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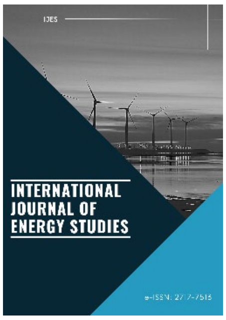

Research Article

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Determining the biomass energy potential derived from agricultural wastes in Uganda

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Highlights

- A comprehensive analysis of the types and quantities of agricultural residues available in Uganda, such as crop wastes.
- Evaluation of the calorific value and energy potential of different types of agricultural wastes.
- Assessment of the environmental benefits and economic viability of utilizing agricultural wastes for energy, including potential impacts on rural development.

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ABSTRACT

Biomass energy derived from agricultural residues holds significant potential for addressing energy needs in Uganda. As a country heavily reliant on traditional biomass sources, the utilization of agricultural waste, such as crop residues, offers a sustainable and renewable energy alternative. This study explores the availability, energy potential, and environmental benefits of using agricultural residues for biomass energy production in Uganda. By analyzing various types of residues, including maize stalks, rice straw, and potatoes stalks, the energy yield was estimated. The findings highlight the potential of agricultural residues to contribute significantly to Uganda's energy supply while reducing environmental degradation associated with conventional biomass use. The amount of agricultural residues produced from annual crops cultivated in Uganda, measured in tons of dry matter per year, was determined using agricultural production data from the Food and Agriculture Organization Statistical Database of the United Nations (FAOSTAT) for the year 2021. The annual gross potential of agricultural residues was calculated by applying the residue-to-product ratio. The total amount of agricultural wastes in Uganda, encompassing annual crop residues such as barley, maize (corn), millet, potatoes, rice, sorghum, soya beans, and wheat was calculated to be approximately 24.9 Kt. The primary crops contributing to the overall residue quantity ratio are maize (59.52%), beans (13.65%), rice (10.53%), sorghum (8.76%), and soya beans (3.85%). Uganda has a significant supply of raw materials suitable for energy production from agricultural residues. For the 2021 production period, the total energy potential of these residues was estimated to be around 432.1 TJ.

Keywords: Agriculture, Biomass energy, Residue, Energy potential, Uganda

1. INTRODUCTION

Uganda is situated in East Africa and covers a total surface area of 241,550.7 km^2 (24,155,070 hectares) [1]. African countries are increasingly investing in their power sectors to enhance energy availability and promote environmental sustainability [2]. Energy has become a major challenge for many countries globally, focusing on the effective management of energy demand while ensuring affordability and sustainability [3]. A crucial element in achieving sustainable development is providing access to clean and reliable energy sources [4].

Energy sources can typically be classified into three primary categories: fossil fuels, renewable sources, and nuclear sources [5]. The use of nonrenewable energy sources, such as fossil fuels, leads to the emission of greenhouse gases, which are major contributors to climate change. Consequently, the release of carbon emissions and the resulting global warming underscore the need to explore alternative energy sources [6]. Numerous researchers, institutions, companies, stakeholders, and policymakers are concentrating their efforts on developing cleaner and more sustainable energy production and application methods [7]. In recent decades, the planet has grappled with severe environmental issues, notably CO_2 emissions stemming from human activities such as fossil fuel combustion for energy and transportation, deforestation, and industrial processes [8].

Renewable energy sources are those that can naturally replenish themselves at a rate equal to or faster than the rate at which they are consumed [9]. Renewable energy (RE) has the potential to significantly reduce the effects of climate change on natural resources and ecosystems by lowering greenhouse gas (GHG) emissions. Furthermore, embracing renewable energy can improve energy security and resilience [10]. Renewable sources are inexhaustible, produce no greenhouse gases, and are available to everyone, regardless of political or geographical boundaries [3]. Renewable energy is crucial for fostering sustainable economic and social development, particularly in reducing poverty and promoting sustainable production and consumption practices. It is also integral to the conservation and management of resources vital for sustainable development. Importantly, renewable energy supports a range of economic objectives, with environmental preservation as a central focus. This recognition has prompted many countries to prioritize the development of renewable energy sources [11]. There are several types of renewable energy that African countries can harness, including hydropower, geothermal energy, biomass, wind power, and solar energy. These sources offer diverse opportunities for sustainable energy production across the continent [6].

Biomass energy includes various biological sources such as agricultural residues, domestic waste, fuelwood, animal waste, and other fuels derived from organic matter. Estimates generally concentrate on the recoverable energy potential from agricultural residues, livestock waste, forestry and wood processing residues, and domestic waste. These sources together contribute to the renewable energy sector through a range of conversion technologies [12].

The study aims to support the development of sustainable energy solutions in Uganda, decrease reliance on non-renewable energy sources, and promote biomass as a viable alternative for energy production.

2. MATERIAL AND METHOD

2.1. Agriculture in Uganda

Agriculture is the backbone of Uganda's economy, employing over 70% of the population and contributing about 24% to the country's Gross Domestic Product (GDP). Most of Uganda's agricultural production depends on rain-fed methods, with less than 2% of the land area being irrigated [1]. In Uganda, agriculture is primarily supported by smallholder farmers, with 95% owning landholdings of less than 2 hectares. The sector is vital as one of the three main growth areas, playing a key role in job creation, providing livelihoods, and representing the largest household enterprises [13]. In Uganda, climate change is recognized as the primary constraint affecting productivity in rainfed agriculture [14].

2.2. Assessment of Biomass Energy in Uganda

The main challenges in using biomass for energy production involve the logistics of collection and transportation, as well as the seasonal availability of biomass. These issues can result in substantial fluctuations in biomass supply, potentially making it an unreliable energy source. Therefore, addressing these barriers is essential for the effective use of biomass in energy applications [15].

2.2.1. Calculation of the avialable amount of agricultural residue

The amount of agricultural residues produced from annual crops cultivated in Uganda, measured in tons of dry matter per year, were determined using agricultural production data from the Food and Agriculture Organization Statistical Database of the United Nations (FAOSTAT) for the year 2021 (FAOSTAT, 2021). The annual gross potential of agricultural residues was calculated by applying the residue-to-product ratio.

The net potential of residues was evaluated based on their availability, which pertains to the portion of the residue that is unused and considered waste. The available potential of agricultural residues in Uganda was calculated using Equation (1) [5].

$$(AAR)_i = (ACP)_i x (RPR)_i x (A)_i \tag{1}$$

where, $(AAR)_i$ is the available amount of agricultural residues of i^{th} crop in ton; $(ACP)_i$is the amount of crop production in tons; $(RPR)_i$ is the residue-to product ratio of the i^{th} crop and $(A)_i$ is the availability of residues.

Table 1. Data regarding the residue-to product ratio, Availability and calorific value of various field crop residues [5, 12, 15, 16]

FC	**R**	**RPR**	**A (%)**	**LHV ($MJkg^{-1}$)**
Beans, dry	Shell	0.006	40	19.4
Maize (corn)	Stalks	0.004	60	17.95
Millet	Straw	0.010	15	12.39
Potatoes	Stalks	0.005	60	18.61
Rice	Straw	0.006	60	14.92
Sorghum	Stalks	0.011	60	12.38
Soya beans	Straw	0.006	60	19.4
Wheat	Straw	0.014	15	18.20

Agricultural residues are materials left in the field after agricultural activities, they are by-products of crop production and processing, including stalks, husks, leaves, and shells. These residues are often underutilized or discarded as waste. However, they hold significant potential for energy production through processes such as combustion, gasification, pyrolysis, and anaerobic digestion. While some of these residues are used for domestic purposes such as heating, animal fodder, and bedding, the primary residues from the production of industrial agricultural products often remain unused in the field.

2.2.2. Calculation of the energy potential

The calorific values of agricultural residues were determined using a calorimeter according to the ASTM D 5865 Standard Test Method for Coal and Coke (2002) [16]. These values are presented in Table 1. To determine the energy potential of the residues, the calorific values of specific agricultural residues from Table 1 were multiplied by the available quantity of each residue, as described in Equation (2) [17].

$$(EP)_i = (AAR)_i x (LHV)_i \tag{2}$$

where $(EP)_i$ the energy potential of agricultural residues of i^{th} crop in GJ/Kg, $(AAR)_i$ is the available amount of agricultural residues of i^{th} crop in tons and $(LHV)_i$ lower heating value of air dry residues of i^{th} crop in $MJ.Kg^{-1}$.

The following flowchart illustrates the process for calculating the total heat value (total energy potential).

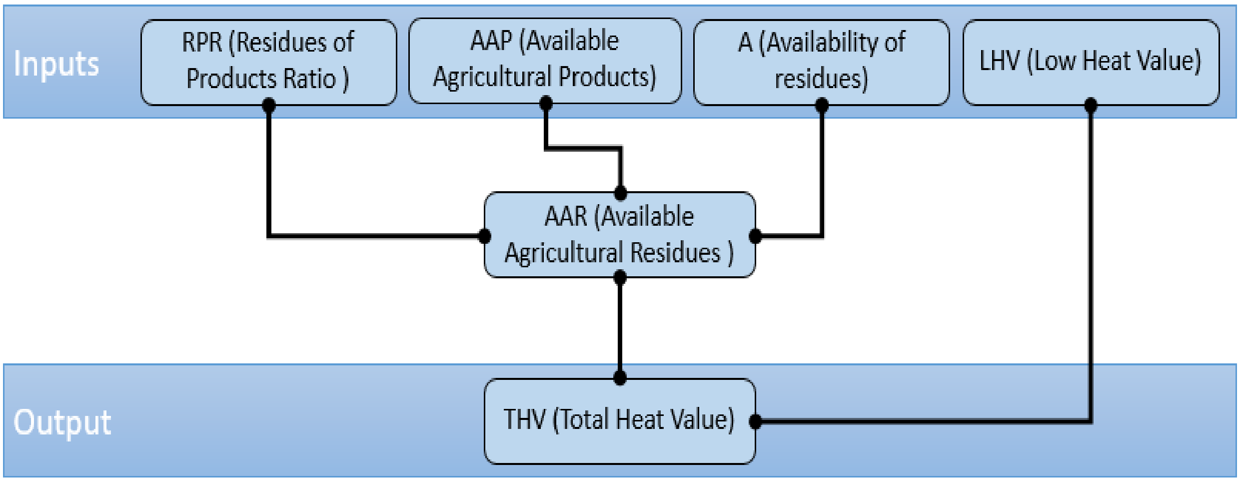

Figure 1. A flowchart for calculating the total energy potential

3. RESULTS AND DISCUSSION

Table 2. Total crop production and the potential for agricultural residues in Uganda [18]

FC	ACP (Ton)	R	TPR (Ton)
Beans, dry	1414574	Shell	7821.1
Maize (corn)	6164663	Stalks	25024.3
Millet	89773	Straw	915.9
Potatoes	241230	Stalks	1106.6
Rice	727120	Straw	4284.1
Sorghum	330000	Stalks	3744.9
Soya beans	265870	Straw	1512.3
Wheat	25000	Straw	355.8
Total	**9258230**	**Residues**	**44765**

The efficiency of converting agricultural residues into usable energy depends on the technology used (examples of those Technologies such as Direct Combustion, Biogas Production, Gasification, Pyrolysis, and Bioethanol Production). The efficiency of these technologies depends on several factors, including the type of residue, pre-treatment methods, and system design. Modern technologies can achieve higher conversion efficiencies, making the process more viable and sustainable. Utilizing agricultural residues for biomass energy can create economic opportunities, particularly in rural areas. It can provide additional income for farmers from selling residues and generate employment in biomass collection, transportation, and processing sectors.

Uganda has a substantial amount of raw materials from agricultural residues that are suitable for energy production. For the 2021 production period, the total energy potential of these residues was calculated to be approximately 432.1 TJ. The amount of biomass energy represents a substantial amount of energy. To put it in perspective, this is equivalent to the energy required to power around 100,000 homes for a year, depending on the average household energy consumption.Table 3 details the heating values of various agricultural residues along with the respective available amounts for each product. From table 3 we can see that rice residue is the best option to produce energy in Uganda which has energy potential of 39054.6 KG/ kg followed by sorghum and maize residuies with the energy potential of 26963.6 and 265573.8 KG/ kg respectively. The following figure shows the energy potential of various crop residues in Uganda.

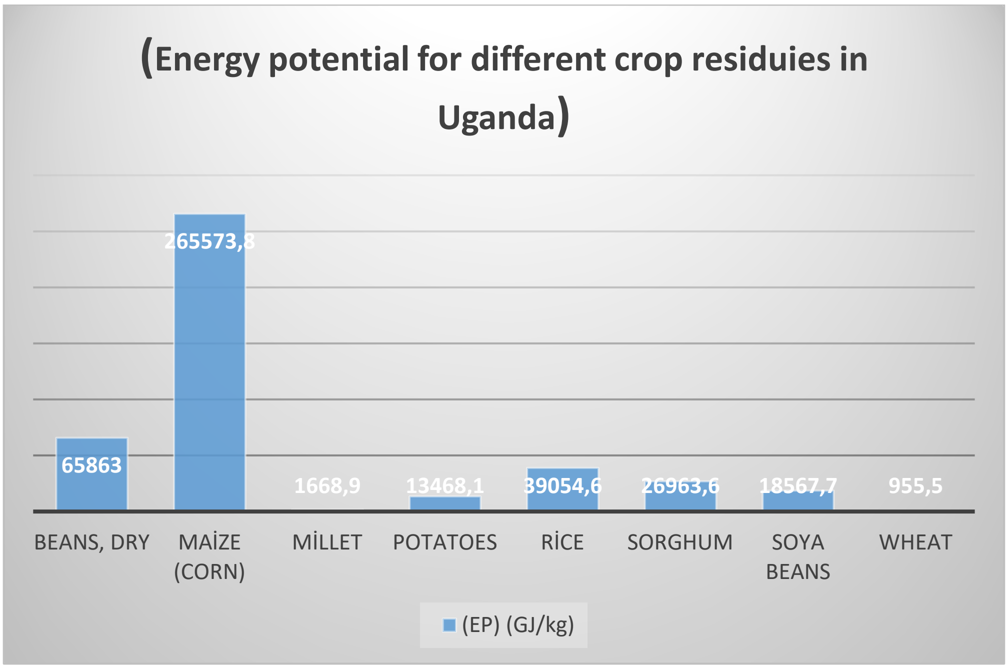

Figure 2. Energy potential for different crop residues in Uganda

As shown in the figure above the residue from the maize (corn) constitutes more than half of the energy potential in Uganda. Maize residues have relatively high calorific values, significantly contributing to energy potential.

Table 3. The total energy potential and the corresponding amount of available agricultural residues in Uganda

FC	R	AAR (Ton)	(EP) (GJ/kg)
Beans, dry	Shell	3395	65863
Maize (corn)	Stalks	14795.2	265573.8
Millet	Straw	134.7	1668.9
Potatoes	Stalks	723.7	13468.1
Rice	Straw	2617.6	39054.6
Sorghum	Stalks	2178	26963.6
Soya beans	Straw	957.1	18567.7
Wheat	Straw	52.5	955.5
Total	**Residues**	**24853.8**	**432115.2**

Several studies have been conducted to assess the energy potential of agricultural residues in various countries; in a study conducted by [12] investigated the energy potential of agricultural residues in Turkey's Black Sea Region. Their study estimated the total calorific value of these residues for the 2016 production period at approximately 33.60 PJ per year, which is higher than the corresponding value for Uganda. [5] conducted a study in Sudan to calculate the biomass energy potential from agricultural residues for the 2016 production period. The total calorific value was estimated at approximately 154 petajoules (PJ), significantly surpassing Uganda's figures. This highlights a considerable difference in the energy potential of agricultural residues between the two countries, with Sudan showing a substantially higher capacity. A study by [19] evaluated the energy potential of agricultural residues in Libya, estimating it at around 17.7 TJ for the 2021 production season, which is lower compared to Uganda. In a study by [20] assessed Syria's energy potential and estimated that, for the 2016 production season, the total calorific value of agricultural residues from field and orchard crops was approximately 68,904 Btu, surpassing the corresponding value for Uganda.

The difference in energy potential from agricultural residues among these countries is primarily influenced by several key factors such as agricultural productivity and crop types (Countries with higher agricultural productivity and a greater variety of crops generally produce more agricultural residues), land area and cultivation practices (The size of arable land and the intensity of agricultural practices play a significant role), climate and environmental conditions (Variations in climate impact the types and quantities of crops grown, which in turn affect the volume of agricultural residues), type and usage of residues (The type of agricultural residues and their utilization also affect energy potential), and economic and technological development (Countries with better access to technology and infrastructure may have more efficient residue collection systems, enabling them to maximize their energy potential).

Understanding these differences offers valuable insights into optimizing biomass energy production and utilization in various countries. By analyzing factors such as agricultural productivity, residue types, and resource management practices, policymakers and stakeholders can identify opportunities to enhance energy yields. Tailored strategies can then be developed to improve residue collection systems, promote sustainable agricultural practices, and integrate biomass energy into broader energy frameworks. This understanding helps to maximize the efficiency and sustainability of biomass energy utilization, catering to each country's unique agricultural and economic conditions.

The total quantity of agricultural wastes in Uganda, including annual crop residues from barley, maize (corn), millet, potatoes, rice, sorghum, soybeans, and wheat, was estimated to be around 24.9 Kt, as shown in Table 3.

The primary crops contributing to the overall residue quantity ratio are maize (59.52%), beans (13.65%), rice (10.53%), sorghum (8.76%), and soya beans (3.85%).

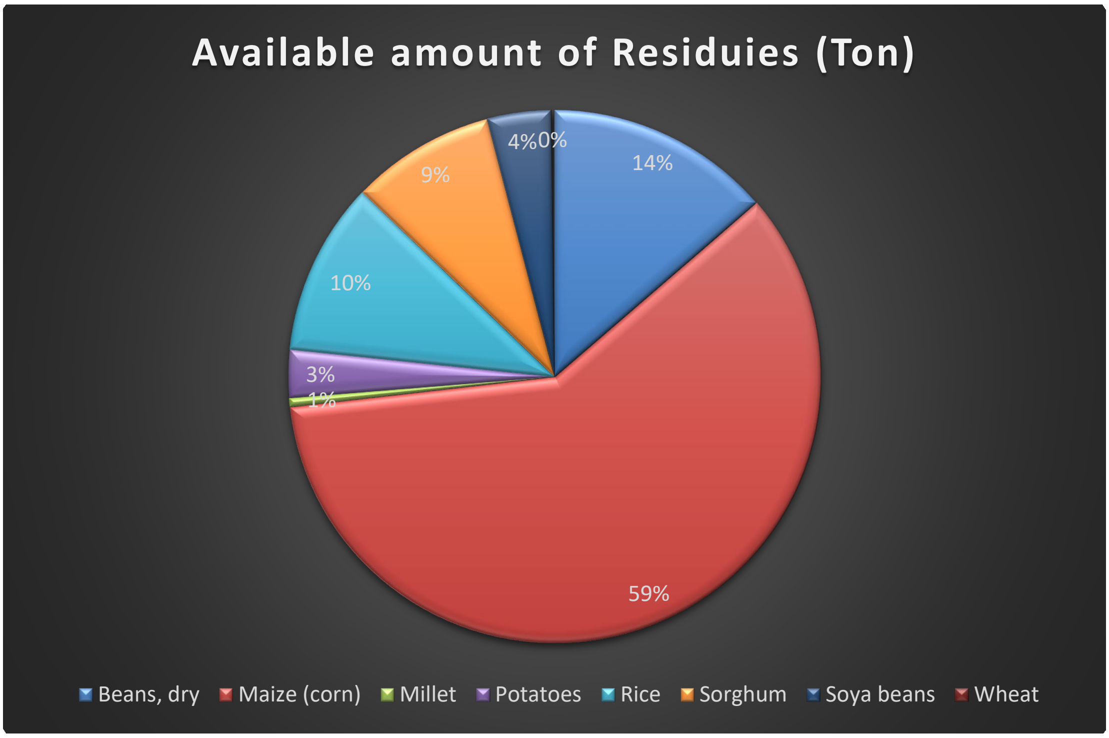

Figure 3. Available amount of crop residues in Uganda

4. CONCLUSION

The exploration of biomass energy from agricultural residues in Uganda based on agricultural residue availability, environmental benefits, economic feasibility, government and policy support, technological readiness, and socioeconomic ımpact reveals a promising avenue for sustainable energy production. This study underscores the substantial energy potential contained within crop residues such as beans dry, maize millet, potatoes, rice, sorghum, soyabeans and wheat. Utilizing these residues can significantly augment Uganda's energy supply, alleviate pressure on traditional biomass sources, and mitigate environmental degradation. To realize this potential, concerted efforts are required in policy formulation, infrastructure development, and the adoption of appropriate technologies.

Embracing biomass energy from agricultural residues not only offers a renewable energy solution but also supports rural development and economic growth, paving the way for a more sustainable and resilient energy future for Uganda. The estimated total energy potential of these agricultural residues is considerable. By converting these residues into usable energy, Uganda can significantly enhance its energy supply, contributing to energy security and sustainability.

In this study, crops like barley, maize (corn), millet, potatoes, rice, sorghum, Soya beans, and wheat were identified as potential sources for energy production. The total amount of agricultural waste in Uganda, including annual crop residues, was calculated to be around 24.9 Kt. Despite variations in biomass density among these crops in Uganda, their combined biomass can generate a significant amount of renewable energy. The study determined that the total energy potential of agricultural residues from these crops in Uganda for the 2021 production period is approximately 432.1 TJ. This biomass energy potential from agricultural residues in Uganda represents a significant resource that, if harnessed effectively, could contribute to energy needs, and support economic development.

Recommendations:

- Establish collection centers close to farming areas to facilitate the aggregation of agricultural residues.
- Invest in infrastructure to ensure efficient and cost-effective transportation of residues to processing facilities.
- Promote cooperative models where farmers can collectively gather and transport residues, reducing individual costs and increasing efficiency.
- Encourage the use of modern biomass conversion technologies such as gasification, pyrolysis, and anaerobic digestion to increase energy yield.
- Implement pilot projects to demonstrate the benefits and feasibility of advanced biomass technologies to local stakeholders.
- Formulate policies that support biomass energy development, including clear guidelines on the use of agricultural residues.
- Conduct training programs to educate farmers on the benefits and methods of collecting and utilizing agricultural residues for energy production.
- Support research institutions to develop and improve biomass conversion technologies suited to local conditions.

NOMENCLATURE

FC	Field Crops
R	Residues
RPR	Ratio of Residue to Product
A	Availability
LHV	Lower Heating Value ($MJkg^{-1}$)
ACP	Amount of Crop Production (tons)
TPR	Total Potential of Residues (tons)
AAR	Amount of Agricultural Residues (tons)
EP	Energy Potential (GJ/kg)
ASTM	American Society for Testing and Materials

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Mohamedeltayib Omer Salih EISSA: Conceptualization, Analysis; Writing- review & editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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