Mapping Biomass Energy Potential from Agricultural Residues in Tanzania

Geofrey Prudence Baitu[1](✉), Khaled Adil Dawood Idress[2], Omsalma Alsadig Adam Gadalla[3], and Yeşim Benal Öztekin[4]

[1] College of Agriculture and Food Technology, Department of Agricultural Engineering, University of Dar es Salaam, P.O. Box 35091, Dar Es Salaam, Tanzania
prudencegeofrey@gmail.com

[2] Department of Agricultural Engineering, Al-Neelain University, P.O. Box 12702, Khartoum, Sudan

[3] Department of Agricultural Engineering, University of Khartoum, P.O. Box 321, Khartoum, Sudan

[4] Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, Ondokuz Mayis University, Samsun, Turkey

Abstract. Tanzania, like many countries in sub-Saharan Africa, faces significant challenges in meeting its growing energy demands while simultaneously promoting sustainable development. Biomass energy, derived from agricultural residues, has emerged as a promising alternative to fossil fuels, offering a range of economic, social, and environmental benefits. This paper presents a comprehensive assessment of the biomass energy potential from agricultural residues in Tanzania. The analysis incorporates data on crop production and residue generation to estimate the potential contribution of agricultural residues to the national energy mix. GIS was utilized to map the spatial distribution of the biomass energy potential. The data were obtained from multiple sources, including national surveys and existing literature. Thirteen mostly grown crops in Tanzania (maize, paddy, sorghum, cassava, groundnut, sunflower, sesame, banana, cotton, tobacco, coffee, sugarcane, and coconut) were selected for this study. The results of the study indicate that Tanzania has significant untapped potential for biomass energy from agricultural residues of about 135PJ/year only from the selected crops. The highest potential is in the central and southern regions of the country. The study concludes with policy recommendations for promoting the sustainable utilization of agricultural residues for energy production. These include the development of appropriate technologies for small-scale farmers, the establishment of incentives for biomass production, and the promotion of public-private partnerships for the development of biomass energy projects. The research contributes to the growing body of literature on renewable energy in Africa and provides valuable insights for policymakers, researchers, and practitioners working in the energy and agricultural sectors.

Keywords: Biomass energy · Agricultural residues · GIS · Renewable energy · Sustainable development

E. Cavallo et al. (Eds.): ANKAgEng 2023, LNCE 458, pp. 84–93, 2024.
https://doi.org/10.1007/978-3-031-51579-8_9

1 Introduction

As the global demands for sustainable and renewable energy sources skyrocket, biomass has emerged as a significant contender in the quest for cleaner and more environmentally friendly alternatives [1]. In particular, agricultural residues present a promising resource for biomass energy production due to their abundant availability and potential to mitigate waste management challenges [2, 3]. Tanzania, a country gifted with ample agricultural lands and a diverse agricultural sector, stands to benefit greatly from the exploration and utilization of biomass energy emanating from agricultural residues [4]. In recent years, Tanzania has glimpsed impressive economic growth and rapid urbanization, resulting in a surge in energy consumption. However, this increased demand for energy has been predominantly met by fossil fuels, which not only contribute to greenhouse gas emissions but also make the nation heavily reliant on costly and non-renewable resources [5]. A study by [6] estimated that for every 1% increase in the level of urbanization, an estimated increase of 12%, 14%, and 14% would be expected in electricity, petroleum, and charcoal consumption respectively. Conceding the need for a sustainable energy transition, Tanzania has embraced the potential of biomass energy as an important solution to address these pressing challenges [7]. Agricultural residues encompass a broad range of byproducts generated from various agricultural activities, such as crop residues, agro-industrial residues, and animal waste [8]. Leaving these residues unused or treated just as waste leads to environmental problems and missing the opportunity for energy generation.

Harnessing the biomass energy potential from agricultural residues in Tanzania holds immense promise for several reasons. Firstly, Tanzania boasts a favourably diverse agricultural sector that encompasses staple crops, cash crops, agro-industrial activities, and livestock farming [9]. As a result, a noteworthy volume of agricultural residues is generated across the country. By mapping and quantifying these residues, researchers, policymakers, and energy stakeholders can identify the most viable sources of biomass energy, optimize resource utilization, and design suitable energy generation and distribution strategies.

Secondly, biomass energy from agricultural residues offers a sustainable alternative to fossil fuels, lessening the carbon footprint and fostering the transition towards a low-carbon economy [10]. It not only aids in mitigating greenhouse gas emissions but also promotes rural development by equipping energy access to remote areas, thereby improving the livelihoods of local communities.

Furthermore, the utilization of agricultural residues for biomass energy can contribute to waste management and environmental sustainability [11, 8]. Proper management of these residues can help reduce pollution, prevent the release of harmful gases during decomposition, and minimize the pressure on landfills [12].

[13] conducted a study to assess the potential of energy generation from biomass wastes in Tanzania, where four types of wastes were examined, which are agricultural residues, livestock wastes, forestry residues, and urban human waste. Agricultural residues were found to have the highest energy potential of all four wastes, accounting for more than 87% of the total energy potential. Another study by [14], demonstrated that the proper utilization of agricultural residue for energy generation can improve energy access in rural and urban areas and significantly reduce the consumption of fossil fuels.

[15] assessed the energy potential of agricultural residues from commercial crops grown in Tanzania and the study revealed that the use of these residues would improve and secure energy supply as well as enhance the sustainability of the land-use practices.

As summarized above, many studies have been done to explore the potential of biomass energy from agricultural residues in Tanzania. However, none of these studies explored the potential of biomass energy at the regional level in Tanzania and visually presented that potential distribution. In this article, we aim to explore and map the biomass energy potential from agricultural residues in Tanzania. By analyzing available data and utilizing advanced geospatial techniques, we identified and evaluated the key biomass energy sources and their geographical distribution. Ultimately, this research will contribute to the formulation of evidence-based strategies for biomass energy development in Tanzania, promoting sustainable and clean energy generation, rural development, and environmental conservation. By unlocking the untapped potential of agricultural residues, Tanzania can position itself as a regional leader in the biomass energy sector, paving the way for a more sustainable and resilient future.

2 Materials and Methods

2.1 Study Location

The study location, Tanzania, was carefully selected to probe the untapped potential of agricultural residues for biomass energy production. Situated in East Africa within the Great Lakes region and bordered by a mosaic of nations, including Kenya, Uganda, and Rwanda Re (Fig. 1). Its distinguishable regions, each marked by distinctive landscapes and cultural nuances, present a microcosm of diversity and complexity for agricultural activities. In the northern highlands, regions like Arusha and Kilimanjaro showcase fertile soils and temperate climates conducive to coffee, tea, and horticultural crops. Moving towards the coastal plains and valleys, Tanga and Morogoro experience a tropical climate, supporting a variety of crops including cashews, coconuts, and fruits. The central regions, including Dodoma and Singida, present a semi-arid climate, which has led to the cultivation of drought-resistant crops such as millet, sorghum, and pulses. The western regions, bordering Lake Victoria, are known for their rice and fish production. The semi-autonomous archipelago of Zanzibar, off the coast of Tanzania, focuses on spices like cloves and tropical fruits, leveraging its unique climate and historical trade connections. Lastly, the southern regions of Mbeya and Ruvuma exhibit agro ecological diversity, ranging from highlands to lowlands enabling farmers to engage in a mix of subsistence and cash crop agriculture, cultivating everything from maize and beans to tobacco and sugarcane. Tanzania's diverse agricultural landscape provides an ideal setting for investigating the viability of utilizing crop residues as a renewable energy source.

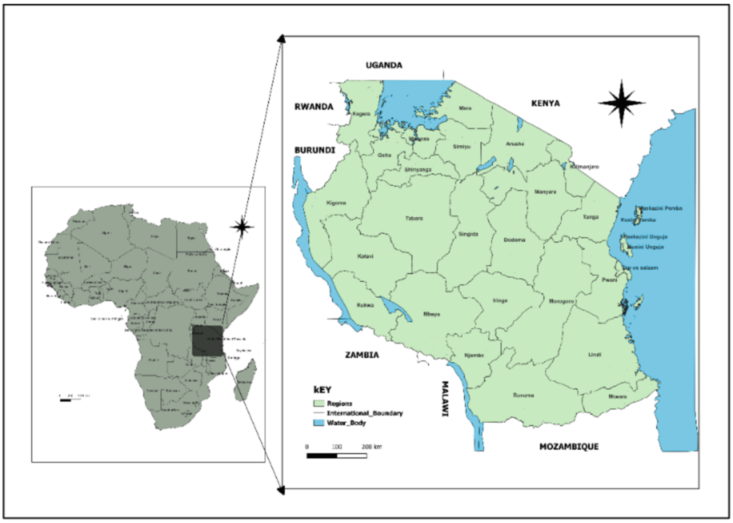

Fig. 1. Location of the study area (Tanzania) in the African map

2.2 Agricultural Residue Biomass Potential Assessment

In this study, 13 commonly grown crops grown in Tanzania were selected. The data of the yield of the selected crops for each region in the 2019/20 cultivating season was retrieved from the Tanzania National Bureau of Statistics (NBS) database in the National Sample Census of Agriculture 2019/20 report. From the yearly production for every crop, the amount of agricultural residues was estimated by using the residue-to-product ration (RPR) [16]. The RPR used in this study were average of different RPR values from different literatures Re (Table 1). The gross agricultural residues of the i^{th} crop in tons per year was calculated using Eq. (1). Where $AR_{G(i)}$ is the gross amount of residue for the i^{th} crop in tons per year, RPR_i is the residue product ratio of the i^{th} crop, and TP_i is the total production of crop i^{th} in tons per year.

$$AR_{G(i)} = RPR_i \times TP_i \tag{1}$$

Since agricultural residues have competitive uses including animal feed usage and fuel for cooking in rural areas [17], not all can be available for biomass energy production. Hence, the surplus availability factor was used to estimate the surplus agricultural residues available that can be used for energy production as shown in Eq. (2). Where $AR_{S(i)}$ is the surplus amount of residue for the i^{th} crop in tons per year, and SF_i is the surplus residue availability factor. Table 1 shows the surplus factors for each crops.

$$AR_{S(i)} = AR_{G(i)} \times SF_i \tag{2}$$

Furthermore, Table 1 shows the lower heating values retrieved from different literatures that were used to calculate the energy potential from agricultural residues as shown in Eq. (3). Where, $BE_{(i)}$ is the technical biomass energy potential for the i^{th} crop in MJ/year, and $LHV_{(i)}$ is the lower heating value of the i^{th} crop in MJ/Kg.

$$BE = AR_{S(i)} \times LHV_{(i)} \quad (3)$$

2.3 Mapping the Biomass Energy Potential

Geographic Information Systems (GIS) were employed as a fundamental tool to analyze and visualize the potential of biomass energy derived from agricultural residues. After the technical biomass energy potential from agricultural residue for each region of Tanzania was evaluated and complied together, they were integrated with geospatial dataset including land use to create a comprehensive map that visually represents the spatial distribution of biomass potential.

Table 1. Residue type, residue-to-product ratio, surplus availability factor, and low heating value for the crops used in the study.

No	Crop	Residue type	RPR	SF	LHV (MJ/Kg)
1	Maize	Stalk	*1.65 [a,b]	0.6	5.25 [b]
		Cob	*0.24 [a,c]	0.8	*15.46 [a,c]
		Husks	0.2 [a]	0.8	1.5 [a]
2	Paddy	Straw	*1.19 [a,b,c]	0.43	*14 [a,b,c]
		Husk	*0.26 [a,c,d]	0.8	*15.77 [a,c,d]
3	Sorghum	Straw	1.25 [c]	0.6	12.38 [c]
4	Cassava	Stalks	0.062 [c]	0.6	17.50 [c]
5	Groundnut	Husks/Shells	0.477 [c]	0.8	15.66 [c]
		Straw	2.28 [a]	0.4	17.58 [a]
6	Sunflower	Stalk	3 [f]	0.3	*14.47 [f,g]
7	Sesame	Stalk	1.2 [f]	0.6	14.35 f
8	Banana	Peel	0.28 [e]	0.6	18.89 [e]
9	Cotton	Stalk	*3.14 [a,c]	0.6	*16.21 [a,c]
10	Tobacco	Stalk	2 [h]	0.4	15.5 [i]
11	Coffee	Husk	2.1 [c]	0.6	12.38 [c]
12	Sugarcane	Bagasse	*0.59 [a,b,c]	0.6	*11.69 [a,b,c]
		Tops/Leaves	0.18 [a]	0.6	16.61 [a]
13	Coconut	Husk	0.419 [c]	0.8	18.62 [c]
		Shell	0.12 c	0.8	18.09 [c, j]

* An average of different values obtained from various literatures [a] [16], [b] [18], [c] [19], [d] [20], [e] [21], [f] [22], [g] [23], [h] [15], [i] [24], [j] [25].

3 Results and Discussion

3.1 Agricultural Production and Residue Availability Status in Tanzania

The total agricultural production for the specific selected crops across all regions was almost 16 million tons, according to the National Sample Census of Agriculture 2019/20. Among these regions, Kagera emerged as the leading producer, contributing approximately 1.4 million tons, with a predominant production of banana. Dodoma followed closely with a production level of 1 million tons. Notably, there were substantial regional differences in agricultural output, with the Unguja Kusini Region recording the lowest output with only roughly 35,291 tons of the selected crops produced. These discrepancies are due to the issue of crop preference in different regions that can be attributable to regional differences in climate, soil types and farming methods.

3.2 Biomass Energy Potential

A thorough assessment of the biomass potential from agricultural residues was made using Eq. (3) and data gathered for each region. The findings show Tanzania's biomass resources to be a diversified environment. Tanzania's total biomass potential from agricultural residues of the selected crops was estimated to be around 135 PJ/year in th2019/20 farming season. This is a sizable renewable energy source that has the potential to considerably improve the country's sustainability and energy security.

The analysis shows that some areas have a very high potential for biomass than others. Notably, Dodoma emerged as a leader in biomass energy potential, with an estimated capacity of about 11 PJ/year, despite being behind Kagera Region in terms of agricultural production. This is attributed by the type of crops grown in these areas. About 70% of the total production in Kagera is banana, which has a RPR of 0.28, a surplus residue availability factor (SF) of 0.6, and a lower heating value (LHV) of 18.89 MJ/Kg. On the contrary, the production in Dodoma was not only distributed throughout a variety of crops, but Dodoma also held the top spot for producing a number of different crops including sorghum, sunflowers, and groundnuts. It may be understood why Dodoma, as opposed to Kagera, came up with the largest biomass energy potential by referring to the RPR, SF, and LHV of these crops from (Table 1). With projected values of almost 10 PJ/year, 8.7PJ/year, 8.6 PJ/year, and 8.2 PJ/year, respectively, Tabora, Simiyu, Morogoro, and Mbeya regions also rated well in terms of biomass energy potential. Likewise, the diversity of their agricultural practices and high levels of productivity benefit these areas. Geita, Shinyanga, Mwanza and Kagera regions also exhibit significant biomass energy potential, with estimated values of approximately 7.9 PJ/year, 7.9 PJ/year, 7.2 PJ/year and 6.8 PJ/year, respectively. Conversely, Unguja Kusini, Unguja Kaskazini, and Pemba Kaskazini regions show relatively limited biomass energy potential, with estimated values of about 0.1 PJ/year, 0.15 PJ/year, and 0.23 PJ/year, respectively.

3.3 Implications for Energy and Sustainability

The substantial biomass energy potential identified in different parts of the country holds significant promise for Tanzania's energy security and sustainability and reducing the country's dependence on non-renewable energy sources. The estimated 135 PJ/year of biomass energy is equivalent to 37,500 GWh, which would have a very significant contribution to the national grid, according to the national energy demand. The utilization of this potentialwould help to reduce the energy crisis in the country hence, improving the livelihood of the people especially in rural area (Fig. 2).

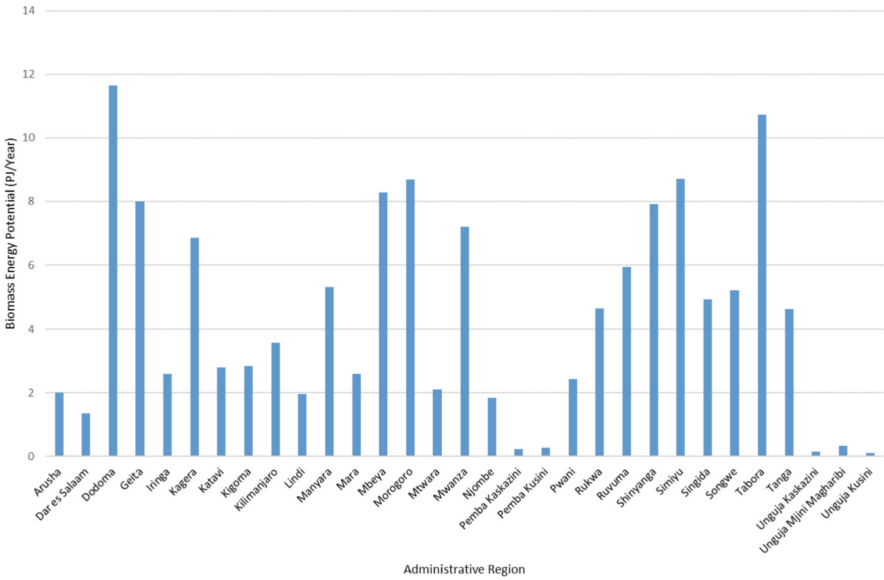

Fig. 2. Region wise biomass energy potential from agricultural residues in Tanzania.

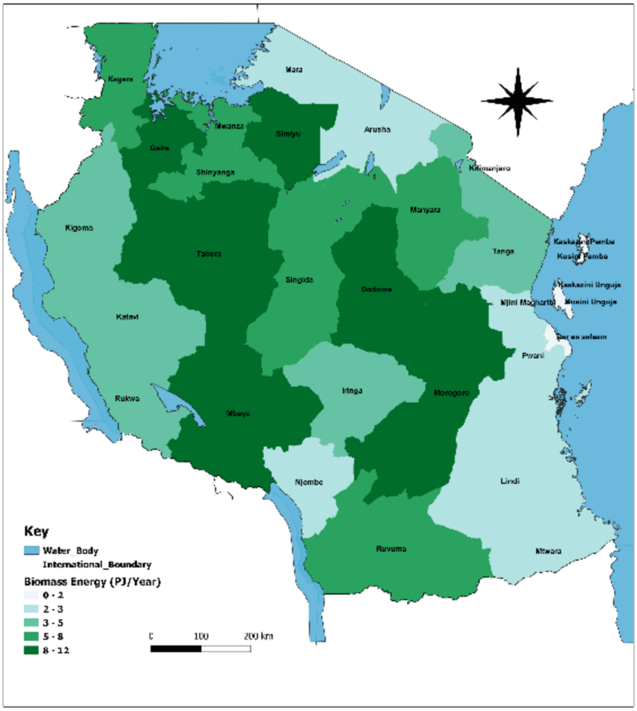

Fig. 3. Biomass energy potential from agricultural residues distribution in Tanzania.

4 Conclusion

In conclusion, this study successfully demonstrated the potential of biomass energy potential from agricultural residues in Tanzania. By leveraging the power of geospatial analysis, we have been able to visualize areas with significant potential for biomass energy production, thereby contributing to the country's renewable energy goals and sustainable development targets. The comprehensive map created through this methodology serves as a valuable resource for policymakers, investors, and local communities, offering insights into optimal locations for biomass energy projects while considering ecological, economic, and logistical factors (Fig. 3).

Moving forward, several recommendations emerge from this research. First and foremost, it is essential to continuously update and refine the dataset regarding agricultural activities, incorporating the latest land use changes, crop yields, and technological advancements. More research should be done to develop appropriate technologies to help small scale farmers in rural areas utilize biomass energy in a more sustainable way. Collaborative efforts between government agencies, research institutions, and private enterprises are crucial for sharing data, expertise, and resources to further refine the assessment of biomass energy potential.

Furthermore, a comprehensive cost-benefit analysis should be undertaken to assess the economic feasibility of biomass energy projects in the identified zones. This will aid in attracting investments and ensuring the long-term viability of such ventures. Local capacity building and awareness campaigns are also recommended to engage local communities and stakeholders in the sustainable management of agricultural residues for energy production.

In conclusion, this study not only contributes valuable insights into Tanzania's biomass energy potential but also serves as a blueprint for other regions aiming to harness renewable energy from agricultural residues. By combining advanced geospatial techniques with on-ground efforts, the vision of a greener and more energy-independent Tanzania can be realized, fostering both environmental conservation and socio-economic growth.

Conflict of Interest Statement. The authors declare no conflict of interest.

References

1. Demirbas MF, Balat M, Balat H (2009) Potential contribution of biomass to the sustainable energy development. Energ. Convers Manag. 50(7):1746–1760
2. Ali M, Saleem M, Khan Z, Watson IA (2019) The use of crop residues for biofuel production. Biomass, Biopolymer-Based Materials, and Bioenergy. Elsevier, pp 369–395. https://doi.org/10.1016/B978-0-08-102426-3.00016-3
3. Babu S et al (2022) Exploring agricultural waste biomass for energy, food and feed production and pollution mitigation: a review. Bioresour Technol 360:127566. https://doi.org/10.1016/j.biortech.2022.127566
4. Kusekwa, M. A. (2013). Biomass conversion to energy in Tanzania: A critique. In H. Arman I. Yuksel (Eds.), New development in renewable energy (pp. 240–270). Intech Open. https://doi.org/10.5772/52956
5. Albiman MM, Suleiman NN, Baka OH (2015) The relationship between energy consumption, CO2 emissions and economic growth in Tanzania. Int J Energ. Sect Manag. 9(3):361–375
6. Hosier RH, Mwandosya MJ, Luhanga ML (1993) Future energy development in Tanzania. Energ. Policy 21(5):524–542. https://doi.org/10.1016/0301-4215(93)90039-I
7. Felix M, Gheewala SH (2011) A review of biomass energy dependency in Tanzania. Energ. Procedia 9:338–343. https://doi.org/10.1016/j.egypro.2011.09.036
8. Koul B, Yakoob M, Shah MP (2022) Agricultural waste management strategies for environmental sustainability. Environ Res 206:112285. https://doi.org/10.1016/j.envres.2021.112285
9. Acland, J. D. (1971). East African Crops. (An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda ed.). Longman [for the] Food and Agriculture Organization
10. Abbasi T, Abbasi SA (2010) Biomass energy and the environmental impacts associated with its production and utilization. Renew. Sustain Energ. Rev. 14(3):919–937. https://doi.org/10.1016/j.rser.2009.11.006
11. Daza Serna L, Solarte Toro J, Serna Loaiza S, Chacón Perez Y, Cardona Alzate C (2016) Agricultural waste management through energy producing biorefineries: The Colombian case. Waste biomass valorization 7:789–798
12. Foo K, Hameed B (2009) Utilization of rice husk ash as novel adsorbent: a judicious recycling of the colloidal agricultural waste. Adv Coll Interface Sci 152(1–2):39–47

13. Aslam HZ, HammertonLi J, Andrews G, Ross A, Lovett JC (2021) Increasing access to electricity: an assessment of the energy and power generation potential from biomass waste residues in Tanzania. Energies 14(6):1793. https://doi.org/10.3390/en14061793
14. Lyakurwa FS (2016) Assessment of the energy potential of crop residues and animal wastes in Tanzania. Independent J. Manag. Prod. 7(4):1227–1239
15. Terrapon-Pfaff J (2012) Linking energy- and Land-Use Systems: energy potentials and environmental risks of using agricultural residues in Tanzania. Sustainability 4:278–293. https://doi.org/10.3390/su4030278
16. Koopmans A, Koppejan J (1997) Agricultural and forest residues-generation, utilization and availability. Reg. consultation Mod Appl. Biomass energy 6:10
17. Prasad S, Malav MK, Kumar S, Singh A, Pant D, Radhakrishnan S (2018) Enhancement of bio-ethanol production potential of wheat straw by reducing furfural and 5-hydroxymethylfurfural (HMF). Bioresour. Technol. Rep. 4:50–56. https://doi.org/10.1016/j.biteb.2018.09.007
18. Strehler, A., Stutzle, W. (1987). Biomass residues in Biomass Regenerable Energy, ed. by Hall DO and Overend RP. In: John Wiley & Sons Ltd., Chichester
19. Bhattacharya, S., Pham, H., Shrestha, R., Vu, Q. (1993). CO2 emissions due to fossil and traditional fuels, residues and wastes in Asia. Workshop on Global Warming Issues in Asia, Asian Inst. of Technol., Bangkok,
20. Mahajan K, Mishra J (1992) Energy from paddy husks-An overview. Energy Manag. 16:5–14
21. Wilaipon P (2009) The effects of briquetting pressure on banana-peel briquette and the banana waste in Northern Thailand. Am J Appl Sci 6(1):167
22. Zabaniotou A, Ioannidou O, Antonakou E, Lappas A (2008) Experimental study of pyrolysis for potential energy, hydrogen and carbon material production from lignocellulosic biomass. Int J Hydrogen Energy 33(10):2433–2444
23. Maj, G., Szyszlak-Bargłowicz, J., Zając, G., Słowik, T., Krzaczek, P., & Piekarski, W. (2019). Energy and Emission Characteristics of Biowaste from the Corn Grain Drying Process. Energies, 12(22), 4383. https://www.mdpi.com/1996-1073/12/22/4383
24. Mijailovic I, Radojicic V, Ecim-Djuric O, Stefanovic G, Kulic G (2014) Energy potential of tobacco stalks in briquettes and pellets production. J Environ Prot Ecol 15(3):1034–1041
25. Tanko, J., Ahmadu, U., Sadiq, U., Muazu, A. (2021). Characterization of rice husk and coconut shell briquette as an alternative solid fuel. Adv. Energy Convers. Mater., 1–12