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Research article

Potential for electricity generation from maize residues in rural Ghana: A case study of Brong Ahafo Region

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Abstract

The increased demand for electricity resulting in a perennial power shortage recently has deepened renewed interest in the option of decentralized bioenergy generation in Ghana. Biomass contributes 64% of Ghana's total primary energy supply (TPES), yet it is not fully utilized. The main objective of this article is to assess the potential of dry maize residues to generate electricity in rural Brong Ahafo Region on a sustainable basis. The total amount of maize residues was evaluated based on the annual production of maize and the percentage of residues left over after harvest. The study made use of maize production data of 2010 gathered from the Ministry of Food and Agriculture, Ghana. A thorough review was done in choosing the appropriate crop to residue ratio as well as the characteristics to determine the biomass available as bioenergy potential. The study found that the area with the least dry maize residue – the Atebubu-Amantim district, had sufficient residues to generate electricity of 3,597MWh annually on a sustainable basis. The study concluded that maize residues have a high potential for energy generation in rural Brong Ahafo Region and will facilitate decentralized power generation, thereby contributing towards expansion of energy access in Ghana. It is hoped that the results will be of direct use to stakeholders, policy makers, researchers, NGOs and energy planners seeking the transformation of local energy systems to expand access to electricity.

Keywords: Bioenergy; Biomass gasification; Decentralized generation; Maize residue

Introduction

Globally, over 1.4 billion people are without access to electricity, with 85% of them living in rural areas [1]. According to GSS [2], 77% of the rural population in Ghana lack access to electricity. However, access to reliable electricity is central to the attainment of sustainable development in Ghana. Unfortunately, the interventions being pursued by Government of Ghana (GoG) to meet the demand of rural communities are all based on expanding the centralized systems. Recent studies by Otchere-Appiah and Hagan [3] and Appiah [4] have criticized the centralized planning of electricity generation and recommended expansion of decentralized generation as the main option of making electricity accessible to remote areas. In addition, the increased demand for electricity resulting in a perennial power shortage recently has combined to deepened renewed interest in the option of decentralized bioenergy generation in Ghana.

Biomass has been accepted globally, as the best alternative source of energy since it is readily available locally, cheaper, renewable, and carbon neutral [5]. It supplied almost six times the combined energy generated by geothermal, solar and wind energy sources globally [6].

Ghana is blessed with large resource of biomass energy yet it is not fully utilized. It is available in all rural communities throughout the country and it is the commonest eco-friendly renewable source of energy for Ghanaians. The energy balance of the year 2007 estimated that the total primary energy supply (TPES) in Ghana was 9.50 Mtoe of which biomass fuel alone constituted about 64%, as shown in Figure 1[7]. Recent biomass assessment done in five regions in Ghana by Hagan [8] confirms that enough local biomass residues are available annually. Using biomass to generate electricity will facilitate decentralized power generation, spur continue economic growth, and accelerate social development. It is against this background, that this paper seeks to ascertain whether the biomass resources available will be able to meet the power requirement of rural people on a sustainable basis.

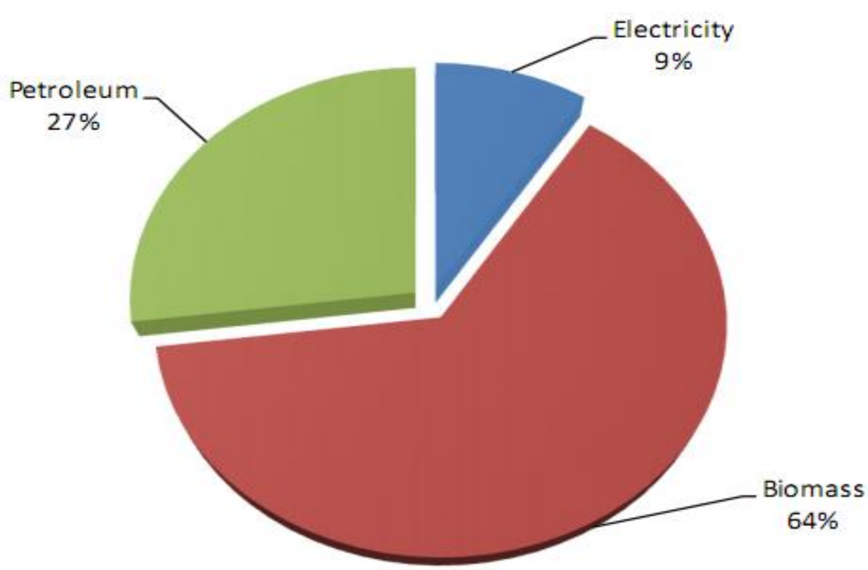

Figure 1: Energy balance in Ghana in 2007 [Total = 9.50 Mtoe] [7]

Agriculture is the backbone of the Ghana's economy and the sector generates significant quantity of residues that can be used wisely for thermal and electric power applications. It constituted 37% of GDP and employed about 57 % of the work force, mainly small landholders in 2005 in Ghana [9, 12]. It covers a total land area of 13,628,179 ha, which constitutes about 57.1 per cent of the total land area of Ghana which is 23,853,900 ha [14]. Most of the rural people are engaged in maize farming and 90% of the national food consumption needs are met by local maize production [11]. As a result, maize residues constitute the largest available biomass resource of about 47% of biomass assessment done in five regions in Ghana [8] as shown in Figure 2, yet it is not adequately tapped. The article seeks to address this important question: *(a) Is it possible to produce the required electricity from maize residues in rural Ghana on a sustainable basis?* The main objective of this article is to assess the potential of dry maize residues to generate electricity in rural Brong Ahafo Region on a sustainable basis.

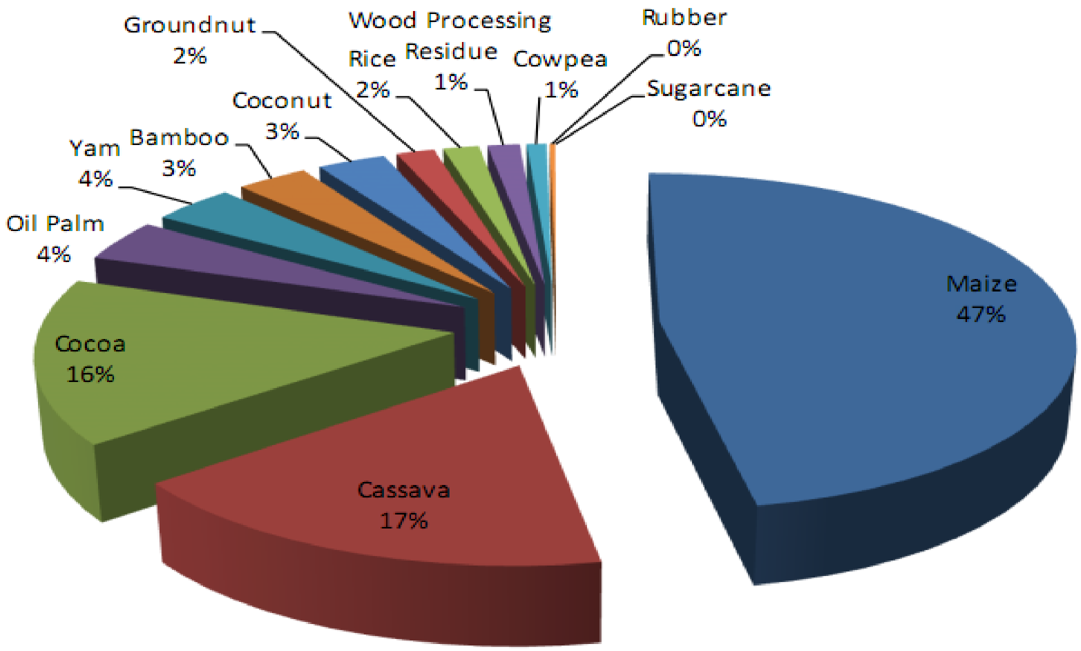

Figure 2: Share of the Types of Available Biomass Resource [8]

Materials and Method

The study focused on the use of agricultural crop residues, specifically maize residues, in the administrative districts in the Brong Ahafo Region because it is the main food crop grown in the region. Maize generates a substantial amount of residues. According to Bernard and Prieur [12] maize residues consist of the non-edible parts of the plant that are left in the farm after harvesting the targeted crop such as stalks and cobs. A minimum quantity of these residues are used locally for heating purposes such as water heating, fish smoking, small scale smelting and palm kernel oil processing [13] while a significant quantity is left in the farms to rot. The maize residues available as bioenergy resources in the Brong Ahafo Region were estimated from the annual quantities of the crop produced in the Brong Ahafo Region, followed by field verification and the application of the appropriate crop-to-residue ratio as presented in Table 1.

Table 1: Crop to Residue Ratio, Moisture content and LHV of Maize crop [10]

COMMODITY	RESIDUE TYPE	CROP TO RESIDUE RATIO	MOISTURE CONTENT (%)	LHV (MJ/kg)
Maize	Maize stalk	1.00	15.5	15
	Maize cob	0.25	8	15

Maize production in the Brong Ahafo Region in 2010 amounted to 510,172 tonnes as shown in Table 2 [14].

Table 2: Production of Maize in the Brong Ahafo Region in 2010, tonnes/year [14]

	Municipality or District	**Maize**
1	Sunyani	71,147
2	Asutifi	12,940
3	Wenchi	26,880
4	Dormaa	81,732
5	Berekum	23,316
6	Tano North	11,418
7	Tano South	12,914
8	Sene	14,077
9	Nkoranza	78,760
10	Techiman	32,792
11	Asunafo North	10,278
12	Asunafo South	10,427
13	Jaman North	7,120
14	Jaman South	13,244
15	Kintampo North	59,432
16	Kintampo South	30,329
17	Atebubu-Amantin	3,718
18	Pru	5,244
19	Tain	4,404
	Total	**510,172**

The following assumptions were employed:

- Based on information from similar assessments and field verification, it was assumed that the average availability of the maize crop residues was 60% of the total crop residue production due to the competing uses (eg mulching) of these residues. This value was chosen in consultation with various experts in the field [8].
- The study used an average conversion of 1.5MWh per tonne of dry biomass with efficiency in the range of 20 - 40%.
- Based on load assessments done in remote villages a 40 kW gasifier plant used for a twelve-hour operation a day and 365 days in a year was assumed.

The study employed the following formula to achieve the desired result:

The Annual Generated residues in tonnes, G_A, can be obtained by multiplying Annual Production in tonnes and Crop to Residue Ratio as it appears in Eq. (1).

$$G_A = A_P \ x \ CRR \qquad (1)$$

where Ap is Annual Production in tonnes and CRR is Crop to Residue Ratio

To obtain the Annual Available residues in tonnes, A_A, the Annual Generated residue in tonnes G_A, is multiplied by 60% as indicated in Eq. (2).

$$A_A = G_A \ x \ 60\% \qquad (2)$$

The annual dry maize residues, D_A, is given by Eq. (3) where MC is the Moisture content

$$D_A = A_A - [\, A_A \; x \;\; MC] \tag{3}$$

Similarly, the total energy, E_T, in (T J/yr) is given by Eq. (4) where LHV is Lower Heating Value of the maize residues.

$$E_T = \frac{D_A \text{ x LHV}}{1000} \tag{4}$$

To obtain the Electricity produced annually, MWh, an average conversion of 1.5MWh per tonne of dry biomass was considered and the final expression is indicated in Eq. (5).

$$\text{MWh} = \frac{D_A \text{ x 1.5MWh}}{1 \; tonne} \tag{5}$$

Technology Option

The appropriate biomass technology option to generate electricity in remote areas depends largely on biomass resource availability, load requirements and location of the community. The bioenergy technology options available are anaerobic digestion (to produce biogas), biomass combustion and biomass gasification.

Biogas production technology requires municipal and animal wastes. However, municipal wastes cannot be used for this project because they are mostly generated in large quantities in the urban centers. Collecting these wastes and transporting them to the rural communities will make the production cost of electricity high as compared to biomass resources that can be generated from the rural communities or the district. The sorting mechanism to limit the high moisture content of urban waste presents another challenge making it difficult to use as a potential bioenergy resource [8]. Currently, from literature and field verification, animal waste does not represent good potential for bioenergy resource because it is generated in small quantities in scattered locations in the region. There is not enough data on this resource to suggest that it can be used for power generation in remote areas.

Combustion-based power generation can be used only if it produces at least 1MWe, and makes economic sense to employ in remote areas if the power generated is above 5MWe in terms of efficiency [15]. It is therefore not good to employ this technology in remote rural areas where the loads are very small.

The demand for electric power in remote areas in Ghana is very small and it is in the range of 10kW to 100kW [16]. This is because most of the rural dwellers rely solely on lighting points, street lights and sometimes electric pumps for mechanized boreholes. Available evidence in the literature suggests that for small-scale electrification with small loads in remote areas, biomass gasification represents a sustainable and relatively low cost option for fulfilling basic electricity needs. Biomass gasifiers are available in different sizes for rural application ranging from 5 kW to 500 kW. The study subsequently focuses on the biomass gasification technology option. Unfortunately, the use of biomass gasification technology for rural electrification has been given only little attention in Ghana at the research and development stages even though a large potential for it exists across the country [17].

Biomass Gasification

The term *gasification* is a thermo-chemical process in which a solid biomass material in a close vessel called a *"gasifier"* is subjected to partial combustion or oxidation to produce a combustible gas mixture called *producer gas* or *syngas*. The *syngas* is composed of nitrogen (50-54%), carbon dioxide (9-11%), methane (2-3%), carbon mono oxide (20-22%) and hydrogen (12-15%) [18]. Depending on the type of biomass used, syngas has a low thermal value ranging from 1000 to 1100K.cal/m^3 [18]. The calorific value of the producer gas is about 4.5-5.0 MJ/kg [19].

The producer gas could be used as a fuel for internal combustion engine for mechanical and electrical applications. The gasification reaction of biomass undergoes four distinct processes, namely: Drying, Pyrolysis, Combustion or Oxidation and Reduction. These processes or stages are clearly indicated in Figure 3.

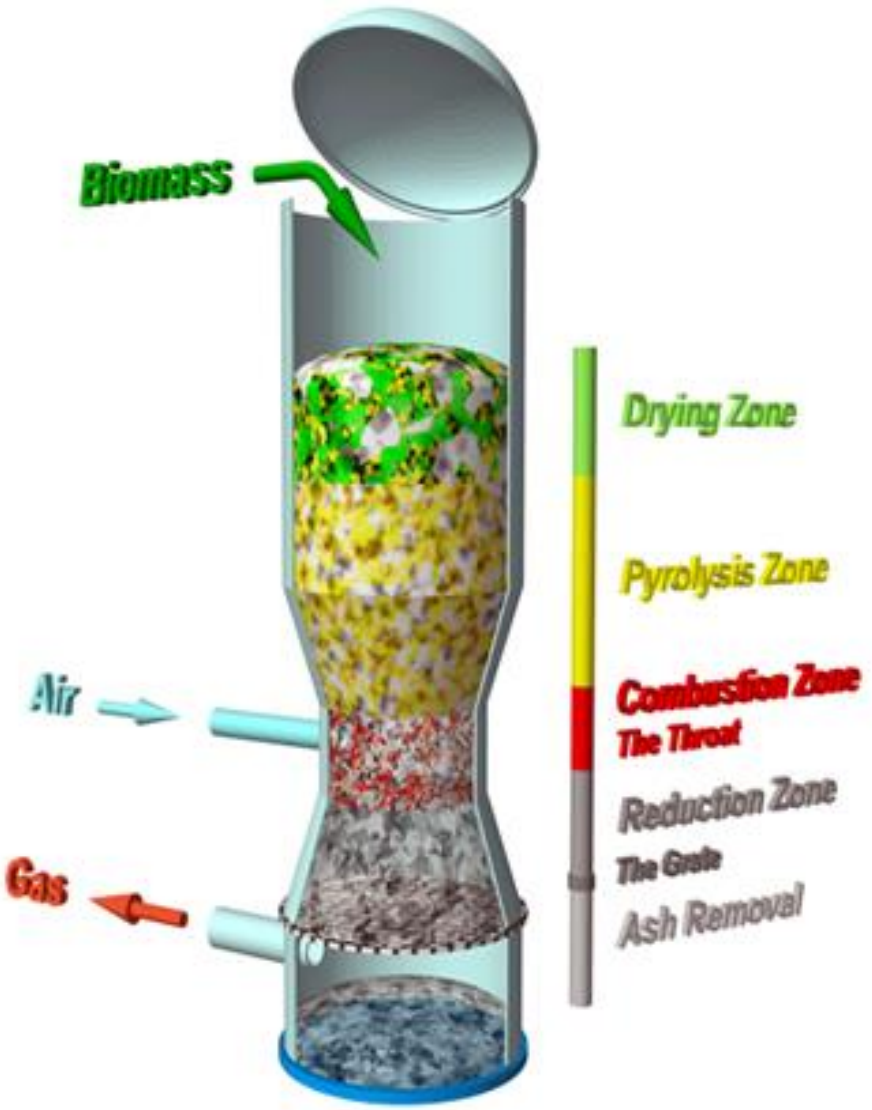

Figure 3: Gasification process showing reaction zones [15]

Gasifier type and Size required

The study assumed a 40 kW Combo downdraft gasifier plant based on load assessment done in remote areas. It is used for a twelve-hour operation in a day and 365 days in a year. To obtain the annual fuel required by the 40 kW Combo gasifier plant it is important to know how much the plant consumes in an hour. According to a leading manufacturer of a gasifier, Ankur Scientific Ltd, a 40 kW Combo gasifier has the following parameters: Gas Flow Rate of 180 Nm^3/hr, Thermal output of 189,000 kCal/hr and Biomass consumption of 72 kg/hr for maize cob and 96 kg/hr for maize stalk. This implies that for the 12 hours a day that the plant will be operating for 365 days in a year, it will consume a total of 315,360 kg maize cobs, equivalent to 315 tonnes annually and 420,480 kg maize stalks annually, equivalent to 420 tonnes annually.

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Results and Discussion

Availability of dry maize residues in the Brong Ahafo Region

The total amount of dry maize residues available in the Brong Ahafo Region was about 329,059 tonnes as indicated in Table 3. Maize stalks contributed the bulk of the residue generated from maize residues and constituted 79% while cob constituted 21% as shown in Figure 4. Among the districts, the Dormaa District had the highest dry maize residue generation and the Atebubu-Amantin District had the least dry maize residue generation, equivalent to 52,717 tonnes and 2,398 tonnes respectively.

Table 3: Generation, Availability, Dry residues, Energy content and Electricity generated annually from B/A

	Municipality/District	**Generated Residues (tonnes)**		**Available Residues (tonnes)**		**Dry Residue (tonnes)**		**Total Energy (T J/yr)**		**MWh**	
		Cobs	**Stalks**	**Cobs**	**Stalks**	**Cobs**	**Stalks**	**Cobs**	**Stalks**	**Cobs**	**Stalks**
1	Sunyani	17,787	71,147	10,672	42,688	9,818	36,071	147	541	14,727	54,107
2	Asutifi	3,235	12,940	1,941	7,764	1,786	6,561	27	98	2,679	9,842
3	Wenchi	6,720	26,880	4,032	16,128	3,709	13,628	56	204	5,564	20,442
4	Dormaa	20,433	81,732	12,260	49,039	11,279	41,438	169	622	16,919	62,157
5	Berekum	5,829	23,316	3,497	13,990	3,217	11,822	48	177	4,826	17,733
6	Tano North	2,855	11,418	1,713	6,851	1,576	5,789	24	87	2,364	8,684
7	Tano South	3,229	12,914	1,937	7,748	1,782	6,547	28	98	2,673	9,821
8	Sene	3,519	14,077	2,112	8,446	1,943	7,137	29	107	2,915	10,706
9	Nkoranza	19,690	78,760	11,814	47,256	10,869	39,931	163	599	16,304	59,897
10	Techiman	8,198	32,792	4,919	19,675	4,525	16,625	68	249	6,788	24,938
11	Asunafo North	2,570	10,278	1,542	6,167	1,419	5,211	21	78	2,129	7,817
12	Asunafo South	2,607	10,427	1,564	6,256	1,439	5,286	22	79	2,159	8,458
13	Jaman North	1,780	7,120	1,068	4,272	983	3,610	15	54	1,475	5,415
14	Jaman South	3,311	13,244	1,987	7,946	1,828	6,714	27	101	2,742	10,071
15	Kintampo North	14,858	59,432	8,915	35,659	8,202	30,132	123	452	12,302	45,198
16	Kintampo South	7,582	30,329	4,549	18,197	4,185	15,376	63	231	6,278	23,064
17	Atebubu Amantin	930	3,718	558	2,231	513	1,885	8	28	770	2,828
18	Pru	1,311	5,244	787	3,146	724	2,658	11	40	1,086	3,987
19	Tain	1,101	4,404	661	2,642	608	2,233	9	33	912	3,350
	Total	**127,543**	**510,172**	**76,526**	**306,103**	**70,405**	**258,654**	**1,058**	**3,878**	**105,612**	**388,515**

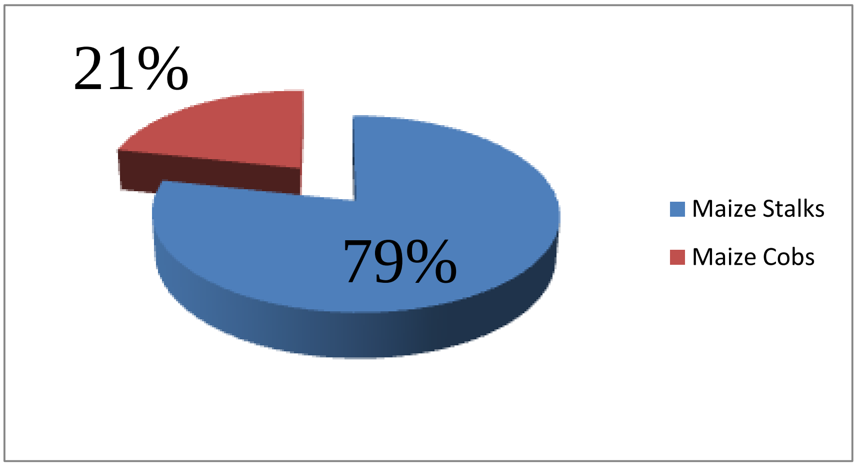

Figure 4: Share of the Types of dry maize residues availability in the Brong Ahafo Region

Energy potential from the estimated dry maize residues

The 329,059 tonnes of dry maize residues generated a total amount of 4,936 TJ of energy content in the Brong Ahafo Region. As regards the availability of dry maize residues, the Dormaa District had the highest energy potential of around 802 TJ with the least coming from Atebubu-Amantin District with 36 TJ. Subsequently, the total amount of electrical energy that could be produced from maize residues in the Brong Ahafo Region annually was around 494,127 MWh, equivalent to 494 GWh. Maize stalks contributed the bulk of the residues needed to produce electrical energy of 389 GWh and cobs contributed 105 GWh as shown in Figure 5.

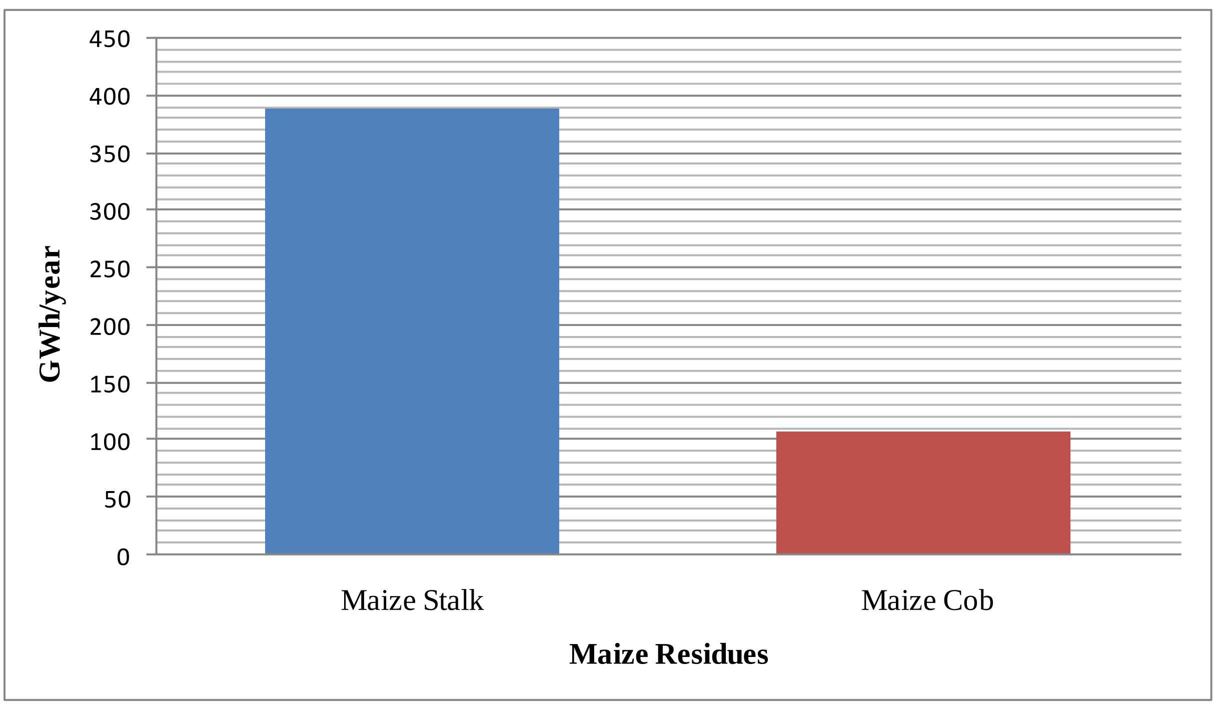

Figure 5: Electricity produced annually from maize residues

Supply of dry maize residues for a 40kW plant on a sustainable basis

The analysis above suggests that the least dry maize residue district, that is, Atebubu-Amantim, will be able to supply a 40kW plant on a sustainable basis to produce electrical energy. This is because the amount of dry maize cobs required to fuel the plant for a year is 315 tonnes while the district produces an average of 513 tonnes annually. Similarly, with regard to maize stalks the district produces an average of 1,885 tonnes and the amount required to fuel the plant for a year was 420 tonnes. The dry maize residues consumed by the 40 kW are 735 tonnes and can generate electricity of 1,103 MWh on a sustainable manner. However, the total dry maize residues available in the district are 2,398 tonnes capable of producing 3,597MWh. This implies that the remaining districts can supply dry maize residues on a sustainable basis to generate power.

Conclusion

The results have shown that 329,059 tonnes of dry maize cobs and stalks are produced annually in the Brong Ahafo Region, and its corresponding energy content of 4,936 TJ, equivalent to 494 GWh of electricity, is available annually. The results confirmed that the least dry maize residue district, Atebubu-Amantim, will be able to supply a 40kW plant on a sustainable basis to produce electrical energy. The main conclusion is that maize residues have a high potential for energy generation in rural Brong Ahafo Region and will facilitate decentralized power generation.

Recommendations

- It is recommended that a techno-economic assessment be done on biomass-based projects suitable for power generation in Ghana to ascertain its viability.
- It is recommended that the decentralized bioenergy generation option should be considered as a medium to long term solution for Ghana as compared to other options to expand access to electricity in remote areas.

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