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THE POTENTIAL OF USING ORGANIC SIDE-STREAMS PRODUCED IN GHANA FOR GENERATION OF BIO-FUEL

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Abstract

Bio-fuel can be generated from organic side-streams of maize, rice, millet, sorghum and groundnut by using fast pyrolysis technology. Data on side-streams of these crops were obtained from the Ministry of Food and Agriculture (MoFA) in 2010 for the study. The study shows that the estimated total crop side-streams generated was 3,475,413 t of which 2,345,903.5 t of bio-fuel can be produced, given a potential energy equivalent of 42,226 PJ/y. The result shows a growth rate of 12.9 per cent in energy equivalent potential for synthetic fuel production as compared to the estimated production in 2009. Northern Region had the highest energy potential of 9,676 PJ/y (22.91%) of the total energy equivalent of bio-fuel, whereas, Greater Accra Region had the lowest with 183 PJ/y (0.43%). It is recommended that the available energy potential at the three northern regions of Ghana be utilised effectively when renewable energy policy is improved for a wider applications of side-streams from crops.

Introduction

Agriculture is a major industry in Ghana, and consequently, large amounts of by-products/residues that can be used for energy production are generated. The two types of agro-fuels are from crop residues and animal waste (Energy Commission, 2012). In the study, the term “side-streams” have been used which could be a raw material for other useful products. Agricultural side-streams are of different varieties, and the most appropriate energy conversion technologies and handling protocols vary. The most significant classification is between those side-streams that are predominantly dry (straw, cob, husk, shell and hull) and those that are wet (animal slurry).

The rate of increase in volume and type of classification is due to the rapid increase in population growth and, therefore, an improved living standard has become a burgeoning problem as rotten agricultural side-stream generates CO_2 and other pollutants. Lack of proper management and strategies for handling organic side-streams is contributing towards climate change debate.

Studies have revealed that organic side-streams are of high value with respect to material and energy recovery. Therefore, it has become necessary to convert most waste into useful energy. This comprehensive side-stream management approach will enable Ghana generate reasonable amount of energy. In 2000, it was estimated that energy can be recovered from the various products such as: maize – 32,513.7 TJ kg^{-1}, rice – 7,076.6 TJ kg^{-1}, cassava – 57,720.1 TJ kg^{-1}, yam – 23,943.9 TJ kg^{-1}, groundnuts – 1,045.3 TJ kg^{-1} and cocoyam – 11,570.6 TJ kg^{-1} (Ghana: Action Plan for Sustainable Energy for All by 2030, 2012). The major challenge is to reduce the high cost of waste collection and management.

In order to manage crop side-streams, it is necessary to convert them into a material resource. Considerable efforts have been made by institutions, but still there remains major gaps to be filled. Some of the setbacks include, lack of technical knowledge and capacity building to convert most of the organic side-streams into materials and energy recovery. This operation when implemented, would reduce the costs for waste disposal, which will again enhance revenue generation from the sale of the recovered materials, energy and wealth creation. Bio-mass is noted to be the dominant energy resource in Ghana. Currently, there is an emerging trend on the utilisation of bio-mass conversion technologies from combustion of rice husk to gasification of other organic side-streams. It has been reported that bio-mass is still largely underutilised, and are left to rot, or are openly burned in the fields, especially in developing countries which lack strong regulatory instruments to control such practices (Converting Waste Agricultural Bio-mass into a Resource, 2009).

Energy technologies that are available to convert organic side-streams into electricity, heat and fuel include 1) combustion, 2) gasification, 3) pyrolysis, 4) anaerobic digestion, 5) fermentation, and 6) esterification. Of all these technologies only thermal technology (pyrolysis) has been considered in the study. Pyrolysis has been defined as a form of treatment that chemically decomposes organic materials by heat in the absence of oxygen that typically occurs under pressure, and at operating temperatures above 430 °C (*http://www.cpeo.org/techtree/ttdescript/pyrols.htm*). Fast pyrolysis maximizes production of bio-oil with bio-char and pyrolysis gas as lower-yielding co-products. The study presents the dry features of the organic side-stream. It is known that the fast pyrolysis produces a substantially higher value energy product from the organic side-streams. *(http://onlinelibrary.wiley.com/doi/10.1002/bbb.254/abstract)*.

Studies have shown that, there has not been any consistency on the amount of organic side-stream that can be conveniently removed from the field. Some are left in the field to decompose to enhance soil fertility. Researchers have quoted side-stream fractional values used in calculations as 35 per cent and 50 per cent for Cooper & Laing (2007) and Lynd *et al.* (2002), respectively. It has been observed that actual data on exact organic side-streams produced are not usually available and are, therefore, approximated using the ratio between side-stream and crop production for each particular commodity (Mensah & Abdul-Samii, 2011).

The objective of the study was to determine the quantity of organic side-streams produced from five selected major crops in Ghana for the year 2010, that can be processed into bio-fuel through fast pyrolysis technology, and also to compare the production yield of bio-fuel estimated for 2009.

Experimentals

Sources of materials

The agriculture sector plays a major role in terms of Gross Domestic Product (GPD) in the economy of Ghana, and besides the main crops, large quantities of side-streams are generated every year. Rice, maize (corn), sorghum, soybeans and groundnuts are just a few crops that generate considerable amounts of organic side-streams. These constitute a major part of the total annual production of bio-mass side-streams, and are important source of energy both for domestic and industrial purposes. There are also other organic side-streams from cassava, yam, cocoyam, plantain and cowpea which have been quantified (MoFA, 2011) but not used in the study. These organic side-streams were obtained from farms, processing units and very few from domestic processes in the regions of Ghana.

Maize, rice, millet, sorghum and groundnut were used in the study. Data were obtained from MoFA 2010 and compared to that of 2009.

Methods

Potential organic side-streams can be estimated by the following formulae:

$$P = \sum_{i=1}^{i=n} a_i b_i + \sum_{i=1}^{i=n} \alpha_i \beta_i + \sum_{i=1}^{i=n} R_i S_i \quad (1)$$

where $\sum_{i=1}^{i=n} a_i b_i$ is the potentiality of crop, residues, a the crop production, b the crop residue yield production, and i the type of crop. When the calorific value of each type of crop is used, the potentiality can be calculated in TOE (tonne crude oil equivalent) as:

$$\sum_{i=1}^{i=n} \alpha_i \beta_i$$

where α is the number of animal head, β is the garbage yield production, and i the animal species. The potentiality of crop residue is calculated as:

$$\sum_{i=1}^{i=n} R_i S_i$$

where S is the area of plantation, R is the residue yield production per unit of surface, and i the type of crop (*http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17302&_dad=portal&_schema=PORTAL*).

Jölli & Giljum (2005) determined residues by using harvest index (HI), where it was described as corn to straw ratio, and defined as the proportion of the straw to the grain RPR-value (Residue-to-Product Ratio). Unused agricultural residues (t/y) = Production (t/y) × Unused bio-mass factor (2)
Unused agricultural residues (t/y) can be calculated as:
Area harvested (ha) × Coefficient (t/ha-y) (3)
where the coefficient of the unusable amount of the agricultural residues, and seed crops results from the conversion factor and the technical availability factor (Jölli &Giljum, 2005).

Residue (side-stream) production (t/year) = Crop production (t/year) × Residue (side-stream) to product ratio RPR × M (4)
where M is the maximum proportion of side-stream that can be removed from field without affecting the fertility of soil. It is assumed to be 35 per cent of the amount of field side-streams, and 100 per cent in the case of process side-streams. The above assumed percentages have been used by Mensah & Abdul-Samii (2011).

The two methods used to characterise crop side-streams are the physico-chemical analysis through their oxides. The proximate analyses used in the former method were based on ASTM standard test methods to determine moisture (ASTM E1756-01), volatile matter (ASTM E872-82) and ash content (ASTM E17755-01). The fixed carbon contents of the samples were determined by differences. The analyses based on the oxides were determined by using X-ray fluorescence (Spectro X-Lab 2000). Characterisation of the samples using the two methods is presented in Tables 1 and 2 for the physcio-chemical and their oxides, respectively.

The amount of yields from bio-oil production by employing fast pyrolysis technologies has been reported to be in the range of 60 per cent to 75 per cent weight per weight biomass (Bridgewater, 2004). In the study, an average value of 67.5 per cent has been used for the calculations. However, typical yields (dry biomass basis) obtained from the technology was 12 per cent char (solid), 75 per cent synthetic fuel/tars (liquid) and 13 per cent gases.

Results

*Maize (*Zea mays*) side-streams from various regions*

Maize is a stable grain and is grown in all the 10 regions of Ghana with an annual production of about 1,872,000 t from a total area of 992,000 ha in 2010, given an average yield of 1.89 t ha^{-1} as compared to annual production of 1,619,590 t in 2009 with a growth rate of 15.6 per cent. Estimated side-streams from maize (cobs, stalks and husks) from each region, calculated by using equation 4 and are average RPR values (Koopman & Koppejan, 1997; and Maither, 2009) were as follows: cobs - 25 per cent and a percentage removal of 100; stalk - 1.85 and removal of 35 per cent from the field and husks - 0.2 and percentage removal of 100.

Table 1

Phscio-chemical analysis for the characterisation of the sampled side-streams (% dry wt basis)

Crop	*Side-stream*	*Moisture (%)*	*Ash content (%)*	*Volatile matter (%)*	*Fixed carbon (%)*	*Heating value (MJ/kg)*
Maize	Cop	12.20	1.50 - 3.60	54.60	29.90	15.23 - 18.90
	Stalk	11.87	6.40-11.87	71.78	20.80	05.25-18.50
Rice	Husk	2.95	14.90-25.35	61.09	13.56	12.98-19.33
	Straw	4.49	13.42-25.71	60.77	13.52	16.02-16.30
Millet	Stalk	N/A	N/A	N/A	N/A	15.40
	Straw	N/A	N/A	N/A	N/A	12.39
Sorghum	Stalk	N/A	N/A	N/A	N/A	N/A
	Straw	N/A	N/A	N/A	N/A	12.38
Groundnut	Shell	N/A	4.40-6.91	N/A	N/A	15.66-20.74
	Husk	N/A	4.40-6.91	N/A	N/A	15.66-20-74
	Straw	N/A	4.40	N/A	N/A	17.58

Sources: Kristotferson & Bokalders (1991), Koopman & Koppejan (1997), Potgieter (2011), Bascetincelik, *et al.* (2011), Lu, *et al.* (2006) and Lori, *et al*. (2007).

TABLE 2

Per cent dry wt of major elements and their oxides

Crop	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	Cl	K_2O	CaO	TiO	MnO	Fe_2O_3
Corn Stalk	0.87	0.58	0.18	1.60	0.25	0.01	0.92	1.20	0.26	-	0.01	0.06
Rice Straw	0.54	0.45	0.24	16.30	0.19	0.03	0.62	2.10	0.37	0.02	0.20	0.08
Rice Husk	0.27	0.52	0.42	22.38	0.32	0.03	0.08	0.39	0.09	0.02	0.03	0.12

*Rice-(*Oryza sativa*) side-stream from various regions*

Rice is likely to compete with maize which has an annual production of about 491,600 t from a total area of about 181,230 ha in 2010 with an average yield of 2.71 t ha^{-1} as compared to annual production of 391,442 t in 2009 and a growth rate of 25.6 per cent. Estimated side-streams from rice (straw and husks) from each region was calculated using equation 4 and an average RPR values of 2.2 (Koopman & Koppejan, 1997; Maither, 2009) are shown in Table 4. The following RPR values were used: rice straw - 1.70 and a removal of 35 per cent from the field, and husk (processed side-stream) - 0.28 and percentage removal of 100.

*Millet - (*Pennisetum glaucum*)) side-stream from various regions*

Millet is grown in only three regions of Ghana (Northern, Upper West and Upper East), with an annual production of about 218,950 t from a total area of about 176,600

TABLE 3

*Estimated maize (*Zea mays*) side-stream (t) available as feedstock for fast pyrolysis from the various regions*

Region	Crop	Cobs	stalks	Husk	2010 residue	2009 residue	% change
Western	74191.0	18547.8	48038.7	14838.2	81424.6	86713.5	(6.1)*
Central	195394.0	48848.5	126517.6	39078.8	214444.9	248496.0	(13.7)*
Eastern	380505.0	95126.3	246377.0	76101.0	417604.2	332981.5	25.4
Gt. Accra	3584.0	896.0	2320.6	716.8	3933.4	3632.7	8.3
Volta	93887.0	23471.8	60791.8	18777.4	1 03041.0	106523.4	(3.3)*
Ashanti	253374.0	63343.5	164059.7	50674.8	278078.0	205045.9	35.6
Brong Ahafo	510172.0	127543.0	330336.4	102034.4	559913.8	489770.4	14.3
Northern	202316.0	50579.0	130999.6	40463.2	222041.8	170661.3	30.1
Upper West	96015.0	24003.8	62169.7	19203.0	105376.5	77549.4	35.9
Upper East	62256.0	15564.0	40310.8	12451.2	68326.0	56126.2	21.7
Total	1871694.0	467923.7	1211921.9	374338.8	2054184.2	1777500.3	15.6

*Figures in brackets indicate a decrease in per cent change from 2009 to 2010.

TABLE 4

*Estimated rice (*Oryza sativa*) side-stream (t) available as feedstock for fast pyrolysis from the various regions.*

Region	*Crop*	*Straw*	*husks*	*2010 residue*	*2009 residue*	*% change*
Western	23022.0	13698.1	6446.2	20144.3	17596.3	14.5
Central	5241.0	3118.4	1467.5	4585.9	4453.8	3.0
Eastern	20703.0	12318.3	5796.8	18115.1	17272.5	4.9
Gt. Accra	12741.0	7580.9	3567.5	11148.4	2572.5	333.4
Volta	67229.0	40001.3	18824.1	58825.4	53112.5	10.8
Ashanti	27705.0	16484.5	7757.4	24241.9	10885.0	122.7
Brong Ahafo	6573.0	3910.9	1840.4	5751.4	5066.3	13.5
Northern	185877.0	110596.8	52045.6	162642.4	127531.3	27.5
Upper West	7291.0	4338.2	2041.5	6379.6	6658.8	(4.1)*
Upper East	135221.0	80456.5	37861.9	118318.4	97363.0	21.5
Total	491603.0	292503.9	137648.9	430152.8	342512	25.6

*Figures in brackets indicate a decrease in per cent change from 2009 to 2010.

ha in 2010 with an average yield of 1.24 t ha^{-1} as compared to annual production of 245,550 t in 2009. This shows a decrease of 10.8 per cent in annual production.

*Sorghum (*Sorghum bicolor*) side-stream from various regions*

Sorghum and millet are essential to diets of poor people in the semi-arid tropics, where droughts cause frequent failures of other crops. However, sorghum was grown in five regions of Ghana in 2010 as compared to only four regions in 2009. This indicated that farmers in Brong Ahafo Region have shown much interest in sorghum cultivation. An annual sorghum production in 2010 was about 324,420 t from a total area of about 252,555 ha with an average yield of 1.28 t ha^{-1} as compared to annual production of 350,550 t in 2009. This shows a decreased rate in annual production by 7.5 per cent. It has been noted that sorghum production decreased by 3.3 per cent over the period 2007-2009 (Mensah & Abdul-Samii, 2011). The decrease may be due to lack of logistics delivered to the farmers in the Northern Region. Estimated side-streams from sorghum (stalks) from the various regions using equation 4 and average RPR values of 2.2 (Hagan, 1997) for sorghum stalks and a removal of 35 per cent from the field are shown in Table 6.

TABLE 5

*Estimated millet (*Pennisetum glaucum*) side-stream (t) available as feedstock for fast pyrolysis from the various regions*

Region	*Crop*	*2010 Residue (stalk)*	*2009 Residue (stalk)*	*% change*
Northern	90619.0	69776.6	72441.6	(3.7)*
Upper West	64247.0	49470.2	55316.8	(10.6)*
Upper East	64086.0	49546.2	61315.1	(19.2)*
Total	218952.0	168793.0	189073.5	(33.4)*

*Figures in brackets indicate a decrease in per cent change from 2009 to 2010.

*Groundnut - (*Arachis hypogaea*) side-stream from various regions*

Groundnut is grown in all the 10 regions of Ghana except that data are not available for some of the regions, but those obtained showed an annual production of about 530,890 t from a total area of about 353,376 ha in 2010, given an average yield of 1.50 t ha^{-1} as compared to annual production of 485,080 t in 2009 and a growth rate of 9.4 per cent. Estimated side-streams from groundnut (shell and straw) from the various growing regions is shown in Table 7 by using equation 4 and average RPR value of 2.5 for straw (Koopman & Koppejan, 1997; Maither, 2009) and a removal of 35 per cent from the field. Meanwhile, a small amount of groundnut is sold directly to consumers in shells that cannot be readily available to be used as raw material. However, due to lack of information on quantities sold in shells, the total quantity generated would, therefore, be considered as potential. It was, therefore, assumed to use RPR value of 0.46 (Hagan, 1997; Koopman & Koppenjan, 1997; Maither, 2009).

Table 6

*Estimated Sorghum (*Sorghum bicolor*) side-stream (t) available as feedstock for fast pyrolysis from various the regions*

Region	Crop	2010 Residue (stalk)	2009 Residue (stalk)	% change
Volta	4849	1697.2	1767.5	(4.0)*
Brong Ahafo	425.0	148.8	NA	(100)*
Northern	108495.0	37973.3	47803.0	(20.6)*
Upper West	124041.0	43414.4	42497.0	2.2
Upper East	86613.0	30314.6	30625.0	(1.0)*
Total	324423.0	113548.3	122692.5	(7.5)*

*Figures in brackets indicate a decrease in per cent change from 2009 to 2010.

Potential production of bio-fuel from organic side-streams

The estimated amount of bio-fuel that can be produced from available organic side-streams, the total available side-streams obtained from the 10 regions of Ghana, and the estimated potential of bio-oil based on 2010 crop data are shown in Fig. 1. The total crop organic side-streams estimated to be generated in 2010 was 3,475,413 t of which 2,345,903.5 t of bio-fuel could be produced given an energy equivalent of 42,226 PJ/y. The energy content (on mass basis) of dry biomass fuels is in the range of 17–19 MJ kg^{-1}, and the differences are due to differences in density and moisture content (Clarke & Preto, 2011). An average value of 18 MJ kg^{-1} as heating value was used for all the side-streams, since there was no specific data to be used on a particular side-stream.

From Fig. 1, Northern Region has the highest bio-energy (bio-oil) potential from organic side-streams with an amount of 9,676 PJ/yr which is about 22.91 per cent of the estimated total energy equivalent in Ghana. This is followed by Brong Ahafo – 16.82 per cent, Upper West – 13.44 per cent and Eastern Region – 12.92 per cent. The Greater Accra Region produced an estimated amount of 183 PJ/y (i.e. 0.43%).

Energy equivalent for 2009 and 2010 are shown in Fig. 2, which shows an increase in energy equivalent through-out the various regions. In 2009, the total organic side-streams generated was 3,079,369 t of which 2,087,568 t of bio-fuel was estimated to be produced with

TABLE 7

*Estimated groundnut (*Arachis hypogaea*) side-stream (t) available as feedstock for fast pyrolysis from the various regions*

Region	*Crop*	*Shell*	*Straw*	*2010 residue*	*2009 residue*	*% change*
Eastern	9859.0	4535.1	8626.6	13161.8	NA	100
Ashanti	8762.0	4030.5	7666.8	11697.3	8757.6	33.6
Brong Ahafo	14132.0	6500.7	12365.5	18866.2	NA	100
Northern	227650.0	104719.0	199193.8	303912.8	285609.9	6.4
Upper West	196676.0	90470.1	172091.5	262562.5	267947.9	(2.0)*
Upper East	73808.0	33951.7	64582.0	98533.7	85266.5	15.6
Total	530887.0	244207.1	464526.2	708734.3	647581.9	9.4

*Figures in brackets indicate a decrease in per cent change from 2009 to 2010.

energy potential of 37,414 PJ/yr. This shows a growth rate of 12.9 per cent in equivalent potential bio-fuel production when compared to 2009 (Mensah & Abdul-Samii, 2011). The comparison between estimated bio-fuel production for 2009 and 2010 is shown in Fig. 2.

Discussion

The total available organic side-streams obtained from the 10 regions of Ghana and the estimated potential for bio-fuel production are presented in Table 8 based on 2010 crop data. The total crop organic side-streams estimated to be generated in 2010 was 3475413 t of which 2345903.5 t of bio-fuel could be produced, given an energy equivalent of 42226 PJ/yr. The energy content (on mass basis) of most dry biomass fuels is between 17–19 MJ kg^{-1}, and the differences are due to differences in density and moisture content (Clarke & Preto, 2011). An average value of 18 MJ kg^{-1} as heating value was used for all the organic side-streams, since there was no specific data to be used on a particular side-stream. In 2009, the total crop side-streams generated was 3079369 t of which 2087568 t of bio-oil was estimated to be produced with energy potential of 37414 PJ/yr. This shows a growth rate of 12.9 per cent in energy equivalent potential bio-fuel production when compared to 2009 (Mensah & Abdul-Samii, 2011).

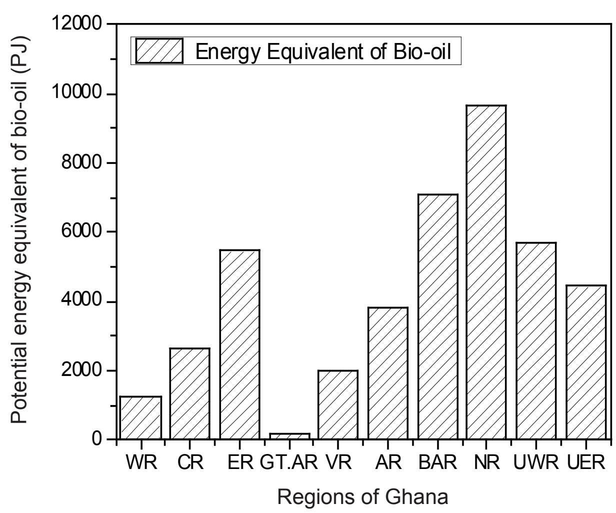

Fig. 1. Potential energy equivalents (PJ) of bio-oil estimated production for 2010 for the regions of Ghana

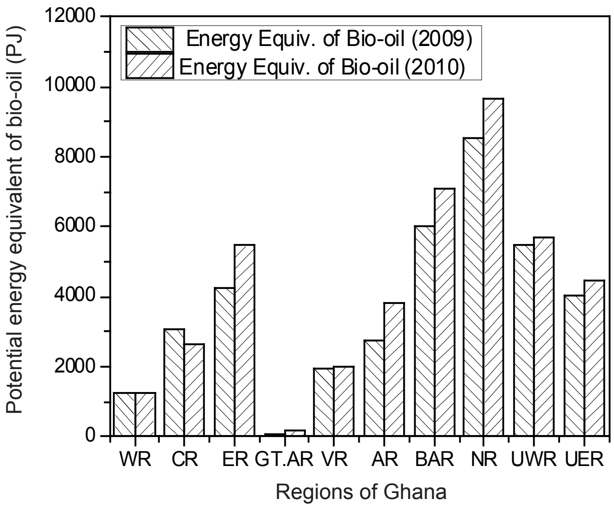

Fig. 2. Potential energy equivalents (PJ) of bio-oil estimated production for 2009 and 2010 for the regions of Ghana

cent and Eastern Region – 12.92 per cent. Greater Accra produced an estimated amount of 183 PJ/yr (0.43%).

Conclusion

Estimates of potential energy in the form of bio-oil that could be available from side-streams (maize, rice, millet, sorghum and groundnuts) from the 10 regions of Ghana have been studied. The use of fast pyrolysis technology would be very beneficial if it is introduced in all the regions to produce the bio-oil, where storage facilities would be put in place for easy access for end-users.

Table 8

Crop side-streams (t) and estimated energy equivalent of bio-fuel (PJ) production for 2010 in the various regions of Ghana.

Region	*Maize*	*Rice*	*Millet*	*Sorghum*	*Groundnut*	*Total*	*Bio- fuel*	*Energy equivalent of bio-oil (PJ)*
Western	81424.6	20144.3				101568.9	68559	1234
Central	214444.9	4585.9				219030.8	147845.8	2661
Eastern	417604.2	18115.1			13161.8	448881.1	302994.7	5454
Gt. Accra	3933.4	11148.4				15081.8	10180.2	183
Volta	103041	58825.4		1697.2		163563.6	110405.4	1987
Ashanti	278078	24241.9			11697.3	314017.2	211961.6	3815
Brong Ahafo	559913.8	5751.4		148.8	18866.2	584680.2	394659.1	7104
Northern	222041.8	162642.4	69776.6	37973.3	303912.8	796346.9	537534.2	9676
Upper West	105376.5	6379.6	49470.2	43414.4	262562.5	467203.2	315362.2	5677
Upper East	68326	118318.4	49546.2	30314.6	98533.7	365038.9	246401.3	4435
Total	2054184.2	430152.8	168793	113548.3	708734.3	3475413	2345903.5	42226

Northern Region has the highest bio-fuel potential from organic side-streams with an amount of 9676 PJ/yr which is about 22.91 per cent of the estimated total energy equivalent. This is followed by Brong Ahafo with 16.82 per cent, Upper West – 13.44 per Northern Region has the highest energy potential with 22.91 per cent of the total energy equivalent of bio-oil that can be produced in Ghana followed by Brong Ahafo (16.82%). Greater Accra has the lowest energy equivalent of 0.43 per cent of the estimated energy equivalent in Ghana. Maize and rice are the only crops that are grown in all the 10 regions of Ghana. The analysis showed that in 2009, sorghum was not grown in the Brong Ahafo Region but in 2010, 425 t was grown on 400 ha of land. This means that with little improvement in logistics, production of sorghum in the Brong Ahafo Region will increase with an increase in bio-oil production.

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