboratory experiments and complimented with data from Duku et al. [12] and Brew-Hammond et al. [7]. Of the residues considered in this study, thermochemical characteristics were determined in the laboratory for corn stover, corn husks, corn cob, rice husk and millet stalk. Fresh samples of these residue types were collected during the fieldwork and Lower Heating Value (LHV) and ash content determined in the laboratory. The methods used were ISO 1928 for LHV, using a bomb calorimeter and ISO 1171 for ash content, using a Nabertherm L-240H1SN muffle furnace.

2.3. Approach to electricity generation feasibility

2.3.1. Technologies

Biomass-to-electricity technology systems are already in use in power plants in several countries and industries, notable among which are the sugar-cane milling and timber processing industries [15]. Capacities of these plants range from a few megawatts to hundreds of megawatts. Depending on the power output capacity required, the most widely used technologies are the Steam Rankine cycle and the Organic Rankine (ORC) cycle [30]. Both technologies are fully mature and readily available; commercial steam Rankine cycles are used in power plants with generation capacities above 2 MW, while ORC are used for smaller plants. A third technology, fluidized bed gasification, has also been developed for the use of biomass waste, and there are a few Combined Heat and Power (CHP) plants in the capacity range of 1–10 MW in operation [30]. The main advantage of gasification is a slightly higher electrical generation efficiency (up to 25%–28%), but synthesis gas cleaning, purification and waste management requirements are complex and currently there are very few full commercial suppliers on the market offering this technology with the same level of reliability as ORC plants. Tables 3 and 4 show the technology and the technical assumptions considered in the feasibility analysis discussed in this paper.

2.4. Financial viability

2.4.1. Financial appraisal methodology used

The main purpose of the financial analysis is to use the project cash flow forecasts to calculate suitable net return indicators. Two

Table 3
Energy conversion technology considered.

Type of waste	Electrical power (MW)	Technology considered
Biomass with high ash contents and/or low density and/or high Alkali content (typically herbaceous biomass and straw – covering all biomass types considered in this study)	600 kW < P < 2 MW	Organic Rankine Cycle (ORC) with biomass boiler

Table 4
Assumptions used for analysis of electricity generation plants.[a]

Boiler efficiency	85%
ORC cycle electric efficiency	18.5%
Minimum hours of operation per year	7500 h
Conservative estimation of LHV	Considering 30% MC (on dry basis) of biomass received at the plant

[a] Based on information from commercial plants developed by one of the most reputed ORC CHP technology developer in Europe, TURBODEN from Italy.

financial indicators were considered for the financial analysis:

- The Net Present Value (NPV); and
- The Internal Rate of Return (IRR).

The Net Present Value of a project is the sum of the discounted net flows of a project. The NPV is a very concise performance indicator of an investment project: it represents the present amount of the net benefits flow generated by the investment expressed in one single value with the same unit of measurement used in the accounting tables.

The Net Present Value of a project is defined as shown in Equation (2).

$$NPV = \sum_{t=0}^{n} a_{tS_t} = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \ldots + \frac{S_n}{(1+i)^n} \tag{2}$$

where S_t is the balance of cash flow at time t and a_t is the financial discount factor chosen for discounting at time t.

NPV is a very simple and precise performance indicator. A positive NPV, NPV>0, means that the project generates a net benefit and is generally desirable in financial terms. When comparing projects in financial terms, one with higher NPV is preferred.

The Internal Rate of Return (IRR) is defined as the discount rate that zeroes out the net present value of flows of costs and benefits of an investment as shown in Equation (3). The Internal Rate of Return is an indicator of the relative efficiency of an investment.

$$NPV = \sum \frac{S_t}{(1+IRR)^t} = 0 \tag{3}$$

The methodology used for the determination of the financial return is the Discounted Cash Flow (DCF) approach with the following assumption: only cash inflows and outflows are considered (depreciation, reserves and other accounting items which do not correspond to actual flows are disregarded).

2.4.2. Base scenario financial assumptions

In the base scenario, the composition of the capital required for the implementation of a project is distributed as follows: 70% debt; 30% own funding; 0% subsidy.

Key assumptions forming the basis for major financial/economic inputs to the financial analysis for the feasibility study are described below:

- The plant would be available for operation for 7500 h in a year thus giving a capacity factor of 85%.
- Cash flows are discounted over a period of 20 years at a rate of 10%–12% [21,25,33,35].
- Loan Repayment is over a period of ten (10) years, at an interest rate of 4.5% (international rates in EUR)
- The plant will enjoy a 100% exemption from income tax payment for the first 5 years of operation based on incentives for 'rural' development projects provided by the Ghana Investment Promotion Council.
- Straight-line depreciation method is assumed for the lifetime of the project.

2.5. Project revenues

2.5.1. Electricity

The feed-in-tariff (FiT) in Ghana is the regulated price that electricity distribution utility companies would pay to renewable energy generators. The Ghana Public Utilities Regulatory Commission (PURC) published the first FiT in August 2013 and updated same in October 2014 (see Table 5) in line with requirements of the Renewable Energy Act. As at the latest announcement, FiTs in Ghana are valid for 10 years but there are indications of an incoming 20-year FiT in the next review, following industry request. At the time of performing this analysis, the 20-year FiT is not published yet, hence the analysis used the latest 10-year FiT shown in Table 5. The 2014 FiTs introduced maximum capacity limits for technologies with high variability (i.e. solar and wind) due to the limited capacity of the transmissions and distributions systems to manage highly variable loads. Limits were not imposed on biomass and hydro plants. Biomass FiTs vary between US dollar cents 17.5 to 19.8, depending on the technology type and feedstock source. This study assumes that 100% of the electricity generated from the plants (after internal consumption) is exported and sold to the grid (either the national grid or a dedicated mini-grid), under the reference FiT adopted in Ghana.

Table 5
FiTs published by the PURC.

Electricity generated from Renewable Energy Technologies/Sources	FiT (GHp/kWh) Effective October 01, 2014	US cents/kWh equivalent	Maximum Capacity (MW)[a]
Wind with grid stability systems	55.7369	17.4254	300 MW
Wind without grid stability systems	51.4334	16.0800	
Solar PV with grid stability/storage systems	64.4109	20.1372	150 MW
Solar PV without grid stability/storage systems	58.3629	18.2464	
Hydro (≤10 MW)	53.6223	16.7643	No Limit
Hydro (10 MW>≤100 MW)	53.8884	16.8475	No Limit
Biomass	56.0075	17.5100	No Limit
Biomass (Enhanced Technology)	59.0330	18.4559	No Limit
Biomass (Plantation as Feed Stock)	63.2891	19.7865	No Limit

[a] Maximum capacity was introduced in 2014. Exchange rates: 1US$ = GHC 3.1986.

Table 6
LHV and ash content obtained from laboratory analysis.

Residue type	LHV (kJ/kg)	Ash content (%)
Corn stover	17,706 ± 24	4.97 ± 0.14
Corn husk	17,221 ± 22	2.70 ± 0.27
Corn cob	19,322 ± 19	1.17 ± 0.01
Groundnut shell	17,432 ± 22	7.05 ± 0.27
Rice husk	13,035 ± 13	24.47 ± 0.40
Millet stalk	17,765 ± 25	2.44 ± 0.07
Cocoa husk[a]	15,480	11
Sorghum stalks[a]	17,000	3.9
Yam Straw[a]	10,610	16.1
Cassava peels[a]	13,380	4.8
Coconut shells[a]	18,000	4

[a] [12]; [7].

2.6. Sensitivity analysis

A basic sensitivity analysis was conducted to assess the impact of an eventual change of the revenues and expenses in the project's expected return. Sensitivity analysis allows the determination of the 'critical' variables or parameters of the model. Such variables are those whose variations, positive or negative, have the greatest impact on a project's financial performance. The analysis is carried out by varying one variable at a time and determining the effect of that change on IRR. By adjusting these variables, it is possible to more confidently project real potential return of the power plant. The critical factors in this analysis are the selling price for electricity, the capital costs, the possibility to benefit from subsidies and/or carbon finance, and the eventual supply cost of the biomass (agricultural waste). The sensitivity was done as follows:

- FiT range from 180 to 350 US$ per MWh
- Eventual biomass (agricultural waste) cost of 5 and 10 US$ per tonne.
- Level of subsidy to initial investment, from 10% to 70%
- Carbon credits at 10 and 130 US$ per tonne CO_2 equivalent.

3. Results and discussion

3.1. Heating value analysis

The results from the LHV and ash content analysis is presented in Table 6. LHV ranged from a minimum 13,000 kJ/kg for rice husk to a maximum of 19,300 kJ/kg for corn stover. The ash content was the exact reverse, starting with a minimum of 1.17% for corn cobs, to 24.47% for rice husk. While we have not sighted any publication that reports LHV for these resources based on experimented results performed on Ghana specific residue, the LHV obtained for corn and millet residues are notably higher than international data reported in Duku et al. [12] and Brew-Hammond et al. [7]. On the other hand, LHV obtained for rice husk is lower than data reported in those same publications. An article by Thomsen et al. [43] on experimental results from residues collected in Ghana only analysed ethanol and biomethane potentials of the residues, relying on Buswell's formula to estimate the products from the anaerobic breakdown of a generic organic material. For samples that were not analysed in the laboratory, the LHV and ash content were obtained from Duku et al. [12] and Brew-Hammond et al. [7]. These included cassava peels, yam straw, coconut shells and sorghum stalks.

3.2. Residue generation potential in small holder farms

From the survey conducted and data obtained from the respective district offices of the Ministry of Food and Agriculture, smallholder farms in the various districts have been categorized into 3 land areas: small (approximately 1 ha), medium (approximately 5 ha) and large (approximately 10 ha). Large commercial scale farms of tens and hundreds of hectares were not considered in this analysis. Using the waste type generated, the respective RPR, and yield per hectare obtained in each of the districts, the specific yields for each farm category have been determined as shown in Table 7. For example, in the Ejisu-Juaben District, 1 ha sized farms each of maize, rice and cassava will produce approximately 37 tonnes of residue per year. Medium and large farms (5-ha and 10-ha) of those same crops would produce approximately 183 and 366 tonnes of residue per year respectively. Of the fourteen districts, the Nzema East Municipality, the only district in the rainforest agro-ecological zone, had the highest residue yields. Generally, the forest regions had higher residues, compared to the transitional and savanna zones. Also, residue generation from coconut and cassava is much higher on a per hectare basis, compared to the other crops. Based on the estimated residue yields, the residue density was computed as shown in the last column of Table 7.

Having determined the residue yields, the minimum yields needed to feed CHP plants are summarized in Table 8. For rice husks

Table 7
Expected yield from clustered small holder farms.

District	Region	Main crops	Small holder farms categories reference residue yields (tonnes/year)			Residue density (kg/km^2 day)
			Small 1ha	Medium 5ha	Large 10ha	
Ejisu Juaben	Ashanti	maize, rice, cassava	37	183	367	10,041
Asante Akyem north	Ashanti	maize, rice, cassava, cocoa	50	250	499	13,677
Sunyani west	Brong-Ahafo	maize, yam, cassava	23	113	227	6214
Nzema East	Western region	maize and coconut	54	268	56	14,674
Ejura Sekyedumasi	Ashanti	maize	4	19	38	1027
Lawra district	Northern region	millet, sorghum, maize, groundnut	24	119	239	6534
Ga East	Greater Accra	maize, cassava	24	118	237	6488
Nkoranza	Brong-Ahafo	maize, cassava	34	167	333	9134
Techiman	Brong-Ahafo	maize, cassava	33	165	329	9025
Kintampo North	Brong-Ahafo	maize, cassava	27	137	273	7490
Dormaa	Brong-Ahafo	maize, cassava	27	136	273	7490
Sekyere West	Ashanti	maize, cassava	32	162	324	8871
Kintampo south	Brong-Ahafo	maize, cassava	34.	170	341	9332
Wenchi	Brong-Ahafo	maize, cassava	30	150	299	8195

Table 8
Example of reference minimum yields for CHP plants using specified residue type.

Residue type	Minimum CHP plant Power output (kWe)	Annual Electricity generation at 7500 h/year (MWh/year)	Annual residue required at 15.72% electrical efficiency[a] (t/year)	Daily average residue needed (t/day)
Rice residue	600	4500	7896	22
	1000	7500	13,160	36
	2000	15,000	26,320	72
Cocoa husk	600	4500	6666	18
	1000	7500	11,109	30
	2000	15,000	22,219	61
Maize residue	600	4500	6514	18
	1000	7500	10,857	30
	2000	15,000	21,714	59

[a] Based on data obtained from the laboratory.

for example, a 1000 kWe plant generating 7500 MWh/year of electricity will require approximately 36 tonnes/day of residue. This has been computed for various capacities of plants, from 600 kWe to 2000 kWe. Determination of minimum yields resulted in the computation of the minimum number of clustered small holder farms needed to consider for various capacities of potential CHP plants with details shown in Table 9. Using the set of assumptions described in Table 4, the minimum input biomass availability (in tonnes per day) has been calculated for each size of CHP plant. Below 200 kWe, the technical reliability of CHP plants is not completely mature. Gasification combined with internal combustion engines is commonly regarded as the most promising conversion technology given its higher efficiency than ORC, but to date it is not a fully commercial technology. The use of gasification would in any case need a preliminary phase of in-country (pilot) validation, preferably at a laboratory scale.

Table 9 shows that in the majority of districts, a minimum of 33–53 large (10 ha) farms would need to be clustered to enable a viable supply to a 1000 kWe CHP plant. A 600 kWe plant would require 13 to 30 farms. With regards to medium or small farms, the minimum number of clustered farms would be much higher. Two districts: Nzema East and Asante Akyem north, have slightly better conditions than the rest, needing a minimum of 22 large (10 ha) farms to enable a 1000 kWe CHP plant.

These requirements are rather restrictive, given the rather dispersed nature of smallholder farms. Using a formula proposed by Velo [46] (see details in Fig. 2), the radius of dispersion of the small holder farms is also indicated. For the case of 1000 kWe CHP plant in Nzema East or Asante Akyem north, it can be noted that the required minimum 22 farms should be clustered in an area of about 800 m radius from the location of the CHP plant. Within these radius references, and considering a reference of local biomass transport costs of GHC 65 for a load of 2 tonnes at distance of 7 km, transport costs would stay between 17,000 and 18,000 US$ per year.

For further distances, the cost of biomass would increase and seriously challenge the profitability of a CHP plant. The supply logistics will be specific to each case and the residue collection points should be optimized in terms of the location of the small farms, and the CHP plant siting needs to be optimized in terms of collection points and point of feeding into the grid. Therefore, based on the identification of those districts with better prospects carried out in this study, a site specific basic engineering outline will be needed to define the technical and logistic conditions in detail for each eventual CHP plant development, to finally ascertain the technical viability. Once the technical viability is clear, then specific business models can be considered and adapted to the case of the small holder farms, the security of supply, the specific land ownership regimes, and the potential interest of public or private investors in CHP plant development.

3.3. Financial analysis

3.3.1. Base case financial results

Summary results of a 1000 kWe plant is presented in Table 10 as a case study. Experience has shown that larger scale plants often have better unit cost, hence the decision to choose the larger of the two plants from the technical analysis for financial analysis. The investment cost considered (from consultations with industrial CHP system suppliers) is approximately US$ 6.5 million or US$ 6500 per kWe installed. Construction will take place in year ‘zero’ and the plant is assumed to serve a lifetime of 20 years. Electricity sales would amount to about US$ 1.4 million a year. The base scenario's NPV over the 20-year project lifetime of the project is US$

Table 9
Number of small holder clustered farms needed for various plant sizes.

District	Min no. of farms for a 600 kWe plant			Min no. of farms for a 1000 kWe plant			Ideal radius of cluster (km)	
	1 ha	5 ha	10 ha	1 ha	5 ha	10 ha	600 kWe plant	1000 kWe plant
Ejisu Juaben	196	39	20	326	65	33	0.8	1.0
Asante Akyem north	144	29	14	239	48	24	0.7	0.9
Sunyani west	316	63	32	527	105	53	1.0	1.3
Nzema East municipal	134	27	13	223	45	22	0.7	0.8
Ejura-Sekyedumasi	1911	382	191	3185	637	318	2.5	3.2
Lawra district	300	60	30	501	100	50	1.0	1.3
Ga East Municipality	303	61	30	504	101	50	1.0	1.3
Nkoranza	215	43	21	358	72	36	0.8	1.1
Techiman	218	44	22	363	73	36	0.8	1.1
Kintampo North	262	52	26	437	87	44	0.9	1.2
Dormaa	262	53	26	437	88	44	0.9	1.2
Sekyere West	221	44	22	369	74	37	0.8	1.1
Kintampo south	210	42	21	351	70	35	0.8	1.1
Wenchi	240	48	24	399	80	40	0.9	1.1

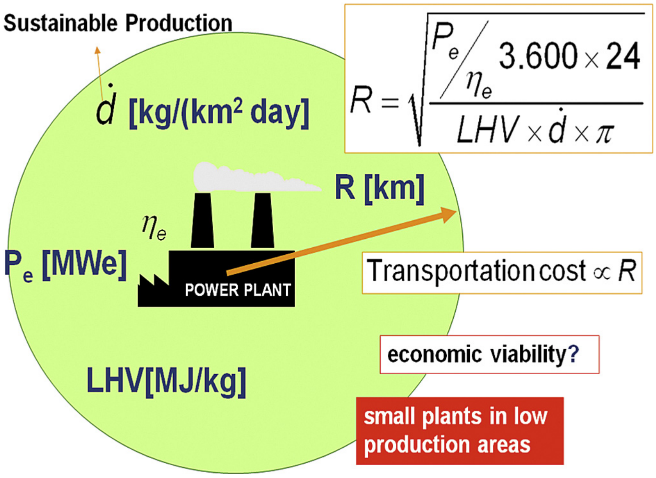

Fig. 2. Biomass utility size as a function of the area biomass sustainable production. Source [46].

Table 10
Summary results for base scenario of a 1000 kWe ORC plant.

Operating conditions	Value	Unit
Gross active electric power	1000.00	kW
Captive gross power	54.00	kW
Gross electric efficiency	20.60	%
Net electric efficiency	19.48	%
Net active electric power	946.00	kW
Operating hours	7500	h/year
Net electricity production	7095	MWh/year
Captive gross power	405	MWh/year
Biomass average LHV (30% MC on dry basis)	4	kWh/kg
Biomass demand (30% MC on dry basis)	12,000	Tonnes/year
Thermal energy (hot water 60 °C) available	3796	kW
Thermal energy (hot water 60 °C) available	28,470	MWh/year
Investment, O&M and biomass costs		
Investment industrial rate	6497	US$/kWe installed
Estimated investment cost	6,497,350	US$
Staff cost	75,000	US$/year
Maintenance cost	97,460	US$
Total O&M	172,460	US$
O&M cost/net MWh generated:	24.31	US$/MWh
Biomass cost[a]	0	US$/Tonne
Taxes	0	US$
Annual review of O&M prices	5	%
Electricity and thermal energy prices		
Feed in tariff – (reference - November 2014)	197.87	US$/MWh
Annual review of FiT	0	%
Thermal energy price	0	US$/MWh
NPV (after 20-year financial period)	−2,773,843	US$
IRR (20-year financial period)	4.3	%

[a] Biomass cost of 'zero' is typical of irrigated rice projects where rice husks are generated at the processing plant and a CHP plant could also be sited therein, eliminating the need for transport. In the sensitivity analysis, biomass is costed over a certain range, to cover transportation cost for smallholder farms.

-2,775,579 with an IRR of about 4.3% using the latest biomass FiT of US$ 197.87 per MWh approved by the Public Utility Regulatory Commission in November 2014. The NPV and IRR obtained shows that at the prevailing FiT, this is not a viable project for a private business and would require some form of support to make it viable. Under these circumstances, there could be two main approaches:

i. Approve specific (higher) FiT that commensurate with efforts to solve rural electricity challenges; and/or
ii. Consider a certain subsidy on initial investment, using appropriate funding budgets

In addition, biomass from clustered farms could eventually be priced, at least to cover its collection and transport costs (from the farms to the CHP plant). In the sensitivity analysis, the effect of increasing FiT and government subsidy on the IRR at certain costs of biomass are explored.

A third option would be to consider additional income from the use of the residual heat generated at the CHP plants [1]. Such option would imply the development of an agro processing activity with a heating (or cooling) demand in the vicinity of the small holder farms or irrigation projects, which falls out of the scope of this paper.

3.3.2. Sensitivity analysis

The base case operating assumptions makes the project unviable for investment. The effects of increasing the FiT, access to subsidies to initial investment and carbon finance is explored in the following sections.

3.3.2.1. Increase of feed-in-tariff (FiT). Fig. 3 shows the sensitivity of profitability (IRR at 20 years, 12% discount rate) versus increases in the FiT, under three different biomass cost references: no cost, 5 US$/tonne and 10 US$/tonne. It can be noted that the pricing of biomass would clearly demand for higher FiT to be allocated to such investment to reach minimum profitability thresholds. To achieve a 12% IRR after 20 years, FiT would need to be increased to 250 US$/MWh (or 25 US$cents/kWh), about 25% increase on the current FiT rates.

3.3.2.2. Access to subsidies to initial investment. Fig. 4 shows subsidies on initial investment under the current FiT rates. Here again, the sensitivity of profitability versus subsidy on initial investment is explored under three different biomass waste cost references: no cost, 5 US$/tonne and 10 US$/tonne. It can be noted that under the current FiT rates for biomass, a minimum of 30% subsidy on the CHP plant investment cost would be needed to enable a financial profitability of 12% IRR on a 20-year financial period analysis. A higher subsidy, between 35% and 45% would be needed to achieve similar IRR if the biomass waste cost ranges between 5 and 10 US$/tonne.

3.3.2.3. Access to carbon finance. An additional source of funding for the development of the agro waste based CHP plants can be the consideration of carbon credits that could offset some of the initial investment costs [11]. To assess this option under a conservative approach, we have considered an emission factor for electricity generation (grid reference) of 0.276 kg CO2 equivalent/kWh [45] and a plant operational time of 20 years.

Regarding carbon prices, there is a wide range of instruments and rates. Indeed, a recent study by the World Bank [27] points out that carbon prices vary significantly – from less than US$ 1 up to US $ 130 per tCO_2 eq., with the most optimistic being the Swedish carbon tax scheme. However, the majority of emissions (over 85%) under carbon finance schemes are priced at less than US$ 10 per tCO_2 eq.

Fig. 5 shows the sensitivity of the profitability of the 1000 kWe CHP plant with increases in FiT rates under carbon credit prices of 10 and 130 US$ per tCO2 eq., both for the cases of the biomass waste being available at no cost, and at a cost of 5 US$ per tonne. Fig. 6 also show the profitability vs subsidy to initial investment under carbon prices of 10 and 130 US$ per tCO2 eq. and current FiT levels.

It can be noted that the consideration of carbon finance under the more probable carbon price of 10 US$ per ton CO_2 eq. currently traded in existing carbon funds would have little impact on the financial results. However, if more favourable schemes (like the Swedish carbon tax) are considered, the viability of CHP plants run on crop residue can be possible if:

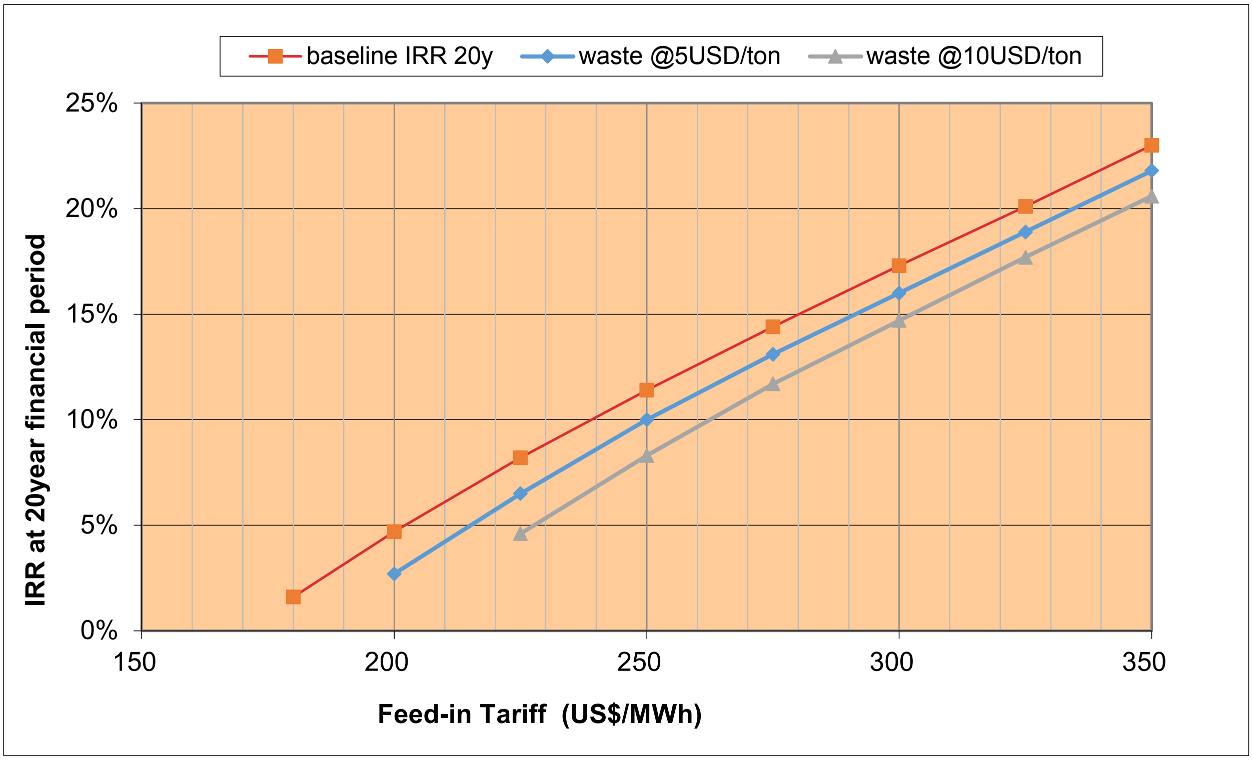

Fig. 3. IRR sensitivity to feed-in- tariff rates.

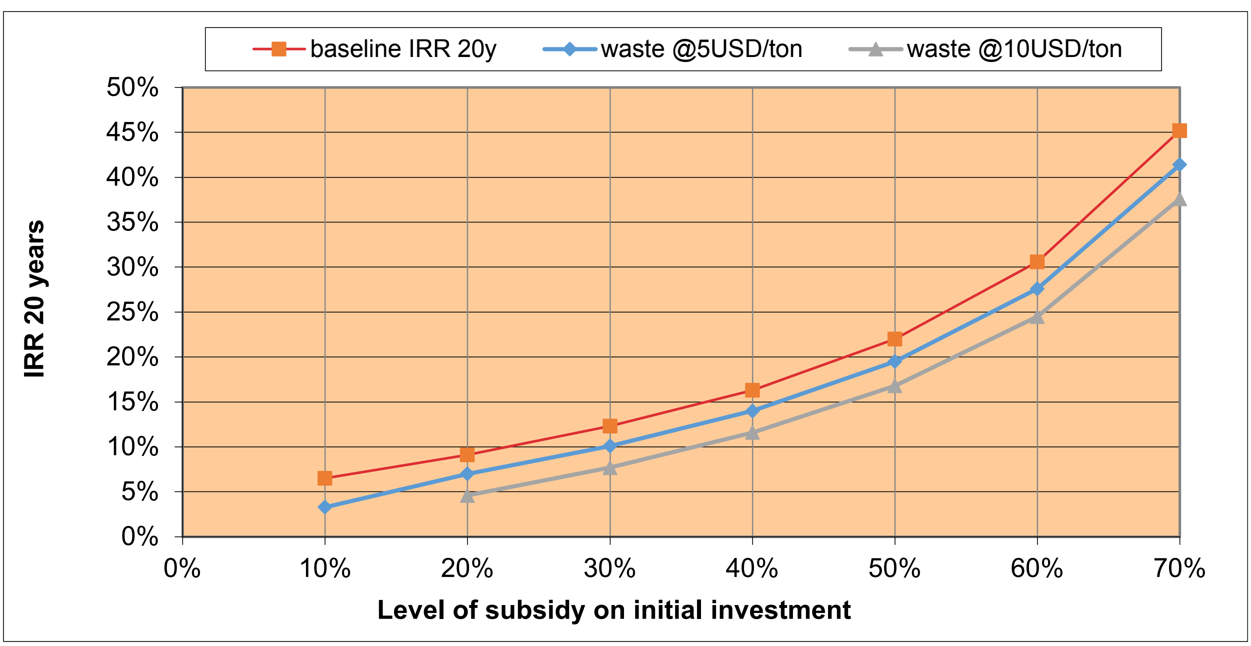

Fig. 4. IRR sensitivity to subsidy on initial investment at different biomass costs.

- Current FiT rates are increased by 8% (up to 215 US$/MWh), or
- A minimum subsidy to initial investment of 10% under current FiT levels.

Figs. 5 and 6 show how some of the key ingredients can affect the profitability of biomass plants and how policy at the local, national and global level can affect investment. Ghana's renewable energy act has instituted a renewable energy fund with the objective of providing financial resources for the promotion, development, sustainable management and utilisation of renewable energy sources. Money from the fund is to be used for, inter alia, production based subsidies and equity participation for ‘mini-grid and off-grid renewable power systems for remote areas and islands’ [34]. The resources available from the biomass sector present an opportunity for the country to support biomass electricity plants to contribute towards the government's aim of achieving

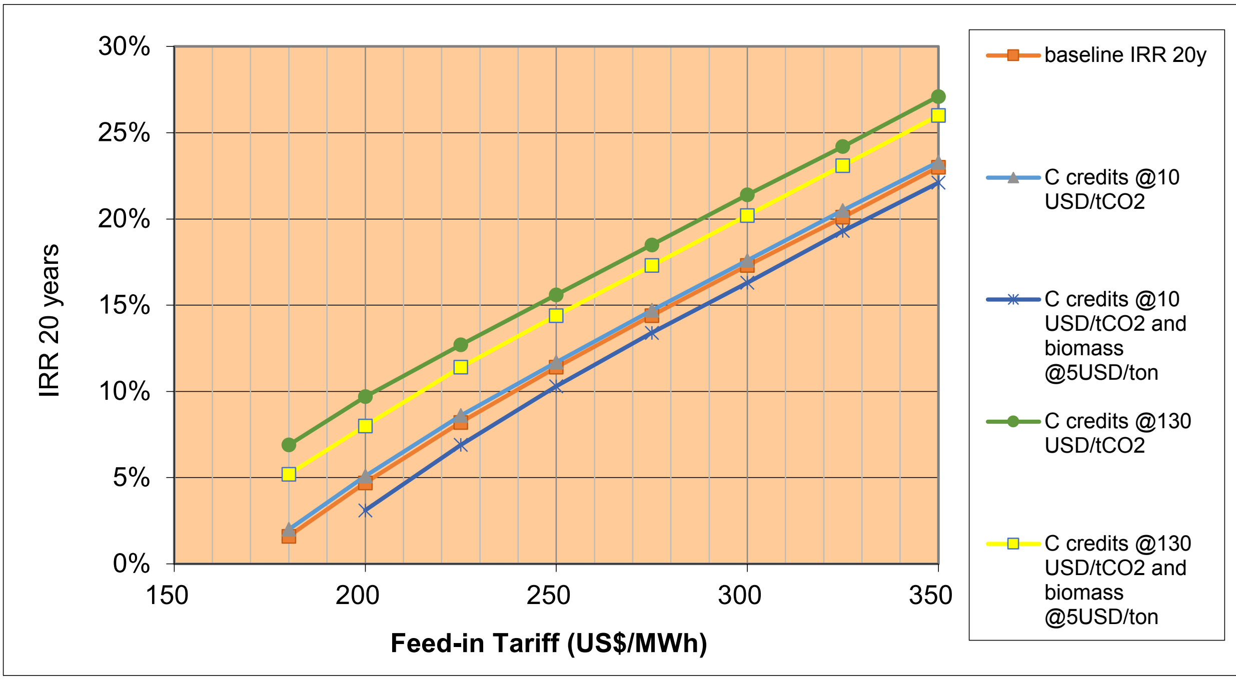

Fig. 5. IRR sensitivity to carbon credits at changing FiT rates.

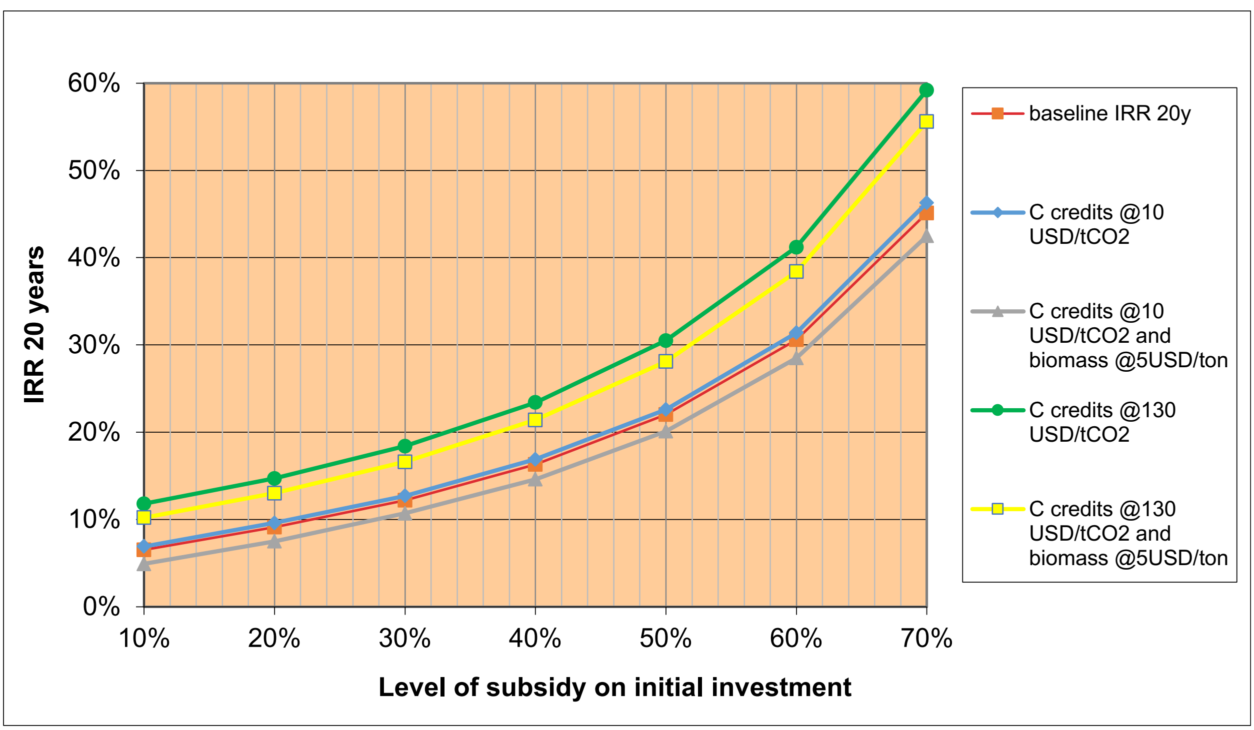

Fig. 6. IRR sensitivity to carbon credits at different levels of capital subsidy.

universal access to electricity by 2020. This could supplement other renewable resources such as solar and wind, either as standalone technologies or as hybrid systems where appropriate, to reduce electricity storage, with the possibility to reduce overall costs.

4. Conclusions

The potential for electricity generation from biomass resources from selected districts in Ghana has been investigated in this study. This study has developed a methodology to analyse crop residues from small farm typologies in selected districts in Ghana and irrigated rice projects to generate electricity. The technical analysis has shown that there is indeed potential to use these resources to generate electricity. The financial analysis shows that a 1000 kWe plant using clustered waste from small holder farms and irrigation projects would not be profitable under current FiT rates unless additional income from the use of residual heat can be mobilised. Either higher FiT (about 25% more on the current rates) or a minimum level of subsidy of 30% on initial investment costs of the plant will be needed to achieve minimum profitability rates above 12% IRR.

Consideration of carbon credit sales could improve the financial situation but then again, even at the most optimistic price of carbon, profitability is still dependent on a slight increase in FiT rates and/or a little capital subsidy. The government of Ghana is aiming to achieve universal access to electricity by 2020. Due to the challenges of extending grid to remote agrarian communities, biomass electricity plants could be considered and piloted as one of the technological solutions. With about 3 million people living in remote and sometimes grid-inaccessible communities, exploring biomass electricity technologies, and where appropriate hybrid technologies combining biomass with solar and wind could be a solution worth exploring. Including biomass technologies in hybrid systems could reduce the need for storage systems in rural mini-grids and eventually reduce the cost of mini-grids for rural electrification.

References

[1] Arranz-Piera P, Bellot O, Gavaldà O, Kemausuor F, Velo E. Trigeneration based on biomass. Specific field case: agricultural residues from smallholder farms in Ghana. Energy Proced 2016;93:146–53. August 2016.

[2] Ayamga EA, Kemausuor F, Addo A. Technical analysis of crop residue biomass energy in an agricultural region of Ghana. Resour Conserv Recycl 2015;96:51–60.

[3] Balat M. Use of biomass sources for energy in Turkey and a view to biomass potential. Biomass Bioenergy 2005;29:32–41.

[4] Bazmi AA, Zahedi G, Hashim H. Design of decentralized biopower generation and distribution system for developing countries. J Clean Prod 2015;86:209–20.

[5] Bilgili F. The impact of biomass consumption on CO_2 emissions: cointegration analyses with regime shifts. Renew Sustain Energy Rev 2012;16:5349–54.

[6] Borsukiewicz-Gozdur A, Wisniewski S, Mocarski S, Bankowski M. ORC power plant for electricity production from forest and agriculture Biomass. Energy Convers Manag 2014;87:1180–5.

[7] Brew-Hammond A, Kemausuor F, Addo A, Awudza J, Darkwah L, Mensah E, et al. Guidebook on modern bioenergy conversion technologies in Africa. 2008. Available from: s3.amazonaws.com/zanran_storage/energycenter.knust.edu.gh/…/106866899.pdf.

[8] Cutza L, Haroc P, Santanaa D, Johnsson F. Assessment of biomass energy sources and technologies: the case of Central America. Renew Sustain Energy Rev 2016;58:1411–31.

[9] De Meyer A, Snoeck M, Cattrysse D, Van Orshoven J. A reference data model to support biomass supply chain modelling and optimization. Environ Model Softw 2016;83:1–11.

[10] Dhillon RS, von Wuehlisch G. Mitigation of global warming through renewable biomass. Biomass Bioenergy 2013;48:75–89.

[11] Disch D, Rai K, Maheshwari S. Carbon finance: a guide for sustainable energy enterprises and NGOs. The Ashden Awards for sustainable energy and GVEP international. December 2010. Available from:. 2010. https://www.ashden.org/files/pdfs/reports/Carbon_finance_guide.pdf.

[12] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. Renew Sustain Energy Rev 2011;15:404–15.

[13] Eisentraut A, Brown A. Technology roadmap: bioenergy for heat and power. International Energy Agency; 2012. Available from: http://www.iea.org/publications/freepublications/publication/2012_Bioenergy_Roadmap_2nd_Edition_WEB.pdf.

[14] Fernandes U, Costa M. Potential of biomass residues for energy production and utilization in a region of Portugal. Biomass Bioenergy 2010;34:661–6.

[15] GNESD. Bioenergy: the potential for rural development and poverty alleviation. Global Network on Energy for Sustainable Development (GNESD); 2011. Available from: http://www.gnesd.org/-/media/Sites/GNESD/Publication%20pdfs/Bioenergy_PotentialForDevelopment_SPM.ashx?la=da.

[16] Gomez A, Rodrigues M, Montanes C, Dopazo C, Fueyo N. The potential for electricity generation from crop and forestry residues in Spain. Biomass Bioenergy 2010;34:703–19.

[17] Grieshop AP, Marshall JD, Kandlikar M. Health and climate benefits of cookstove replacement options. Energy Policy 2011;39(12):7530–42.

[18] Hoffert MI, Caldeira K, Benford G, Criswell DR, Green C, Herzog H, et al. Advanced technology paths to global climate stability. Energy for a greenhouse planet. Science 2002;298(5595):981–7.

[19] IEA. World energy outlook 2013. Paris: OECD/IEA; 2013.

[20] Jimenez O, Curbelo A, Suarez Y. Biomass based gasifier for providing electricity and thermal energy to off-grid locations in Cuba. Conceptual design. Energy Sustain Dev 2012;16:98–102.

[21] Kemausuor F, Addo A, Darkwah L. Technical and socioeconomic potential of biogas from cassava waste in Ghana. Biotechnol Res Int 2015a;2015(10). http://dx.doi.org/10.1155/2015/828576.

[22] Kemausuor F, Akowuah JO, Ofori E. Assessment of feedstock options for biofuels production in Ghana. J Sustain Bioenergy Syst 2013;3:119–28.

[23] Kemausuor F, Bolwig S, Miller S. Modelling the socio-economic impacts of modern bioenergy in rural communities in Ghana. Sustain Technol Assess 2016;14:9–20.

[24] Kemausuor F, Kamp A, Thomsen ST, Bensah EC, Østergård H. Assessment of biomass residue availability and bioenergy yields in Ghana. Resour Conserv Recycl 2014;86:28–37.

[25] Kemausuor F, Nygaard I, Mackenzie G. Prospects for bioenergy use in Ghana using long range energy alternative planning model. Energy 2015b;93:672–82.

[26] Khanna M, Önal H, Dhungana B, Wander M. Economics of herbaceous bioenergy crops for electricity generation: implications for greenhouse gas mitigation. Biomass Bioenergy 2011;35(4):1474–84.

[27] Kossoy A, Peszko G, Oppermann K, Prytz N, Klein N, Blok K, et al. State and trends of carbon pricing 2015. State and trends of carbon pricing. Washington, D.C: World Band; 2015. Available from:http://documents.worldbank.org/curated/en/636161467995665933/State-and-trends-of-carbon-pricing-2015.

[28] Liu Z, Altman I, Johnson TG. The feasibility of co-firing biomass for electricity in Missouri. Biomass Bioenergy 2014;69:12–20.

[29] Maung TA, McCarl BA. Economic factors influencing potential use of cellulosic crop residues for electricity generation. Energy 2013;56:81–91.

[30] Mertens L, Goodwin N, editors. Biomass technology roadmap. The European technology platform on renewable heating and cooling (RHC-Platform); 2014. Available from: http://www.rhc-platform.org/fileadmin/Publications/Biomass_Technology_Roadmap.pdf.

[31] Mohammed YS, Mokhtar AS, Bashir N, Saidur R. An overview of agricultural biomass for decentralized rural energy in Ghana. Renew Sustain Energy Rev 2013;20:15–22.

[32] Nguyen TLT, Hermansen JE, Mogensen L. Environmental performance of crop residues as an energy source for electricity production: the case of wheat straw in Denmark. Appl Energy 2013;104:633–41.

[33] Ofori-Boateng C, Lee KT, Mensah M. The prospects of electricity generation from municipal solid waste (MSW) in Ghana: a better waste management option. Fuel Process Technol 2013;110:94–102. http://dx.doi.org/10.1016/j.fuproc.2012.11.008.

[34] Parliament of the Republic of Ghana. Renewable energy act, 2011. 2011. Available from: www.purc.com.gh/purc/sites/default/…/renewable_energy_act_2011_act_832.pdf.pdf.

[35] Pueyo A, Bawakyillenuo S, Osiolo H. Cost and returns of renewable energy in sub-Saharan Africa: a comparison of Kenya and Ghana, institute of development studies, UK, institute of social, statistical and economi. 2016. Available from: https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/11297/ER190_CostandReturnsofRenewableEnergyinSubSaharanAfricaAComparisonofKenyaandGhana.pdf;jsessionid=6A630AA7203FB6F35E1535A45EC82FC3?sequence=1.

[36] REN21. Renewables 2016 global status report. Paris: REN21 Secretariat; 2016.

[37] Rodriguez LC, May B, Herr A, O'Connell D. Biomass assessment and small scale biomass fired electricity generation in the Green Triangle, Australia. Biomass Bioenergy 2011;35:2589–99.

[38] Rosillo-Calle F, Groot DP, Hemstock SL, Woods J. The biomass assessment handbook. Bioenergy for a sustainable environment. London: Taylor and Francis; 2008. p. 268.

[39] Ruiz JA, Juarez MC, Morales MP, Munoz P, Mendivil MA. Biomass gasification for electricity generation: review of current technology barriers. Renew Sustain Energy Rev 2013;18:174–83.

[40] Shafie SM, Mahlia TMI, Masjuki HH, Ahmad-Yazid A. A review on electricity generation based on biomass residue in Malaysia. Renew Sustain Energy Rev 2012;16:5879–89.

[41] Shahbaz M, Rasool G, Ahmed K, Mahalik MK. Considering the effect of biomass energy consumption on economic growth: fresh evidence from BRICS region. Renew Sustain Energy Rev 2016;60:1442–50.

[42] Silva D, Nakata T. Design of decentralized energy systems for rural electrification in developing countries considering regional disparity. Appl Energy 2012;91:130–45.

[43] Thomsen ST, Kádár Z, Schmidt JE. Compositional analysis and projected biofuel potentials from common West African agricultural residues. Biomass Bioenergy 2014;63:210–7.

[44] Ullah K, Sharma VK, Dhingra S, Braccio G, Ahmad M, Sofia S. Assessing the lignocellulosic biomass resources potential in developing countries: a critical review. Renew Sustain Energy Rev 2015;51:682–98.

[45] UNDP. Ghana GHG inventory. 2012. Available from: http://www.gh.undp.org/content/dam/ghana/docs/Doc/Susdev/UNDP_GH_SUSDEV_2011GHGinventory_PDF.pdf.

[46] Velo E. Overview of small scale biomass to electricity technologies. In: Proceedings of the international workshop small scale biomass systems for electricity generation and decentralised energy services, 15-16 November 2010. Barcelona: Universitat Politècnica de Catalunya; 2011. ISBN 978–8461571635.

[47] WHO. Burning opportunity: clean household energy for health, sustainable development, and wellbeing of women and children. 2016. Available from: apps.who.int/iris/bitstream/10665/204717/1/9789241565233_eng.pdf.