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Bioenergy potential of agricultural and forest residues in Uganda

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ABSTRACT

Biomass is the major source of energy in most developing countries. However, there are concerns about the sustainability of biomass supplies and the environmental impacts resulting from their use. Use of residues could contribute to ensuring sustainable supply of biomass energy. This study presents findings of an evaluation of the energy potential of agricultural and forest residues in Uganda using census data of the year 2008/2009. Annual productions of crop and forest residues were estimated using residue-to-product ratio (RPR) method. Energy potential of each residue class was then determined basing on their respective lower heating values. The biogas generation potential of each animal category was used to evaluate the energy potential of animal manure. Results showed that the total energy potential of the residues amount to 260 PJ y^{-1}, which is about 70% of gross biomass energy requirement of Uganda for the year 2008. Crop residues had the highest contribution of about 150 PJ y^{-1}, followed by animal residues with a potential of 65 PJ y^{-1}. Maize residue is the predominant crop residue with energy potential of 65 PJ y^{-1} followed by beans and banana, each at 16 PJ y^{-1}. This study indicates that agricultural and forest residues can be a major renewable energy source for Uganda. When sustainably utilised, biomass residues could contribute to reduction in environmental degradation in the country.

1. Introduction

Biomass is the major source of energy contributing over 90% of the energy requirements of Uganda [1,2]. However, of recent, rapid population growth, urbanisation and industrialisation have increased the demand for biomass resources in the country. Annual demand for woody biomass and charcoal is reported to be increasing at about 3% and 6%, respectively [3]. The main source of biomass energy in the country is wood from unmanaged natural forests. Natural forests in Uganda are dominated by slow-growing species, thus high rates of harvesting leads to deforestation and environmental degradation. A report on the global forest resource assessment of 2005 [4], indicates that between the year 2000 and 2005, the annual deforestation rate in Uganda was 2.2%, and is one of the highest in the world. Moreover, the demand for biomass energy is expected to increase with increasing population in most sub-Saharan African countries [5,6]. One would therefore expect a similar trend in Uganda, where population growth rate is about 3.3% per year [2]. This leads to concerns

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about the sustainability of forest biomass supplies in the country [7,8].

It is therefore important to search for alternative energy sources to supplement the increasing demand for forest biomass. Several options are available, but among the most promising is the use of biomass residues. The potential of biomass residues to meet energy needs has attracted interest of several researchers in the recent past. For example, Fernandes and Costa [9] evaluated the potential of agricultural and forest residues in the Marvão province of Spain and found an annual potential of 160 TJ. Also, Vasco and Costa [10], evaluated the energy potential of forest residues in Maputo province of Mozambique, and reported that residues could substitute about 32% of the 2004 energy requirements of the province. Other examples of studies on energy potential of biomass residue were carried out at national levels in Zimbabwe [11] and Romania [12]. Other studies have also been conducted at a global scale; for example, Gregg and Smith [13] evaluated the global and regional potential of agricultural and forestry residues, and reported a global potential of 50 EJ y^{-1}. The main advantage of national level studies is their ability to provide more detailed information required for decision making at local levels.

This study therefore aims at evaluation the energy potential of agricultural and forest residues in Uganda. Being a predominantly agricultural-based economy, large quantities of biomass residues from the crop and animal production sectors are generated throughout the country. It is a common practice to burn the residues in cultivated fields as a means of agricultural land preparation. Residues are also generated from agricultural processing facilities are burdensome to processors because of costs incurred in their disposal. Forest residues are also generated during logging and wood processing operations. However, their use as an energy source is still very limited in the country. Use of biomass residues for energy is of advantage since it does not require major changes to the current combustion technologies in the country. Also, when well-managed, use of residues is not competitive with land and water resources required for food production. It also results in reduced deforestation and environmental degradation.

One of the most important steps in developing biomass energy supply from residue is to evaluate their spatial and temporal availability. Such an analysis would provide useful information for decision makers on the opportunities for using biomass residues for energy application in the country. However, the temporal and spatial distribution of the energy potential of biomass residues in Uganda is currently not known. The present study was therefore conducted with the objective of evaluating the energy potential of agricultural and forestry residues in Uganda.

2. Materials and methods

2.1. Sources of data

Annual production of crops, woody biomass, livestock and human population data used for the study were obtained from various sources. Food crop production data were obtained from volume IV of the Uganda census of agriculture 2008/2009 [14]. The report presents data that was collected from all the districts of Uganda through a nationwide census. Procedures used in the census followed generally standard scientific methods. The methodologies used for sample design, enumeration plan, data processing and analysis are well explained in volume II of Uganda census of agriculture 2008/2009 [15]. Production data for coffee, cotton and sugarcane were obtained from reports in Refs. [16], [17] and [18], respectively. Livestock data was obtained from the summary report of the national livestock census of 2008 [19], which gives an estimate of livestock numbers in all the districts of Uganda. Human population data used in the study were obtained from the 2009 statistical abstract [16] and wood production data from the 2010 statistical abstract [20]. To estimate the quantity of residues generated, the residue-to-product ratio (RPR) method was used. The RPR values of different crops and their respective heating values were obtained from published literature. This also applied to heating values of biomass residues and biogas generated from animal manure.

2.2. Determining potential of agricultural residues

2.2.1. Crop residues

To estimate the energy potential of crop residues, the procedure documented by Sigh et al., [21] was used with some minor modifications. The energy potential of agricultural residues was calculated using Equation (1);

$$Q_{AR} = \sum_{i=1}^{n}(C_i \times RPR_i \times LHV_i) \quad (1)$$

where, Q_{AR} is the annual gross energy potential of agricultural residues at 100% efficiency, C_i is the annual production of crop i. Factor, n is the total number of residue categories. The variable RPR_i is the residue-to-product ratio of crop i, and LHV_i is the lower heating value of a given crop residue. Parameters such as moisture content, lower heating values and residue to product ratio were obtained from available literature [22–31].

2.2.2. Animal manure

To estimate the energy potential of animal residues, manure generated by cattle, sheep, goats, pigs, poultry and humans were considered. Properties of animal manures necessary for estimating their energy potential include daily volatile solid production per animal and biogas yield per kilogramme of volatile solid. These parameters were obtained from literature [32,33] and used to estimate the amount of biogas that can be produced by each livestock category. The energy potential of biogas was assumed to be 20 MJ m^{-3} as recommended by Perera et al., [22].

2.3. Determining the potential of forest residues

Forests residues are of two types, namely; the logging residues and wood processing residues. Logging residues are generated during the harvesting operations and include stumps, roots, branches, and saw-dust. Wood processing residues arise from saw-mill and plywood processing operations and include discarded logs, barks, saw-dust and off-cuts [34]. Data of annual production of round and processed wood for the year

2010 were obtained from the statistical abstract [20] and used to estimate the annual forest residue production. The procedure for estimating the energy potential of forest residues proposed by Smeets and Faaij [35] was used. The energy potential of logging residues was calculated using Equation (2),

$$Q_{HR} = \sum_{i=1}^{n} (W_i \times h \times LHV), \quad (2)$$

where, Q_{HR} is the energy potential of logging residues and W_i is the annual production of round wood of category *i*. Factor, *h* is logging residue generation ratio and was assumed to be 0.6 [34,35]. The energy potential of wood processing residue generated was estimated using Equation (3).

$$Q_{PR} = IRW \times p \times LHV \quad (3)$$

where, Q_{PR} is the energy potential of wood processing residues and IRW annual consumption of industrial round wood. Factor, *p* is wood processing residue generation ratio. It is the fraction of logs that is converted into residues during the processing of wood and depends on the efficiency of sawmills. We used a *p* value for developing countries of 70% [36]. The LHV of wood at 50% H_2O mass fraction was assumed to be 8 MJ kg^{-1} [37].

3. Results

3.1. Potential of crop residues

The energy potential of crop residues is given in Table 1. Crop residues represent a gross energy potential at 100% efficiency of about 150 PJ y^{-1}. The results show that maize residues have the highest energy potential of about 65 PJ y^{-1} followed by banana and beans residues, each with 16 PJ y^{-1}. Secondary residues in Table 1 include corn cobs, rice husks, coffee husks and bagasse. The total energy potential of the secondary residues is approximately 10 PJ y^{-1}, representing about 7% of the total crop residue potential.

The energy potential of crop residues for Uganda was analysed and presented spatially using geographical information system (GIS) as illustrated in Fig. 1. The map excludes the energy potential of residues of coffee; cotton and sugarcane because the available data did not provide production statistics for these crops in each district. The figure shows that there is regional variation in the energy potential of crop residues. Mubende district in the central region exhibited the highest crop residues energy potential of about 8 PJ y^{-1}, followed by Iganga at about 7 PJ y^{-1}, while Kampala had the lowest potential of 30 TJ y^{-1}. Other districts with crop residue energy potential of more than 4 PJ y^{-1} include Tororo, Kabarole Luuka, Serere and Ntungamo.

3.2. Potential of animal manure

The energy potential of animal manure in Uganda is given in Table 2, which includes the potential of human manure. The results show that the total energy potential of animal residues amounts to about 65 PJ y^{-1}. In the year 2008, the country had about 11.7 million heads of cattle producing manure with an energy potential of 45 PJ y^{-1}, followed by goats with a potential of 9 PJ y^{-1}.

Table 1 – Theoretical energy potential of crop residues in Uganda.

Crop produced	Annual crop production (kt)	Type of residue	H_2O mass fraction (%)[a]	Residue to product ratio (RPR)	Quantity of residues (kt)	Lower heating value (LHV) (MJ kg^{-1})[a]	Energy potential (PJ y^{-1})
Maize	2363.00 [14]	Stalk	15.0 [24]	2.00 [23]	4726.00	16.3 [23]	65.50
		Cobs	8.7 [22]	0.27 [23]	638.01	12.6 [23]	7.40
Millet	263.59 [14]	Straws	15.0 [24]	1.40 [25]	369.03	13.0 [25]	4.00
Sorghum	373.34 [14]	Stalk	15.0 [26]	1.40 [27]	522.68	13.0 [27]	6.25
Rice	189.18 [14]	Straws	10.0 [29]	0.45 [22]	85.13	8.83 [22]	0.97
		Husks	13.3 [29]	0.23 [22]	0.00	12.9 [22]	0.58
Beans	928.87 [14]	Trash	4.5 [29]	1.40 [25]	1300.42	14.7 [25]	16.44
Groundnuts	244.58 [14]	Trash and shells	8.2 [26]	2.10 [25]	513.62	11.2 [22]	5.33
Banana	4297.07 [14]	Stalk and peels	85.4 [30]	2.00 [29]	8594.14	13.1 [28]	16.44
Cassava	2893.74 [14]	Stems and peels	20.0	0.40 [25]	1157.50	13.1 [25]	7.58
Sweet potato	1817.66 [14]	Vines and peels	20.0	0.40 [25]	727.06	16.0 [28]	9.31
Pigeon peas	10.90 [14]	Stems	20.0	1.40 [25]	15.26	12.8 [25]	0.20
Soybean	23.12 [14]	Trash	15.0 [26]	2.66 [22]	61.50	18.0 [22]	1.11
Sesame	97.80 [14]	Trash	5.5 [29]	2.00 [29]	195.60	15.5 [29]	3.03
Sugar	197.37 [18]	Bagasse	50.0 [22]	0.25 [22]	49.34	15.4 [23]	0.38
		Tops	50.0 [22]	0.32 [22]	63.16	15.8 [23]	0.50
Coffee	211.76 [16]	Husks	15.0 [24]	1.00 [25]	211.76	15.9 [25]	2.86
Cotton	23.18 [17]	Stalks	9.3 [22]	2.10 [31]	48.68	15.9 [31]	0.75
Total							**148.67**

a H_2O mass fractions of cassava, sweet potato and pigeon peas were assumed to be 20%.

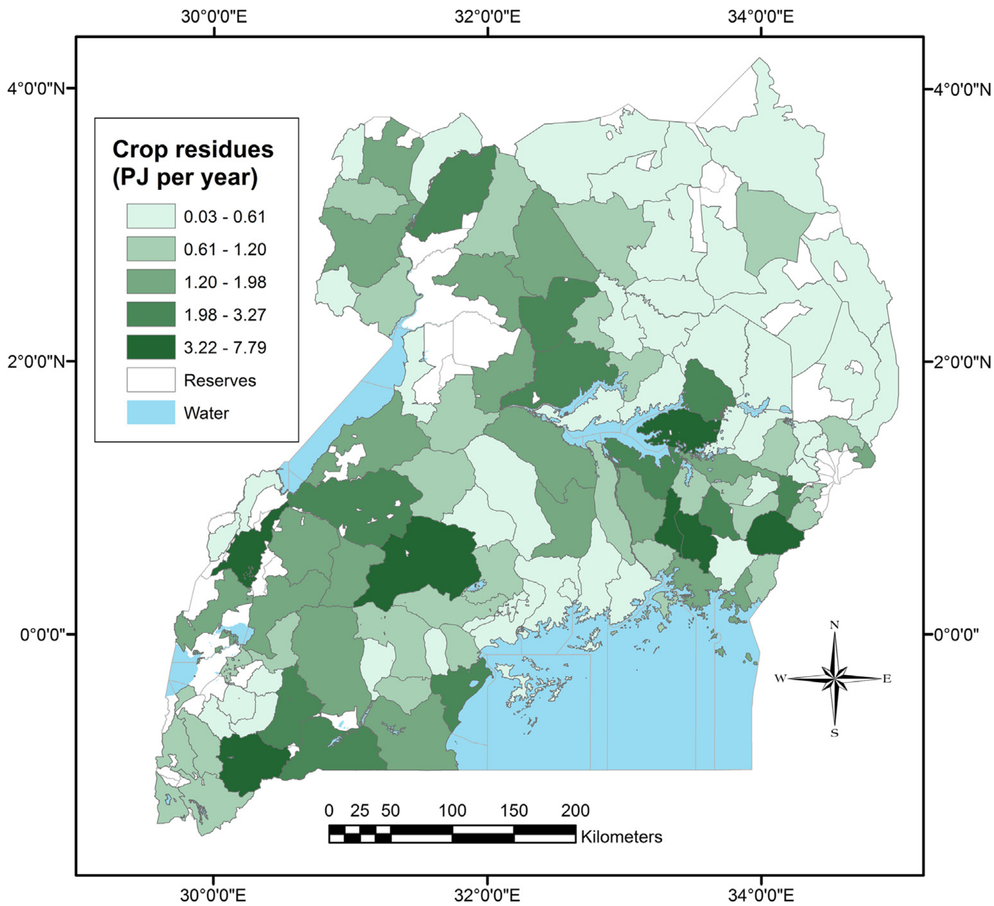

Fig. 1 – Distribution of the theoretical energy potential of crop residues in Uganda.

The spatial distribution of the energy potential of animal manure in Uganda is given in Fig. 2. The distribution is characterised high potential along a corridor from the south-west to the north-east of the country. The corridor is known to have a high density of cattle in Uganda and is generally referred to as the *cattle corridor* [38]. Kotido district reported the highest energy potential from manure of 3.5 PJ y^{-1}. Other districts with more than 2 PJ y^{-1} include Nakapiripirit, Kaabong, and Amodat.

3.3. *Spatial distribution of crop and animal residues potential*

The spatial distribution of the combined energy potential of crop and animal was analysed using GIS and presented spatially, as shown in Fig. 3. Mubende district reported the highest overall biomass residue energy potential of 9 PJ y^{-1}, followed by Iganga and Ntungamu at 8 PJ y^{-1} and 7 PJ y^{-1}, respectively. Other districts with residue energy potential

Table 2 – Theoretical energy potential of animal manure.

Animal category	Population (millions) [16,19]	VS[a] (kg d^{-1}) [33]	B_o[b] (m^3 kg^{-1}) [33]	Potential (PJ y^{-1})
Cattle	11.71	2.67	0.20	45.64
Goats	12.29	0.33	0.31	9.18
Sheep	3.58	0.30	0.31	2.43
Pigs	3.18	0.59	0.31	4.25
Chicken	37.58	0.02	0.18	0.99
Ducks	1.47	0.02	0.22	0.05
Human	30.66	0.06	0.20	2.69
Total				**65.23**

a Volatile solids per animal.
b Biochemical methane potential.

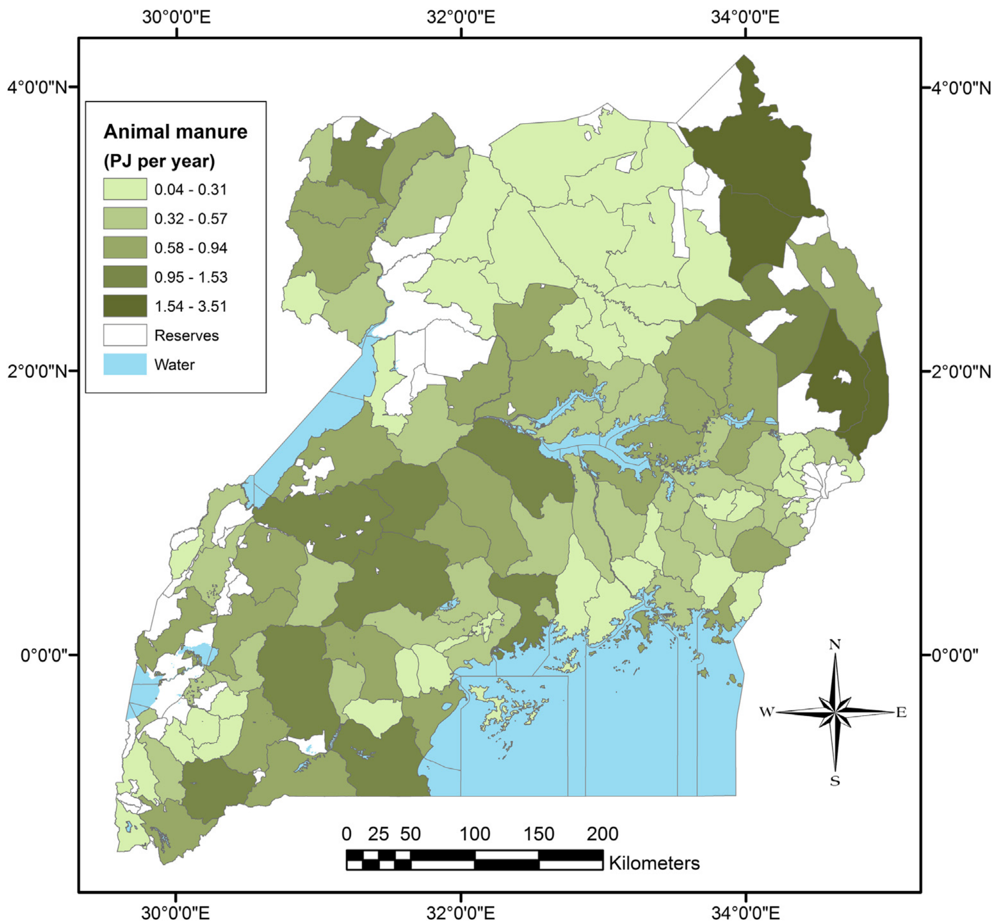

Fig. 2 – Distribution of the theoretical energy potential of animal manure in Uganda.

of at least 5 PJ y^{-1} include Luuka, Serere, Kabarole and Tororo.

The compositions of the residues in the different districts of the country were analysed and presented spatially using GIS as illustrated in Figs. 4–7. Fig. 4 shows biomass residue composition in northern region. It shows that the eastern part of the region is predominated by cattle manure while crop residue potential is very low. However most of the districts in the region do not have a single source of residue exceeding over 50% of the energy potential, though maize and beans residues are more prominent. Fig. 5 is an illustration of the composition of biomass residues in eastern region. It shows that maize residues are dominant in this region followed by banana residues. Central region, shown in Fig. 6 has residues energy potential predominated by maize, cattle manure and banana. Cattle manure is more prominent in the northern part of the region while maize is predominant in mid central region. Finally, the western region is majorly rich in banana residue, which is more prominent in the southern part of the region and maize residues in the northern part, as illustrated in Fig. 7.

3.4. *Potential of forest residues*

Results of energy potential of forest residues are presented in Table 3. In this study, forest residues were categorised as logging and processing residues. Results show that about 5.0 kt y^{-1} of forest residues are generated during logging operations. The processing residues are however much less corresponding to about 0.35 kt y^{-1}. In terms of energy potential, residues from firewood production has the highest potential of about 20 PJ y^{-1}, followed by charcoal production at about 17 PJ y^{-1}. The total energy potential of forest residues in Uganda is estimated at about 44 PJ y^{-1}.

3.5. *Total energy potential*

Table 4 gives a summary of the energy potential from the sources analysed in this study. The total energy potential from all the sources studied is about 260 PJ y^{-1}. The overall result shows that crop residues exhibit the highest energy potential of about 150 PJ y^{-1}. Therefore, crop residues alone contribute over 50% of the overall energy potential of biomass residues in Uganda.

4. Discussions

In this study, we evaluated the energy potential of agricultural and forest residues in Uganda and the findings indicate that the total potential is about 260 PJ y^{-1}. This is close to 70% of the total biomass energy requirements for Uganda in the year

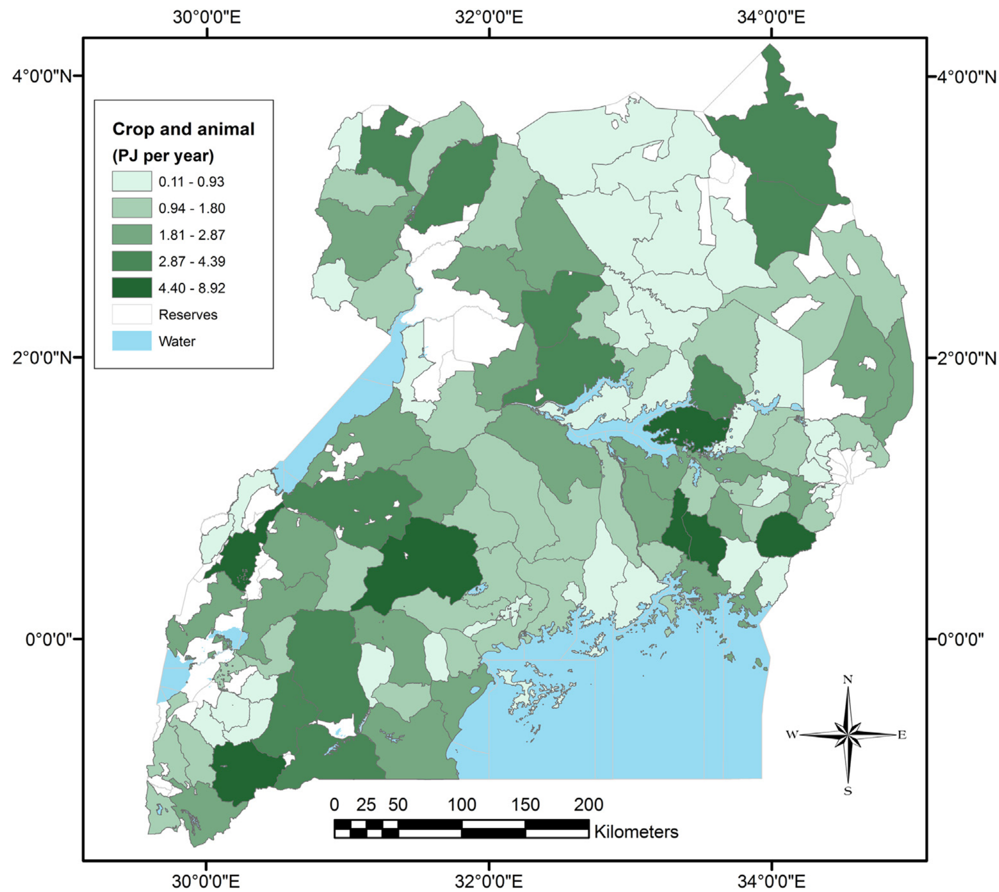

Fig. 3 – Distribution of the combined theoretical energy potential of crop and animal residues.

2008, which was estimated at about 385 PJ [1]. Crop residues exhibited the highest theoretical energy potential of about 150 PJ y^{-1}. However, it is important to note that the accuracy of the estimated energy potential of biomass residues may be subject to errors that are inherent during the collection of census data [39], and seasonal variation in production levels. According to volume IV of the Uganda census of agriculture [14], the estimates of crop production had a coefficient of

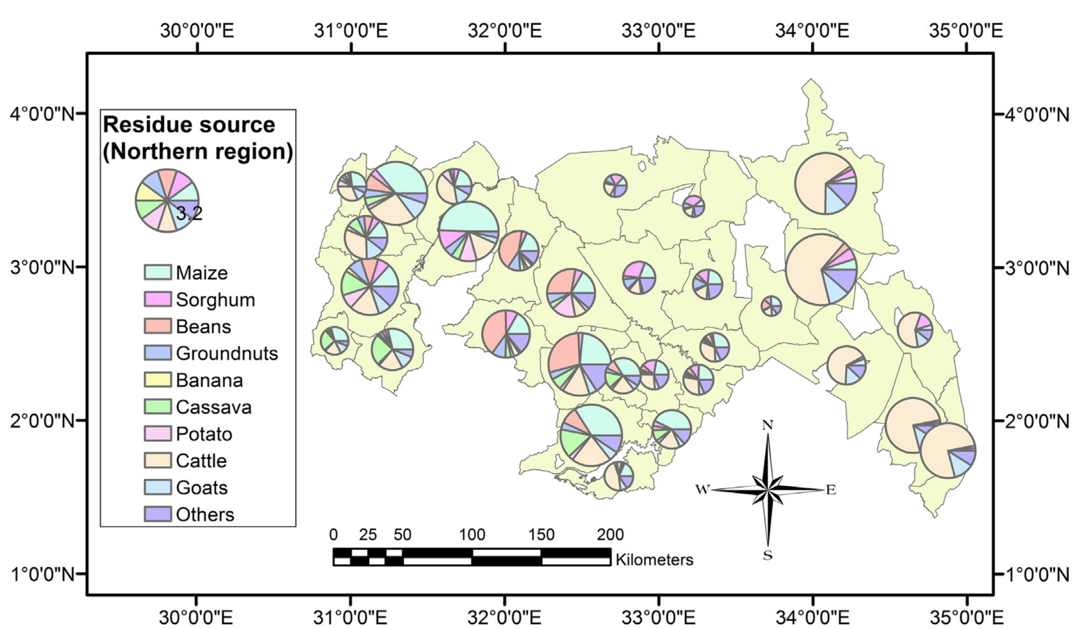

Fig. 4 – Composition of biomass residue in Northern Uganda.

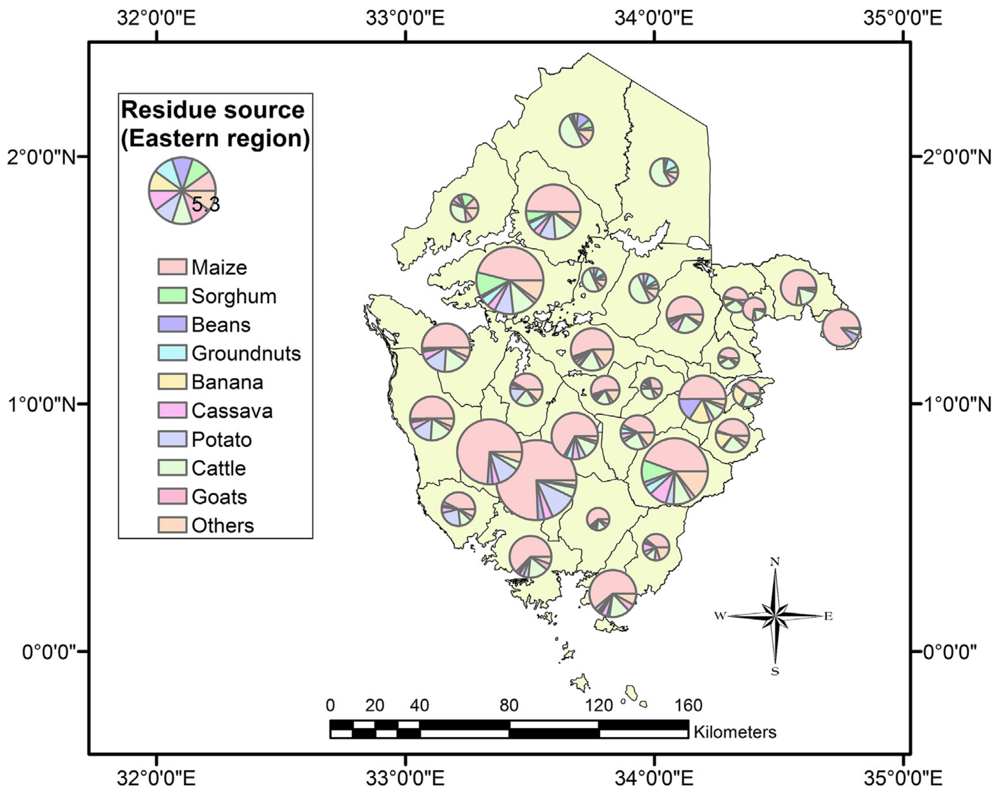

Fig. 5 – Composition of biomass residue in Eastern Uganda.

variation of 20%. This suggests that the estimates of energy potential presented here could be subject to similar levels of accuracy. The energy potential reported here are gross values at 100% efficiency. The actual implementation potential is determined by several factors including economic, social, environmental, and institutional and policy incentives. Logistical considerations, infrastructural and technological constraints as well as availability of skilled personnel are other factors that determine the implementable potential.

4.1. *Recoverability of agricultural residue*

Recoverability of agricultural residues is determined by the type of residues, need to retain some residues to maintain the quality of agricultural soils amongst other factors. Generally, crop residues are classified as primary or secondary residues. Primary residues are generated during harvesting and primary processing of crops in farms and crop plantations. The residues are normally scattered over a large geographical area, therefore presenting a major logistical challenge for their collection for energy application. Primary residues are usually in a loose form and may require bailing or densifying in order to improve their collection and utilisation efficiency. For developing countries like Uganda, provision of the necessary equipment and skilled personnel for collection of loose biomass may present a challenge. Another important consideration is that residues perform ecological functions like providing soil nutrients, control of soil erosion and some fraction should therefore be left in the fields [40]. The amount of primary residues that can be realistically harnessed for energy is estimated using recoverable fraction of biomass. The actual values of recoverable fraction of biomass residues for different crops have been estimated and reported in literature [41,42] and may vary from 19% to 75% of the gross potential.

Secondary residues on the other hand are generated during secondary processing of agricultural produce in large quantities at specific locations. Common examples in Uganda include coffee husks, rice husks and bagasse. These residues have other applications, for example, coffee husks are frequently used as bedding material in poultry housing. However, secondary residues are generally considered to be problematic to agricultural processing industries because of costs incurred in their disposal. As a result, many agricultural processing facilities in Uganda burn the secondary residues in open air near the agro-processing facility, therefore presenting serious environmental problems.

4.2. *Recoverability of animal residues*

Results show that annual energy potential of animal manure is about 65 PJ y^{-1} with cattle manure having the highest contribution of about 45 PJ y^{-1}. The current government policy targets biogas production from cattle manure, with a target of installing 100,000 domestic biogas digesters based on cattle manure by the year 2017 [43]. The findings of this study seem to support this policy since cattle manure has the highest energy potential amongst the animal manure. However, it should be noted that there are several factors that influence the actual implementation potential of the animal residues. First, a large percentage of cattle in Uganda are under

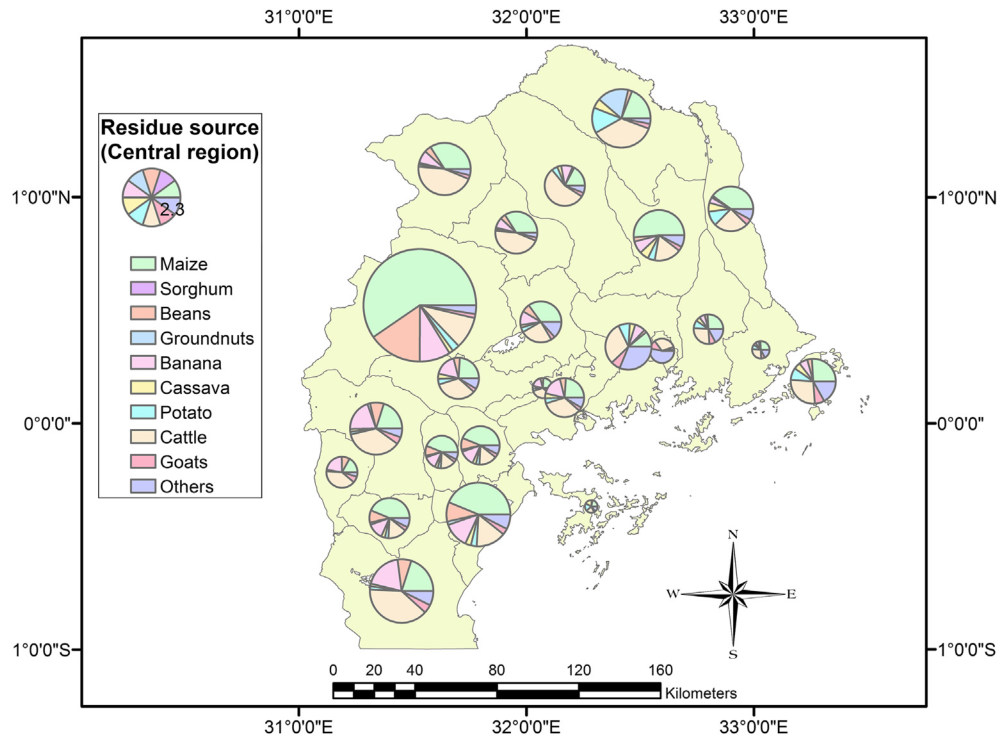

Fig. 6 – Composition of biomass residue in Central Uganda.

pastoralism system, therefore posing constraints due to difficulty in collecting the manure. Normally, domestic biogas technologies common in developing countries are best suited for zero-grazing systems because it reduces the constraints of manure collection. Also, the systems usually require large quantities of water, which is often a challenge to access in many cattle producing areas of Uganda. It should also be noted that human manure has a potential to produce

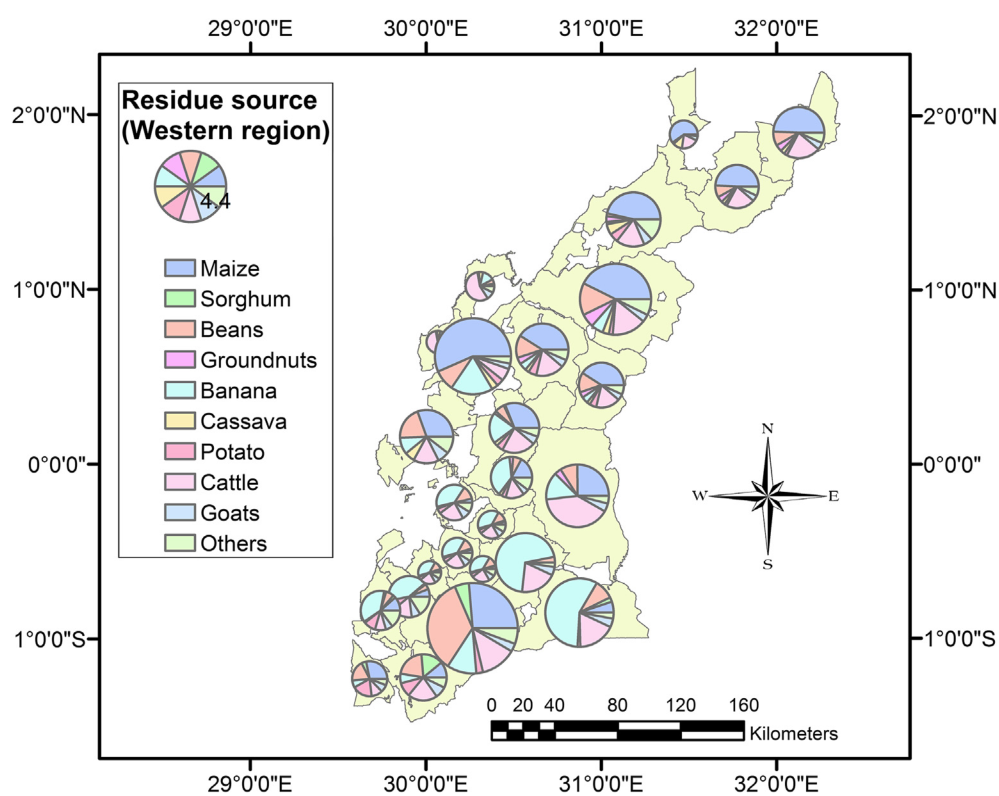

Fig. 7 – Composition of biomass residue in Western Uganda.

Table 3 – Theoretical energy potential of forest residues.

Wood category and purpose	Quantity (Mt y^{-1}) [20]	Logging residues	Processing residues	Total residues (Mt y^{-1})	Energy potential (PJ y^{-1})
Sawn timber	1027	308.10	359.45	667.55	5.34
Poles	888	266.40	–	266.40	2.13
Firewood fuel	5088	2526.40	–	2526.40	20.21
Charcoal fuel	6963	2088.90	–	2088.90	16.71
Total					**44.39**

2.69 PJ y^{-1}. Some of the energy potential could be harnessed in public institutions such as schools, hospitals, and universities.

4.3. *Recoverability of forest residue*

The study showed that the energy potential of forest residues is about 44 PJ y^{-1}. Forest residues are generally classified as logging residues and processing residues. Logging residues are generated during logging operations, which usually take place in geographically sparse locations making it difficult to collect the residues for energy utilisation. There are also technical, ecological and environmental considerations that limit the quantities of forest residues that can be practically recoverable for energy. For example, it may be difficult to recover stumps and roots in many developing countries due to technological constraints. Environmental considerations also requires that the stamps and roots are not harvested since they provide soil stabilisation function. The amount of logging residues that can be practically harvested is estimated using logging residue recoverability fraction. This is the fraction of the generated logging residues that can be realistically harvested for energy application and is estimated to be about 25% in developing countries [44]. Residues are also generated during processing of wood and are estimated using wood processing residue recoverability fraction. Available literature indicates that up to 42% of wood processing residues can be recovered from saw mill in developing countries for energy application [44].

4.4. *Economic, social and environmental considerations*

Sustainable utilisation of biomass residues for energy depends on a number of factors including economic, social and environmental considerations. The cost of the logistical operations for energy conversion of biomass residues has been identified as one of the major bottlenecks in their utilisation. This is because of the complex supply chains usually involved [45]. Economic aspects greatly depend on the costs associated with the collection, transportation, storage and processing of residues. These costs are influenced by specific site conditions, availability of biomass and supply chain design, investment and operational costs [46]. The logistics for biomass residue utilisation may be influenced by the biomass distribution density, operating scale and window, relative distance to supply destination, and the characteristics of the energy conversion technology employed. Usually, use of residues for energy entails gathering of residues from point of generation and transportation to processing facility. Then pre-treatment such as size reduction, drying densification and transportation to market. Other considerations that may influence the economics of the system include availability of infrastructure, geographical location of the area, regulatory environment and competition with other fuels. However, despite these complexities, Skoulou and Zabaniotou [47] noted that use of biomass residues can be economically viable when the logistics is carefully planned in combination with well established energy technologies, more so in the error of increasing fossil fuel prices.

Table 4 – Total energy potential of residues.

Source of energy	Energy potential (PJ/year)
Crop residues	148.67
Animal residues	65.23
Forest residues	44.39
Total	**258.29**

The importance of social aspects in development of bioenergy systems is another consideration that is emphasised in the recent past. Development of suitable systems for biomass residue utilisation will therefore have to involve stakeholders such as potential investors, end users, regulators and decision makers. Environmental aspects should also be taken into account when designing systems for utilising biomass residues for energy. One of the main environmental benefit of utilising biomass residues is the reduction in net CO_2 emission to the atmosphere, therefore contributing to reduction of global warming. A detailed discussion social, economic and environmental consideration in renewable energy sector is given in Akella et al., [48].

5. Conclusions

The energy potential of agricultural and forest residues in Uganda has been evaluated and the spatial distribution presented. The study showed that the country has a gross energy potential from biomass residues equivalent to 70% of the gross biomass energy requirements for the year 2008. However, use of biomass residues for energy application is still limited in the country. For successful utilisation of biomass residues in the country, a number of technical, environmental, social and economic constraints need to be overcome. It is therefore recommended that detailed studies involving sustainability analysis of biomass residue utilisation for energy is carried out by integrating technical, economic, environmental and social considerations in a decision framework. In conclusion, Uganda has enormous potential to generate energy from biomass residues. When exploited in a sustainable manner, biomass residues could contribute to reduction in deforestation and environmental degradation in the country.

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