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Rice residue estimation as basis for energy generational potential in Butuan City, Philippines using GIS Application

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Abstract

The increasing demand for alternative energy sources in the Philippines is driven by population growth and rising fossil fuel prices. Accurate information on locally available biomass resources is essential for assessing energy generation potential and for formulating sustainable resource management strategies. This study estimates the energy generation potential of rice hull residues in Butuan City, Agusan del Norte, Philippines, using a Geographic Information System (GIS)-based approach. Rice production data derived from the Philippine Agricultural Resource Mapping (PARMap) of the Phil-LiDAR 2 Project were used as the baseline for spatial analysis, while field surveys were conducted to validate biomass availability and collection efficiency. Empirical equations were applied to compute both theoretical and available biomass potential, and spatial maps were generated to illustrate residue distribution. Results indicate that the total theoretical potential of rice hulls in Butuan City is 6,623.94 metric tons. Based on field validation, the available energy potential was estimated at 496 MJ/ha for 35% biomass availability, increasing to 1,417 MJ/ha under a 100% availability scenario. Assuming full utilization, the total energy content of rice hull residues was calculated to be 95,086,658.70 MJ, equivalent to 26,412,981.88 kWh, which could potentially supply electricity to approximately 3,201 households annually. These findings demonstrate that rice hull biomass represents a significant renewable energy resource and that GIS-based assessment provides an effective framework for evaluating biomass energy potential to support local energy planning.

Keywords: Rice residue, biomass energy, GIS, lidar, renewable energy, energy potential

Introduction

The energy demand of the industrial, agricultural, transportation, and domestic sectors continues to increase worldwide, with electricity and transportation fuels remaining the dominant energy carriers. These demands are largely supplied by fossil fuels, which are finite resources and may experience significant depletion if current consumption trends persist. Beyond concerns related to resource exhaustion, the extensive use of fossil fuels contributes to environmental degradation through greenhouse gas emissions and air pollutants associated with combustion processes. These pressures are intensified by population growth and economic expansion in developing countries such as the Philippines, reinforcing the need to diversify energy sources and expand the use of renewable alternatives^[1, 3].

Biomass is widely regarded as a viable renewable energy resource because it utilizes locally available materials and may reduce dependence on imported fossil fuels. As an agriculture-based country, the Philippines generates substantial quantities of agricultural residues each year, including rice straw and rice husk. Several studies indicate that rice residues may serve as suitable feedstock for bioenergy applications, supporting decentralized electricity generation and contributing to greenhouse gas mitigation efforts^[3, 4]. However, rice residues remain underutilized in many regions of the country, limiting their contribution to renewable energy development.

Technological interventions have also been examined to improve efficiency within rice production systems. Automation-based approaches have been shown to reduce post-harvest losses and improve operational consistency. For example, a microcontroller-based automated paddy drying system improved drying uniformity and processing efficiency in local rice production environments^[8].

Such findings suggest that engineering solutions may enhance performance across different stages of the rice value chain, including resource recovery and potential energy utilization.

Despite the availability of biomass resources, the development of biomass-based energy systems is constrained by limited spatially explicit data on the distribution and quantity of agricultural residues. Insufficient information regarding the location and accessibility of crop residues restricts effective planning for biomass collection, processing, and energy conversion facilities^[2, 4]. Spatial assessment is therefore necessary to support realistic estimation of energy potential and informed decision-making in biomass resource management.

Geographic Information Systems (GIS) and remote sensing techniques have been applied extensively in land-use analysis, agricultural monitoring, forestry assessment, and biomass estimation. GIS-based methods enable large-scale quantification of biomass resources and facilitate the evaluation of spatial variability and logistical considerations^[2, 5]. Advances in remote sensing, including Light Detection and Ranging (LiDAR), have improved the accuracy of agricultural land cover classification and biomass estimation through high-resolution spatial datasets^[5].

This study estimates the energy generation potential of rice hull residues in Butuan City, Agusan del Norte, Philippines, using a GIS-based analytical framework. Agricultural land cover data derived from the Philippine Agricultural Resource Mapping (PARMap) initiative under the Phil-LiDAR 2 Project were used to identify rice production areas and estimate associated rice hull availability. By integrating spatial analysis with biomass-to-energy conversion parameters, the study provides a localized assessment of renewable energy potential to inform agricultural and energy planning strategies.

Materials and Methods

Study Area

Butuan City is located in the Caraga Region of northeastern Mindanao, Philippines, and covers a total land area of approximately 81,662 hectares (201,790 acres), representing about 4.1% of the total land area of the Caraga Region. Administratively, the city is composed of 86 barangays, of which 27 are classified as urban and 59 as rural.

The current land-use distribution of Butuan City includes agricultural areas covering approximately 397.23 km², forestlands

spanning about 268 km², grassland, shrub, and pasture areas totaling 61.14 km², and other land uses amounting to 90.242 km². Of the total forestland area, around 105 km² are designated as production forests, while approximately 167.5 km² are classified as protection forests. The predominance of agricultural land use highlights the city's strong agricultural character, indicating its potential as a significant source of biomass, particularly rice residues, which may be utilized as feedstock for renewable energy generation.

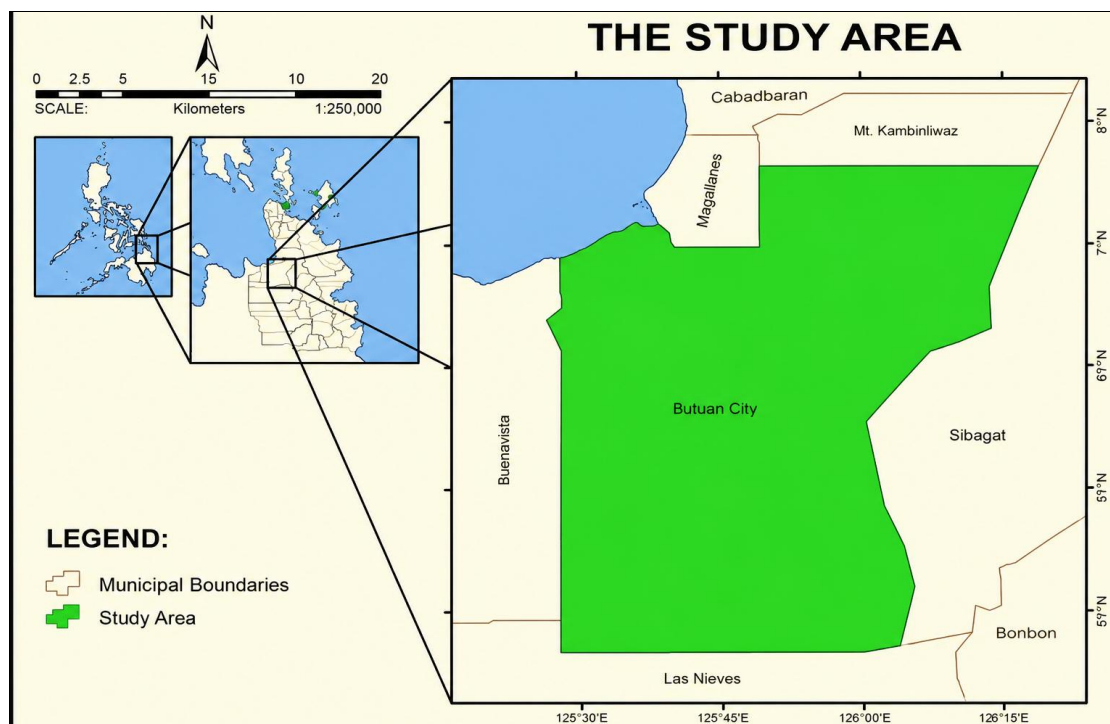


Fig 1: Study Area

Data Collection: Field surveys based on direct interview methods are used to gather information on the production and efficiency of collection of biomasses in Butuan City, Philippines. A total of 86 rice mills were visited for interview and data gathering. Data such as milling capacity, type of mill, drying methods, area coverage and location of available rice mills were collected and analysed. This is done to estimate how much rice hulls are available that may be used for energy production.

Resource Assessment: The agricultural land cover map of the study was generated using remote sensing and derived from the Philippine Agricultural Resource Mapping (PARMap) of Phil LiDAR 2 Project. The data was then analysed and stored in the ArcGIS Application. The data and aerial images were used to determine rice plantation areas. The derived map will be analysed to extract the total area allocated for rice production in Butuan City. The workflow is shown in Figure 2.

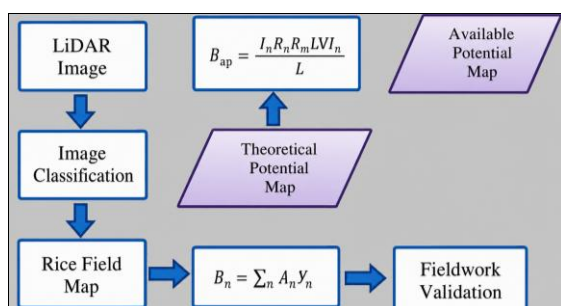


Fig 2: Research Framework

Energy Potential Calculations

The energy potential of rice hulls was estimated by computing both the theoretical biomass potential and the available biomass potential using GIS-based mathematical models. The equations developed by Voivontas *et al.* were adopted to estimate the total annual residue production and the corresponding energy content suitable for power generation [4].

Theoretical Potential: The theoretical biomass potential refers to the total amount of agricultural, forestry, and other residues produced in the area within a year. In this study, the theoretical potential of rice hulls was determined using Equation 1. This value represents the overall quantity of agricultural residues generated and serves as the maximum possible bioenergy that could be obtained from cultivated crops in the area. At this stage, the primary goal is to develop a GIS database of cultivated crops, which will be used to estimate and visualize the biomass potential for a specific geographic area [4].

$$B_n = \sum A_n Y_n$$

(Equation 1)

Where:

A_n = cultivated area for crop n (ha)

B_n = biomass theoretical potential for crop n (t/year)

Y_n = residue yield for crop n (t/ha/year)

Available potential

The available biomass potential refers to the portion of biomass whose energy content can be practically and economically collected and utilized for energy generation. For each crop, the energy content of this available biomass was calculated using Equation (2) [4]. Data on biomass collection efficiency and availability for energy use were obtained through field validation conducted in Butuan City.

$$B_{av} = \frac{f_g \sum B_n a_n LHV_n}{A_r}$$

(Equation 2)

Where:

a_n = biomass available for energy production from crop n (%)

A_r = area of the region under consideration (ha)

B_n = biomass theoretical potential for crop n (t of residue / year)

B_{av} = biomass available potential (KJ/ha/year)

f_g = efficiency of the biomass collection procedure (%)

LHV_n = lower heating value of the residue from crop n (KJ/kg)

Results

Rice Production Map

The data for rice production area in Butuan City, Agusan del Norte was taken from the Results of the Philippine Agricultural Resource Mapping (PARMap) of Phil LiDAR 2 Project. Classification of land cover applied using object-based image analysis recognized concentrations of rice production in exact zones in the study site. Since the LiDAR data was limited, the Researcher undergo digitizing using Ancillary maps like Google earths, to the remaining Rice Field area of Butuan City that was supplementary used in the processing of this Resource Assessment. Using Conversion tool, the Researcher convert the KML (a file format used to show Geographic Data in Earth) from Google Earth to Shapefiles for Data Processing. Based on the generated map (Figure 3), the total land area devoted to rice production in Butuan City, Agusan del Norte was geospatially determined to be 7,279.05 hectares. As the study focused solely on rice-producing areas, all other land classifications were identified and presented on the map as non-rice production areas.

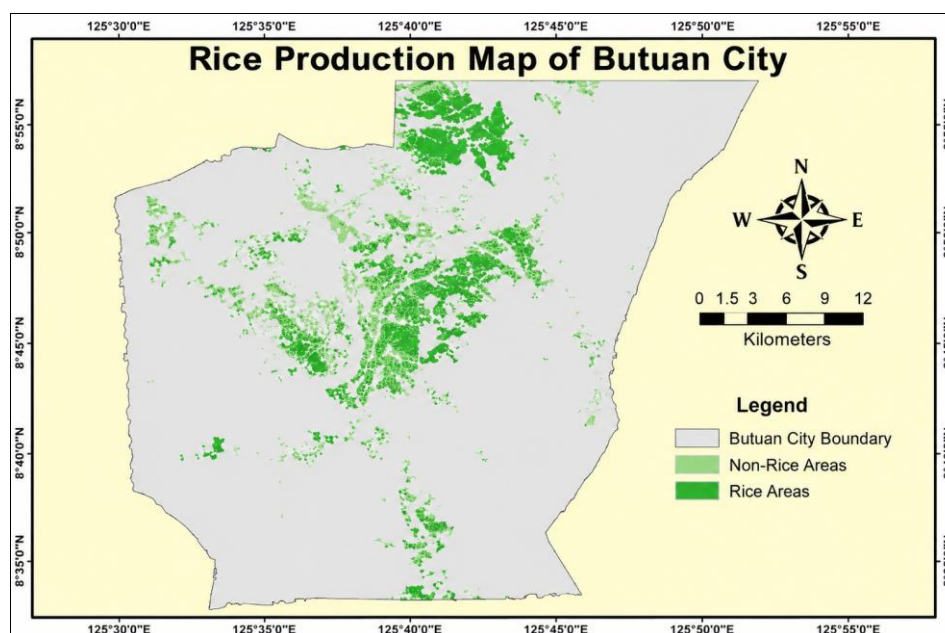


Fig 3: Rice Production Map

Biomass Potential

The Biomass Resource Assessment was applied in Butuan City. The theoretical potential in the Butuan City was assessed based on the availability of rice hull in the area. The average crop yield of 4.06 MT/ha (DA, 2017) was used to calculate the residue yield with a crop to residue conversion factor of 0.225 (IRRI). Using Equation 1, the theoretical potential of rice hulls in the area was estimated at 6,623.94 MT. The parameters applied in calculating this theoretical potential are presented in Table 1.

The estimated theoretical potential of rice hulls in the area amounts to 6,623.94 metric tons. While this value indicates a substantial potential, it does not imply that the entire quantity of rice hulls produced can be utilized for energy generation. To determine the portion of biomass residues that are available for energy use, the available potential (B_{av}) was calculated. The parameters used in computing the available potential are presented in Table 2.

In line with the given data area, theoretical potential, and lower heating value of rice hull which is 16.5MJ/kg (DOE, 2014) and the

efficiency of biomass collection of 0.87 was obtained from fieldwork given 10% and 3% damages in efficiency of Biomass collection, the Available Energy Potential was computed. The Available Potential obtained based to the Field Surveys and validation was 496 MJ/ha considering 35% of Available of Rice Residue. Similarly, considering the 100% Availability of Rice Hull in the area, the Projected Available Potential (Figure 14) was 1417.53 MJ/ha.

Table 1: Theoretical Potential Parameters

Parameter	Value
Crop area	7279.05 ha
Crop yield	4.06 MT/ha
Crop to residue conversion	0.225
Residue yield	0.9135
Theoretical Potential	6623.94 MT

Table 2: Available Potential Parameters

Parameters	Value
Theoretical potential	6623.94 MT
Efficiency of collection	0.87
Availability for energy production	.35
Lower heating value	16500 MJ
Area of the province (LiDAR data)	67079.16 ha

Biomass Potential by Barangay

The theoretical Potential and available Potential by Barangay was considered based on the accessibility of the Residue in every Barangay of Butuan City. From this, we can identify as to where the residues are more feasible and available. Further, it provides the Information as to where these residues will be taken for the generation of Energy. Figure 5 and 6, displays the top 10 barangay with the Highest Availability of residue for Energy Generation. This Barangay are the Baobaohan, Aupagan, Amparo, Mahay, Tagabaca, Bit-os, Cabcabon, Sumilihon, Los Angeles, and Lemon, respectively.

Energy Potential of Rice hull in Butuan

The Energy Potential of Rice hull in Butuan City at different percentage of Biomass Availability was computed and shown in Table 3. Assuming 100% availability, the energy potential rice hulls in the municipality was found to be 95,086,658.70 MJ or 26,412,981.88 Kilowatt-Hours (kWh). From the results obtained, the Energy Generation Potential can cater 3201 Households considering the Average Household capacity and assuming the 100% availability of Residue in the area for Energy Generation Potential. The Energy Potential in MJ was converted into kWh using the conversion factor of 1 MJ = 0.277777778 kWh.

Discussion

The estimated rice hull biomass potential obtained in this study is generally consistent with findings from previous research on rice residue-based energy resources in the Philippines and other rice-producing regions. The computed theoretical potential of 6,623.94 MT for Butuan City aligns with the magnitude of rice residue availability reported in regional and national-scale assessments, which emphasize the substantial contribution of rice by-products to

the biomass energy portfolio of agricultural economies [3], [4]. Studies by Gadde *et al.* demonstrated that rice straw and husk residues in Southeast Asian countries, including the Philippines, can provide meaningful energy contributions when appropriately collected and utilized [3].

The available biomass potential estimated in this study further corroborates findings from GIS-based biomass assessments conducted in other Philippine provinces. Sevilla *et al.* estimated rice hull energy potential in Camarines Sur using Landsat-derived agricultural maps and reported that only a fraction of the theoretical biomass is practically available due to collection, logistical, and competing-use constraints [2]. Similarly, the present study shows that at 35% biomass availability, the available energy potential decreases to 496 MJ/ha, reinforcing the observation that realistic availability assumptions significantly influence energy yield estimates. This consistency suggests that the availability factors applied in this study are reasonable and reflective of actual field conditions.

Comparatively, the projected available potential of 1,417 MJ/ha under a 100% availability scenario represents an idealized upper bound and is comparable to results reported in large-scale biomass feasibility studies, which often present full-availability scenarios to demonstrate maximum technical potential [4]. However, similar to the conclusions drawn by Jamora *et al.*, full utilization of rice residues is unlikely in practice due to competing agricultural uses, seasonal variability, and economic considerations [4]. Thus, the lower availability scenario adopted in this study provides a more conservative and policy-relevant estimate.

The total energy content of 95,086,658.70 MJ (26,412,981.88 kWh) estimated for Butuan City under full availability conditions is comparable to energy potential values reported in Philippine-based rice residue energy assessments, which highlight the capacity of rice biomass to support decentralized or community-scale power generation [1, 6]. Reaño *et al.* demonstrated that rice straw-based power systems can achieve favorable energy efficiencies under Philippine farming conditions, further supporting the feasibility of rice residue utilization for local energy supply [1]. The estimated capacity to supply electricity to approximately 3,201 households emphasize the practical relevance of rice hull biomass as a supplementary renewable energy source.

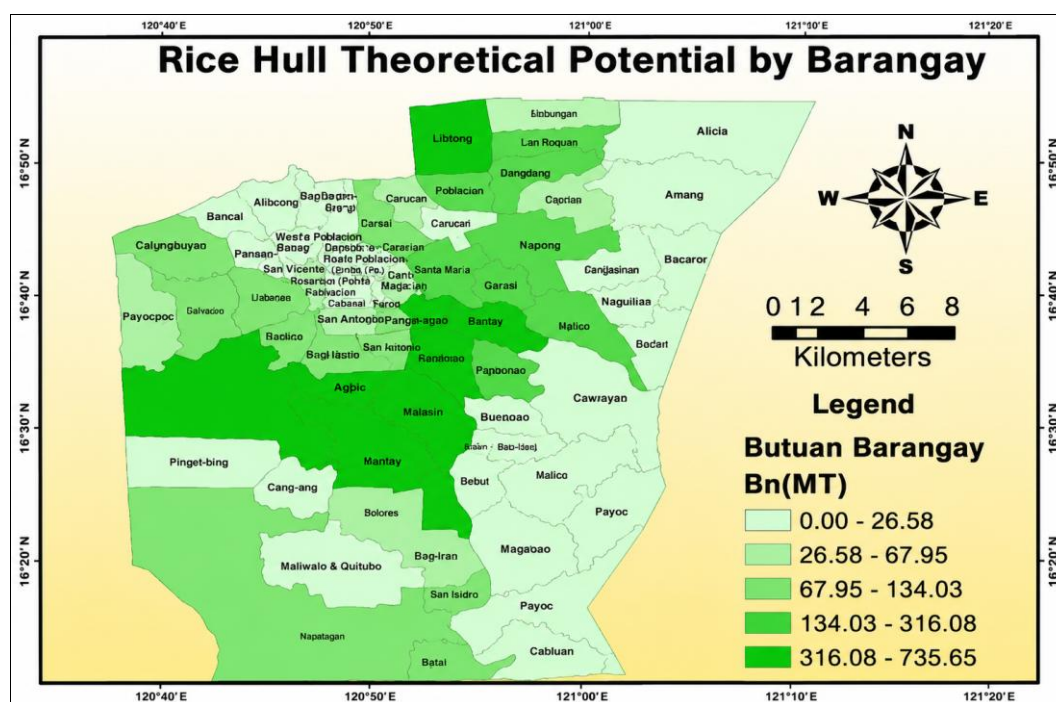


Fig 4: Rice hull Theoretical Potential

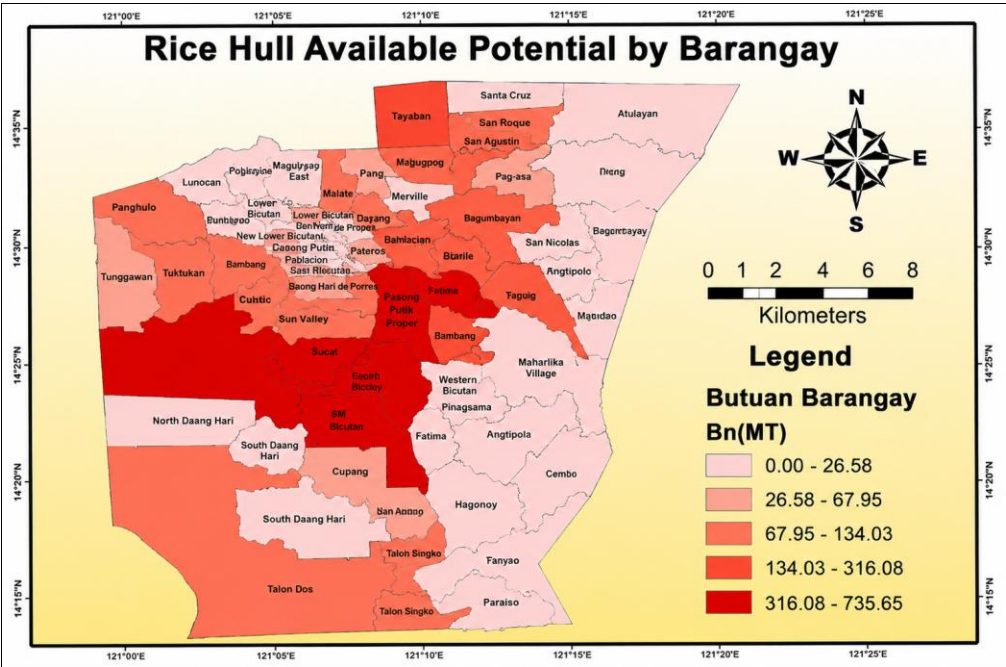


Fig 5: Rice hull Available Potential

Table 3: Energy Generation Potential

Availability of Rice Hull (%)	Energy Potential (MJ)	Energy Potential (kWh)	Household catered
10	9,508,665.87	2,641,298.188	320
20	19,017,331.74	5,282,596.376	640
30	28,525,997.61	7,923,894.564	960
40	38,034,663.48	10,565,192.75	1280
50	47,543,329.35	13,206,490.94	1600
60	57,051,995.22	15,847,789.13	1921
70	66,560,661.09	18,489,087.32	2241
80	76,069,326.96	21,130,385.5	2561
90	85,577,992.83	23,771,683.69	2881
100	95,086,658.70	26,412,981.88	3201

The effectiveness of the GIS-based methodology employed in this study is consistent with findings from national and regional mapping initiatives, such as the Phil-LiDAR 2 Program, which emphasize the value of high-resolution spatial data in agricultural and energy resource assessment 5. The integration of LiDAR-derived land cover data, GIS analysis, and field validation enabled more accurate spatial quantification of rice production areas and biomass availability compared to approaches relying solely on statistical data. This confirms observations by previous studies that GIS-based methods provide superior spatial insight and decision support for renewable energy planning ^[2, 5]. In summary, the results of this study are largely consistent with existing research on rice residue biomass and energy potential in the Philippines, while providing a more localized and spatially explicit assessment for Butuan City, Philippines. The findings confirm that rice hull biomass represents a viable renewable energy resource, particularly for decentralized energy applications in agricultural areas. It is recommended that future research incorporate techno-economic analysis, supply chain optimization, and environmental impact assessment to further evaluate large-scale implementation. Additionally, local government units and energy planners may use the generated biomass potential maps as decision-support tools for identifying priority areas for biomass-based energy projects. Overall, this study demonstrates that GIS-based resource assessment is an effective and reliable approach for quantifying biomass energy potential and supporting sustainable energy planning at the local level.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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