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Exploring the Potential of Producing Biomass Energy from Agricultural Residues in Chad

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ABSTRACT

This study investigates the potential for generating biomass energy from agricultural residues in Chad. Biomass energy, derived from organic materials, is a renewable and sustainable energy source that can significantly contribute to the energy needs of many countries. In Chad, a country with a predominantly agrarian economy, agricultural residues present a promising opportunity for biomass energy production. The biomass energy production from agricultural residues in Chad holds significant potential to contribute to the country's energy needs while promoting sustainable development. The country possesses abundant agricultural resources, with substantial residues remaining after harvest, including sorghum stalks, maize stalks, millet straw, and rice straw, often underutilized. These residues can be converted into biofuels like biogas through anaerobic digestion or burned directly to produce heat and electricity. Using data from the Food and Agriculture Organization Statistical Database of the United Nations (FAOSTAT) for 2021, the annual production of agricultural residues was quantified, and their energy potential was calculated based on the residue-to-product ratio and the calorific values of specific residues. The major crops contributing to the total residue amount in Chad are sorghum (56.50%), rice (17.72%), maize (13.31%), millet (6.70%), and dry beans (5.37%). The total amount of agricultural residues in Chad, including annual crop residues, was calculated to be about 18.1 kilotons (kt). The study reveals that the total energy potential of these residues is approximately 252.5 terajoules (TJ) for the 2021 production period in Chad.

Keywords: *Renewable energy, Biofuel, Electricity, Heating value, Energy potential*

INTRODUCTION

Chad, situated in Central Africa, is a landlocked country located between 7° and 24° north latitude and 13° and 24° east longitude. It shares borders with Libya to the north, Sudan to the east, the Central African Republic to the south, and Cameroon, Niger, and Nigeria to the west. Notably, it shares Lake Chad with these western neighbors (Soulouknga *et al.*, 2020). The rapid population growth in developing countries, coupled with limited access to electricity, particularly in remote or rural areas, presents significant challenges for energy production (Jahangiri *et al.*, 2019). Energy plays a crucial role in economic development, with a clear correlation between energy consumption and living standards (Demirel *et al.*, 2019). Every nation's economic growth is closely tied to its electricity infrastructure and availability. Electricity has become a central element of daily life in the modern world, influencing various sectors and activities essential for economic development (Kriga *et al.*, 2023). Energy sources can be divided into three categories: fossil fuels, renewable sources, and nuclear sources (Eissa *et al.*, 2024). Renewable energy sources are readily available, inexhaustible, and mostly environmentally clean, making them a sustainable option for meeting energy needs (Kelly *et al.*, 2023).

Conversely, the depletion of fossil fuels and the imperative to mitigate greenhouse gas (GHG) emissions have intensified the pursuit of alternative energy sources, particularly in many developing nations where energy poverty remains a significant concern. The increasing global worry about climate change and its impacts has led to a heightened focus on renewable energy as the cornerstone of a dependable and eco-friendly energy provision system (Kidmo *et al.*, 2022). Researchers worldwide have explored the potential of harnessing renewable energy for electricity generation due to the adverse environmental impacts of fossil fuels (Soulouknga *et al.*, 2020).

According to the United States Energy Information Administration projections, global energy consumption is expected to surge by 50% by the year 2050, following the current trajectory (Djimtoingar *et al.*, 2022). Between 1993 and 2005, energy consumption in Chad increased from 200 koe (kilo of oil equivalent) to 292 koe. Wood fuels, including wood and charcoal, dominate energy consumption, accounting for 90% of the total, while conventional energy sources such as petroleum products and electricity contribute only 10%. Wood fuels are predominantly used for cooking in households (88%), while kerosene lamps are the primary source of lighting, utilized by 69% of households (Medjo Nouadje *et al.*, 2024).

Chad currently needs to grapple with an electricity supply deficit, low rates of electricity access, and notably high costs per kilowatt-hour. These challenges stem from heavy reliance on fossil fuels, limited interconnection with neighboring countries, and insufficient integration of renewable energies into electricity generation (Medjo Nouadje *et al.*, 2024). Making electricity accessible in Chad is crucial from a socio-economic standpoint because much of the population still struggles to obtain reliable access (Soulouknga *et al.*, 2023). In Chad, only 8% of the population has access to electricity, highlighting a substantial disparity between rural (1%) and urban (20%) areas. Chad ranks among the countries with the lowest electricity access rates globally (Soulouknga *et al.*, 2022). Over two-thirds of Africa's population, approximately 621 million people, lack access to electrical energy (Jahangiri *et al.*, 2019). Approximately 775 million people worldwide are estimated to lack access to electricity (Verhoeven and Pouget-abadie, 2024).

Biomass energy includes agricultural residues, household waste, fuelwood, animal waste, and other fuels derived from biological sources (Karaca, 2017). Biomass resources are globally recognized as sustainable alternative energy sources due to their widespread availability, renewable nature, and carbon-neutral characteristics (Djimtoingar *et al.*, 2022). It's important to note that Chad, possesses substantial renewable energy potential, including wind, solar, and biomass resources

(Ali *et al.*, 2024). It is imperative that appropriate resource allocation policies are implemented, particularly in relation to water, energy and food resources, in order to facilitate sustainable development (Degirmencioglu *et al.*, 2019). The successful utilization of biomass for energy contributes to the increasing ratio of renewable energy generation, particularly in the context of electricity generation. Biomass energy represents one of numerous clean sources of energy, offering carbon-neutral electricity and heat generation (Ertuğrul *et al.*, 2024).

This study aims to explore the potential of producing biomass energy from agricultural residues in Chad. This includes assessing the availability and types of agricultural residues and evaluating the feasibility and efficiency of converting these residues into biomass energy. The study seeks to provide a comprehensive understanding of how biomass energy production from agricultural residues could contribute to Chad's energy security, rural development, and environmental sustainability.

MATERIALS and METHODS

Agricultural Lands in Chad

In Chad, agriculture is carried out on two distinct types of land: dunes during the rainy season and wadis during the dry season. Both men and women participate in agricultural activities, which serve as the primary food source for households (Narem, 2024). Agriculture in Chad contributes 40% to the GDP and 80% to exports while employing 80% of the workforce. However, farmers need more access to essential services, knowledge, and technology needed for productivity improvements. Furthermore, inadequate access to rural financial services prevents poor farmers from diversifying their income sources or increasing productivity (Senn, 2024). Various factors across different scales and intensities influence agricultural systems in Sub-Saharan Africa. These systems operate within dynamic political and socioeconomic contexts, experiencing frequent transformations. Moreover, they heavily rely on unstable environmental conditions (Nilsson and Uvo, 2020). Due to Chad's challenging climatic conditions and the impact of its unstable political environment, engaging in agricultural activities is already a significant struggle for the population (Su and Amrit, 2024).

Assessment of Biomass Energy in Chad

Biomass can be transformed into energy, which can then be utilized to generate electricity and provide heating This is an alternative to traditional cooking fuels, particularly in rural regions where access to conventional energy sources is limited (Ghanem *et al.*, 2024). Biomass is Chad's main energy source primarily used for cooking and heating in rural and peri-urban areas. The most common forms of biomass are firewood, charcoal, and agricultural residues. The primary challenges in utilizing biomass for energy production are the logistics of collection and transportation, and its seasonal availability. These factors can lead to significant variability in biomass supply, making it an unreliable source for energy applications (Karaca, 2017).

Most of the population relies on traditional biomass for energy, leading to significant deforestation and environmental degradation. Chad has low electricity access, especially in rural areas. Biomass energy fills the gap where modern energy infrastructure is lacking.

Chad has a significant agricultural sector, producing residues that can be utilized for energy production. This includes crop residues from maize (corn), millet, sorghum, rice, etc... Utilizing local biomass resources can enhance energy security and reduce dependency on imported fossil fuels (Boyacı *et al.*, 2021).

Biomass energy projects can create jobs and improve livelihoods in rural areas. Properly managed biomass energy can reduce deforestation, soil erosion, and greenhouse gas emissions. Biomass energy helps to manage agricultural and animal waste, turning potential pollutants into energy.

Calculation of the available amount of agricultural residues in Chad

The quantity of agricultural residues produced annually by crops in Chad, expressed in tons of dry material, was assessed using agricultural production data from the Food and Agriculture Organization Statistical Database of the United Nations (FAOSTAT) in 2021. The annual overall potential of agricultural residues was calculated using the residue-to-product ratio.

The residual net potential was evaluated by considering the availability of residues, which refers to the unutilized and entirely wasted portion of the residues. The attainable potential of agricultural wastes in Chad was calculated using Equation (1) (Karaca, 2015).

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

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 (Karaca, 2015; Karaca, 2017; Karaca et al., 2017; Demirel et al., 2019).*

FC	R	RPR	A(%)	LHV (MJ kg^{-1})
Beans, dry	Stalk	0.016	40	19.4
Maize (corn)	Stalk	0.011	60	17.95
Millet	Straw	0.013	15	12.39
Potatoes	Stalk	0.003	60	18.61
Rice	Straw	0.022	60	14.92
Sorghum	Stalk	0.019	60	12.38
Wheat	Straw	0.014	15	18.2

FC: Field Crops, R: Residues RPR: Ratio of Residue to Product, A: Availability, LHV; Lower Heating Value ($MJ\ kg^{-1}$)

Agricultural residues include materials left behind in fields after operations. Agricultural residues are an abundant and underutilized resource in Chad. These residues, often left to decompose in fields or burned, represent a significant opportunity for biomass energy production. The primary agricultural residues in Chad include stalks and straw from beans, maize (corn) millet, potatoes, rice, sorghum, and wheat. These materials have high energy content and can be converted into bioenergy through various technologies. While some residues are repurposed for domestic uses like heating, animal feed, and bedding, most residues from industrial agricultural production often remain untouched in the fields. These residues include cotton stalks, maize stalks, sunflower stalks, cereal straws, and similar materials.

Determination of the energy potential in Chad

To determine the energy potential of residues, the calorific values of specific agricultural residues, as derived from the analyses presented in (Table 1), were multiplied by the available residue amounts, following Equation (2) (Demirel *et al.*, 2019).

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

Where, $(EP)_i$ the energy potential of agricultural residues of i^{th} crop in GJ kg^{-1}, $(AAR)_i$ 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 flowchart below describes the process that can be used to calculate the total energy potential in Chad. This step-by-step representation (Figure 1) ensures clarity and consistency in calculating the energy potential of biomass in Chad.

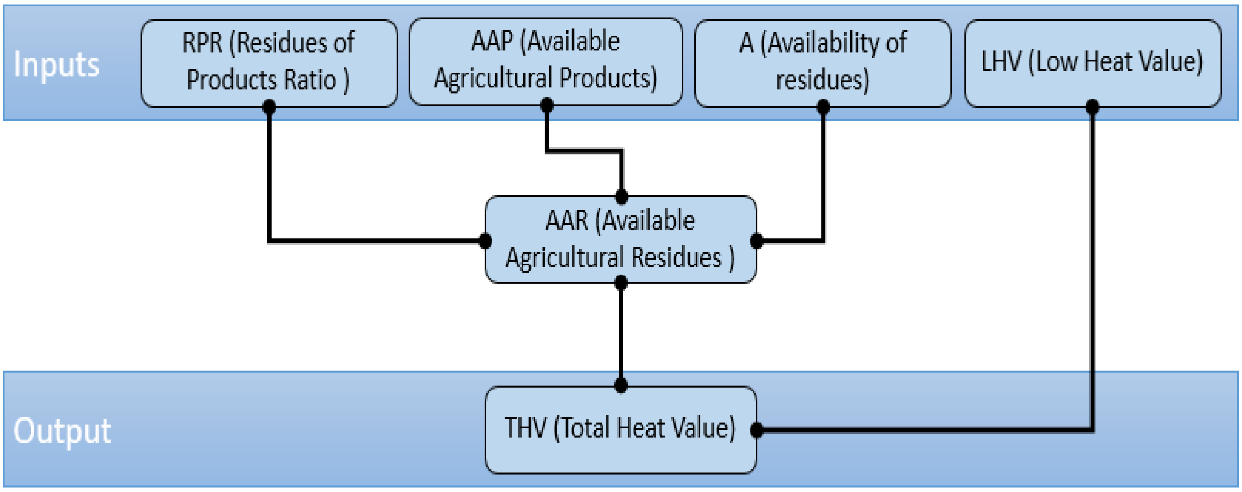

Figure 1. *A flowchart for calculating the total heat value (energy potential).*

RESULTS AND DISCUSSION

Chad produces significant crop residues from staple crops like beans, maize, millet, potatoes, rice, sorghum, and wheat. These residues include stalks and straws.

Table 2. *Total agricultural production and crop residues in Chad, based on data from (FAOSTAT, 2021).*

FC	ACP (Ton)	R	TPR (Ton)
Beans, dry	151696.4	Stalk	2457.3
Maize (corn)	364630.7	Stalk	4089.2
Millet	621367.3	Straw	7998.2
Potatoes	36314.9	Stalk	119.6
Rice	242646.7	Straw	5395.4
Sorghum	895778	Stalk	17837.7
Wheat	1539.5	Straw	21.1
Total	**2313973.5**	**Residues**	**37918.5**

FC; Field crops, ACP; Amount of Crop Production (tons), R; Residues TPR; Total Potential of Residues (tons)

Table 2 provides an overview of Chad's agricultural production, and the estimated quantities of crop residues generated annually, based on data from FAOSTAT (2021). By systematically presenting production and residue data, Table 2 serves as a foundation for energy resource assessments, agricultural policy planning, and biomass utilization projects in Chad.

The energy content of crop residues varies but is generally high enough to make them a viable source of biomass energy. The combined energy potential from all agricultural residues in Chad is substantial, indicating a strong potential for biomass energy production.

Table 3. *Total energy potential and the corresponding quantity of available agricultural residues in Chad.*

FC	R	AAR (Ton)	(EP) (GJ kg^{-1})
Beans, dry	Stalk	970.9	18835.5
Maize (corn)	Stalk	2406.6	43198.5
Millet	Straw	1211.7	15012.9
Potatoes	Stalk	65.4	1217.1
Rice	Straw	3202.9	47787.3
Sorghum	Stalk	10211.9	126423.3
Wheat	Straw	3.2	58.2
Total	**Residues**	**18072.6**	**252532.8**

FC; Field crops, R; Residues AAR; Amount of Crop Residues (tons), EP; Energy Potential (GJ kg^{-1})

Chad has abundant raw materials for energy production from agricultural residues. The total energy potential of agricultural residues was estimated at around 252.5 TJ for the 2021 production period in Chad. There are some studies below performed to determine energy potential from agricultural residues in different countries; Demirel *et al.* (2019) in a study carried out in Sudan, calculated the biomass energy from Agricultural residues, for the production period of 2016; the total calorific value of agricultural residues amounted to around 154 petajoules (PJ), which is substantially higher than Chad's figure. There's a notable difference in the total energy potential of agricultural residues between Chad and Sudan. This suggests that Sudan had a significantly larger amount of agricultural residue energy potential than Chad. In a study conducted by Eissa *et al.* (2024), assessed the energy potential in Libya and found that the total energy potential of agricultural residues for the 2021 production season was approximately 17.7 TJ, which is less than that in

Chad. In a study by Karaca *et al.* (2017), they examined the energy potential of agricultural residues in Turkey's Black Sea Region, they estimated that, for the 2016 production period, the total calorific value of these residues was about 33.60 PJ per year, which is larger than that in Chad. In a study conducted by Ghanem *et al.* (2024), researchers evaluated Syria's energy potential and found that, for the 2016 production season, the total calorific value of agricultural residues from field and orchard crops was approximately 68,904 Btu which is greater than the total calorific value in Chad.

The difference in energy potential among these countries could be influenced by various factors such as agricultural practices, crop types, land availability, and biomass utilization efficiency. Also, thermal efficiency of a biomass-based power plant, which is 35%, is an important factor to be considered before the utilization decisions (Sun *et al.*, 2014). Understanding these differences can provide insights into optimizing biomass energy production and utilization in different countries. This estimate provides a quantitative foundation for understanding the capacity of Chad to produce biomass energy from agricultural waste materials. This energy can enhance energy security, support rural development, and contribute to environmental sustainability. (Table 3) displays the heating value of agricultural residues for each product.

Biomass energy conversion technologies, such as direct combustion, gasification, and anaerobic digestion, have varying efficiencies. The choice of technology and its efficiency will significantly impact on the usable energy derived from these residues. While these technologies are available, their adoption in Chad is currently limited. Small-scale biogas plants exist, but there is significant potential for expansion. Utilizing agricultural residues for energy production can have positive environmental impacts. It can reduce the need for fossil fuels, thereby lowering greenhouse gas emissions. Moreover, proper management of agricultural residues can prevent open burning, which causes air pollution and health problems.

The practical implementation of biomass energy production in Chad hinges on several factors. First and foremost is the availability of infrastructure for collecting, processing, and converting agricultural residues into usable energy. This includes facilities for biomass collection, transportation networks, and conversion plants. Economic factors also play a vital role; the cost of collecting and processing agricultural residues must be weighed against the market price of the energy produced. Additionally, government policies, subsidies, and incentives for renewable energy projects can significantly influence the economic viability of biomass energy production.

The total amount of agricultural residues in Chad, including annual crop residues, was calculated to be about 18.1 kt. The agricultural residues considered in this study typically include crop residues like straw and stalks from major crops such as beans, maize, millet, potatoes, rice, sorghum, and wheat. The quantity and energy content of these residues are critical in determining the overall energy potential.

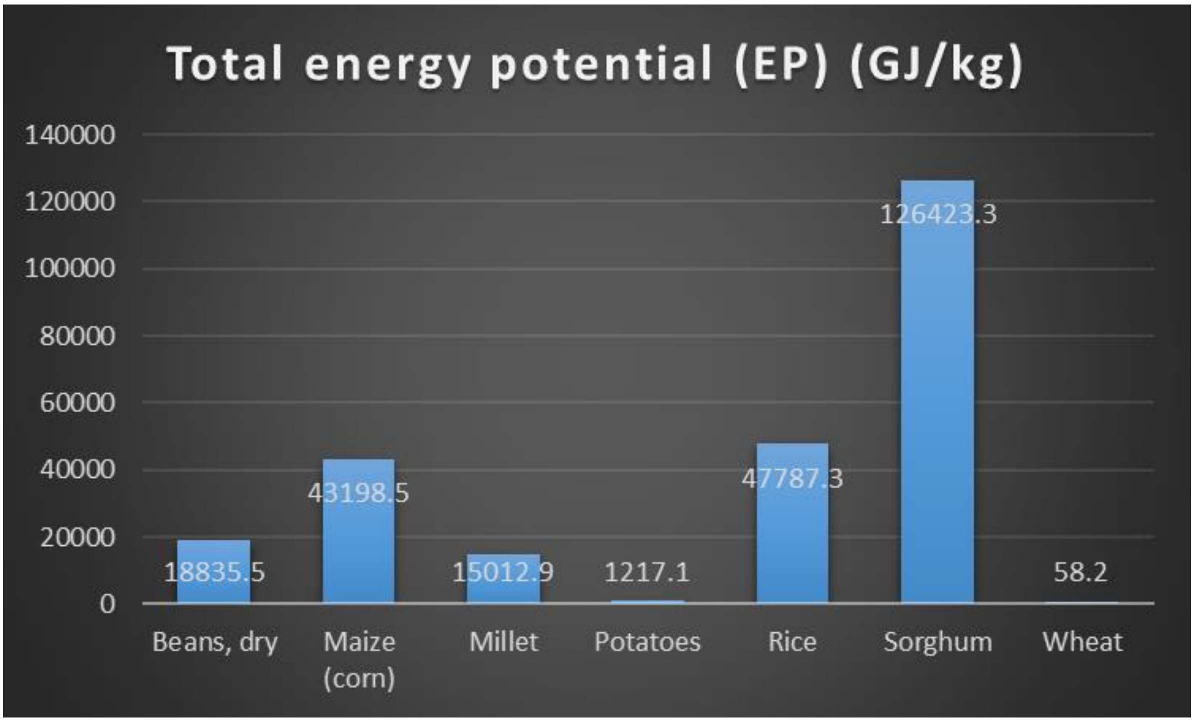

Figure 2*. The amount of energy potential for agricultural residues.*

Figure 2 represents the amount of energy potential for agricultural residues in Chad. This bar chart visually represents the energy potential of various crop residues, emphasizing their contribution to biomass energy production. From this figure, we can see that Chad has a sufficient amount of agricultural residues to produce biomass energy, especially the residues from sorghum.

The major crops contributing to the total residue amount in Chad are sorghum (56.50%), rice (17.72%), maize (13.31%), millet (6.70%), and beans (5.37%).

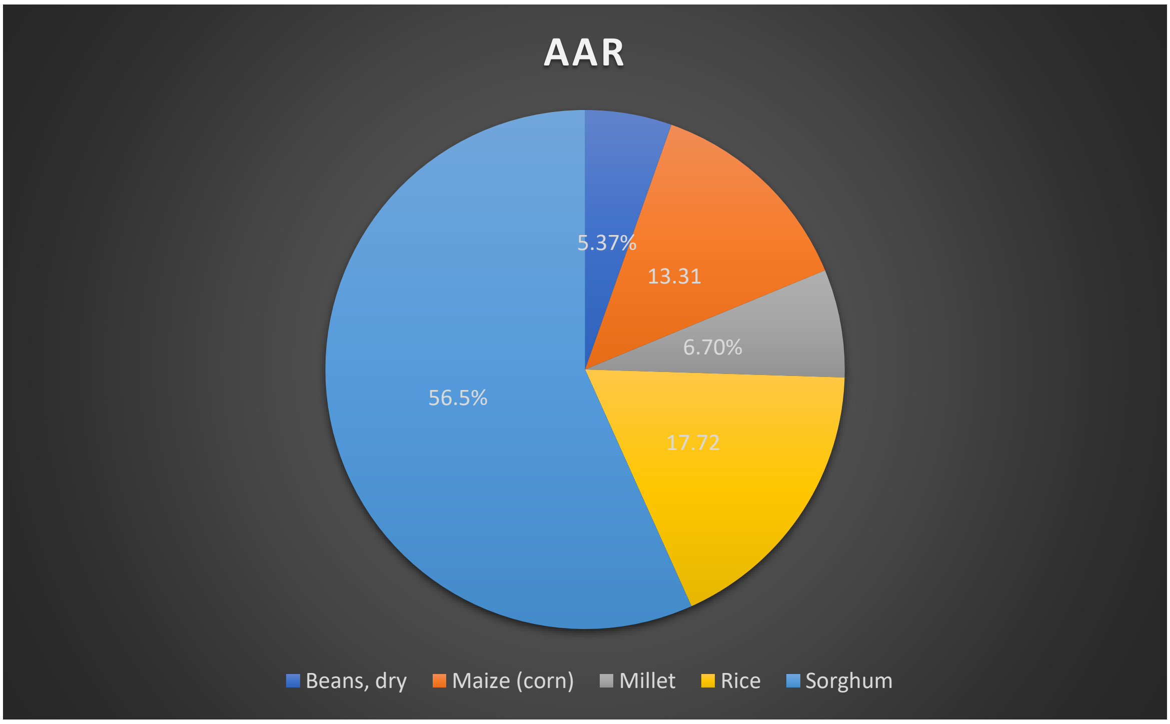

Figure 3*. Amount of agricultural residues in Chad.*

Figure 3 illustrates the total amount of agricultural residues generated annually in Chad, categorized by crop type. This data is critical for assessing the availability of biomass resources and their potential applications in energy production or sustainable agricultural practices.

CONCLUSION

This study aims to investigate the potential for generating biomass energy from agricultural residues in Chad. Chad has abundant agricultural residues, presenting a promising opportunity for biomass energy generation. Harnessing this potential could enhance energy security, promote sustainable agricultural practices, and contribute to the country's overall economic development. Further research and investment in appropriate technologies and infrastructure are essential to realize the complete potential. Utilizing agricultural residues for energy production can provide several benefits, including reducing greenhouse gas emissions, promoting rural development, and diversifying energy sources.

Biomass energy has significant potential to contribute to Chad's energy mix, particularly in rural areas where other forms of energy are scarce. Developing biomass energy aligns with Chad's renewable energy goals and can help reduce dependence on imported fuels. By leveraging data from the Food and Agriculture Organization Statistical Database of the United Nations (FAOSTAT) for 2021, the quantity and energy potential of these residues were assessed. The study examines the calorific values of specific agricultural residues and calculates the total heating value, highlighting the feasibility of converting these residues into a viable energy source. For the 2021 production period in Chad, the total heating value of agricultural residues was estimated to be approximately 252.5 TJ. With the right policies, infrastructure, and community engagement, Chad can make strides in developing a sustainable and economically viable biomass energy sector.

There are potential challenges that need to be addressed. These include the seasonal availability of agricultural residues, storage issues, and the possible competition with other uses of residues. Additionally, the initial capital investment required for setting up biomass energy plants can be a barrier, particularly in developing regions. A supportive policy and regulatory framework are crucial. Governments can play a key role by enacting policies that promote biomass energy, providing subsidies for technology adoption, and ensuring a stable market for the energy produced. Additionally, regulations to manage the sustainable use of agricultural residues can help in maintaining a balance between energy production and other agricultural needs.

Recommendations for Biomass Energy Development

1. Promote sustainable harvesting and reforestation programs to ensure a continuous supply of biomass.
2. Develop a systematic approach to catalogue and quantify the types and amounts of agricultural residues available across different regions in Chad. This data will be crucial for planning and optimizing biomass energy production.

3. Conduct awareness campaigns and train farmers and local communities on the benefits and methods of utilizing agricultural residues for biomass energy. This will enhance community participation and support for biomass projects.
4. Invest in efficient biomass technologies, such as improved cookstoves and biogas digesters, to enhance energy efficiency and reduce health impacts.
5. Develop capacity-building programs to educate communities on sustainable biomass use and management.
6. Establish supportive policies and incentives for biomass energy development, including subsidies for improved technologies and support for research and development.
7. Encourage public-private partnerships to mobilize resources and expertise for biomass energy projects.
8. Integrate biomass energy into the broader national energy strategy, ensuring it complements other renewable energy sources and contributes to overall energy goals.

DECLARATION OF COMPETING INTEREST

I declare that I have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author declared that the following contributions is correct.

Mohamedeltayib Omer Salih EISSA: The author would like to declare that he solely developed all the sections in this manuscript.

ETHICS COMMITTEE DECISION

This article does not require any Ethical Committee Decision.

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